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Appalachian Underground Corrosion Short Course

Intermediate Course

Appalachian Underground Corrosion Short Course
West Virginia University
Morgantown, West Virginia

APPALACHIAN UNDERGROUND CORROSION SHORT COURSE
INTERMEDIATE COURSE

CHAPTER 6 - CORROSION CONTROL FOR PIPELINES 6-1

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Chapter 1 - Corrosion Cells in Action

INTRODUCTION

This first chapter of the Intermediate Course is intended to accomplish two things. The first will be a review of the basic concepts involved in a corrosion cell - what is necessary for corrosion to occur on underground pipeline systems and the development of a basic corrosion formula for steel. The second intended accomplishment is the development of methods for practical classroom demonstrations showing, visually, (1), how various corrosion cell conditions can result in active corrosion and, (2), how cathodic protection can be used to prevent corrosion. Demonstration tests will be outlined to show a variety of corrosion-causing conditions and to show the beneficial effect of cathodic protection.

REVIEW OF BASIC CONCEPTS

A thorough understanding of how a corrosion cell functions is essential for the corrosion worker on underground structures. Full knowledge in this basic area permits the worker to analyze more readily and understand corrosion problems encountered in the field. This in turn permits an informed approach to the development of corrective solutions to the corrosion problems encountered.

Basic Course Reference

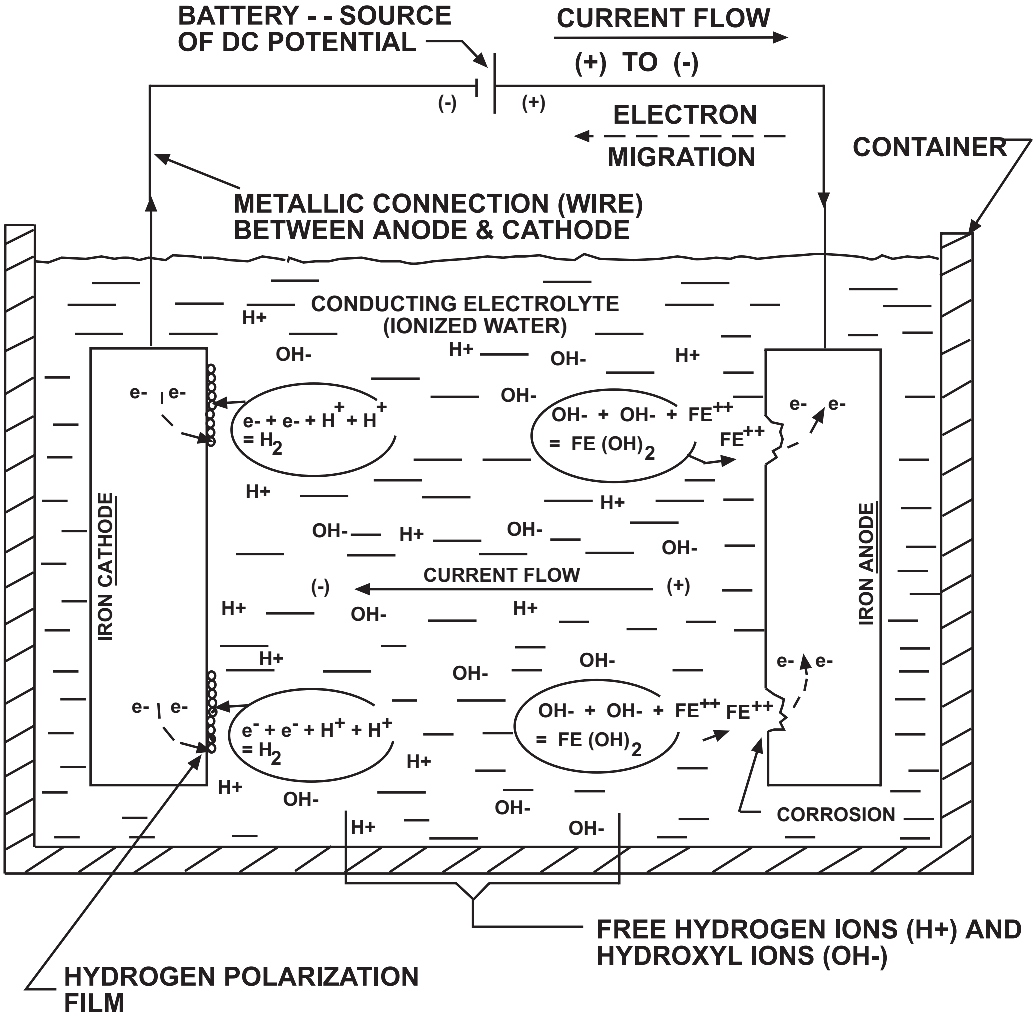
The essential basic concepts of corrosion cell operation and the various field conditions which can result in active corrosion cells on pipelines are covered in Chapter 2, "Corrosion Fundamentals", of the Basic Course. The following material on basics is summarized from the source.

A Corrosion Cell Concept

Figure 1-1, will serve to illustrate basic points.

First - and important to understand - is that there are four essential elements of any corrosion cell if active corrosion is to occur. These are:

1. There must be an anode
2. There must be a cathode
3. There must be a conducting electrolyte in which both anode and cathode are



CORROSION IN ACTION

FIGURE 1-1

immersed.

4. There must be a metallic conductor between the anode and the cathode.

All of these are present in Figure 1-1. In the figure, the electrolyte is shown as water. This could just as well be moist earth or an aqueous chemical solution. In any case, the aqueous component is naturally ionized with positively charged hydrogen ions (H^+) and negatively charged hydroxyl ions (OH^-).

The anode is that metallic element of the cell which discharges ions into the electrolyte and corrodes. The cathode is that metallic element which collects ions from the electrolyte and does not corrode. For there to be a current flowing between the anode and cathode there has to be a driving voltage between the anode and cathode. In galvanic corrosion cells encountered in the field, there will naturally be (for a variety of reasons) a voltage between the anode and cathode. In Figure 1-1, both the anode and cathode of the laboratory cell illustrated are iron such that (under the uniform conditions shown) there would not be a voltage difference between them. For the purpose of the illustration, then, the driving voltage is represented by a battery inserted in the wire connecting the anode to the cathode.

Now we can review the electrochemical reactions that can occur at the anode and cathode under Figure 1-1 conditions. First, as discussed in the Basic Course reference, there is a flow of electrons migrating in the opposite direction from the ions discussed above. Actually, current flow is a flow of electrons - one ampere flowing for one second in the conventional fashion represents a transfer of 6.28×10^{18} electrons. This is basic and directly related to the corrosion process.

At the iron (or steel) anode of Figure 1-1, conventional current discharging from the anode into the electrolyte must be accompanied by electron migration from the anode through the metallic connection (wire) to the cathode. These electrons become available as a result of the ionization of iron atoms. Each atom of iron breaks down (ionizes) into one positively charged iron ion (Fe^{++}) and two negatively charged electrons (e^-, e^-). As a surplus of positively charged iron ions builds up at the anode surface, they are attracted to and combine with negatively charged hydroxyl ions (OH^-) in the ionized electrolytic environment. This results in the reaction (as shown on Figure 1-1):

$$OH^- + OH^- + Fe^{++} = Fe(OH^-)_2$$

$Fe(OH^-)_2$ is ferrous hydroxide.

As this process continues, the iron (or steel disappears (corrodes) and is replaced by corrosion products. The basic reaction developing ferrous hydroxide (typically a whitish or pale greenish corrosion product) as shown is to form ferric hydroxide which is the familiar reddish brown rust.

At the cathode, the negatively charged electrons that have migrated there from the anode combine with positively charged hydrogen ions in the electrolytic environment. This can be represented (as shown on Figure 1-1) by:

$$e^- + e^- + H^+ + H^+ = H_2$$

H_2 is hydrogen.

The hydrogen so developed forms on the surface of the cathode as a cathodic polarization film. There is no attack on the iron cathode during this process.

Earlier, it was indicated that the aqueous component of the electrolyte in which the anode and cathode are immersed is naturally ionized. The representation of the breakdown of water molecules into positively charged hydrogen ions and negatively charged hydroxyl ions is given as follows:

$$2H_2O = 2H^+ + 2(OH^-)$$

Granting the necessary presence of these ions in the electrolyte, a fundamental equation for the corrosion of iron at the anode can be
represented by:

$$Fe + 2H_2O = Fe^{++} + 2H^+ + 2(OH^-)$$

Where the $2H^+$ (after combining with negatively charged electrons) represents the cathodic polarization film and where the Fe^{++} combines with the $2(OH^-)$ to form $Fe(OH^-)_2$ - the ferrous hydroxide corrosion product.

Dry Cell Example of a Corrosion Cell

A simple, yet effective, example of a corrosion cell with which everyone is familiar is the common zinc-carbon flashlight cell although the average user seldom, if ever, thinks of it as a corrosion cell. But it is.

Figure 1-2 illustrates the components of the flashlight cell. In the cell by itself we have only three of the four requirements for an active corrosion cell: an anode (the zinc can), a cathode (the carbon rod central electrode), and an electrolyte (the ammonium chloride). This, then, is an inactive corrosion cell.

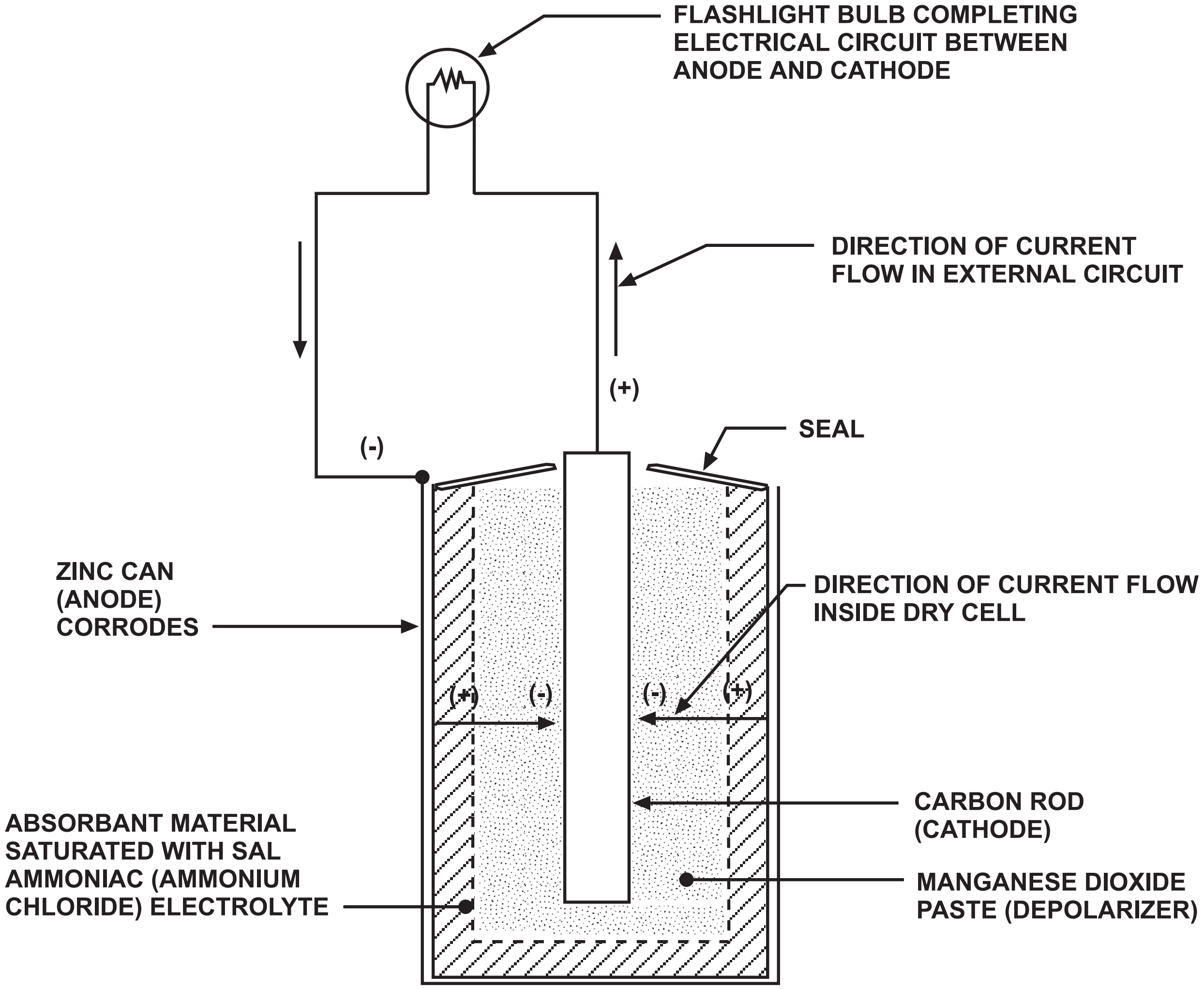
When the cell is placed in a flashlight and the switch is pressed, a metallic circuit is activated between the anode and cathode through the flashlight bulb. This is the fourth necessary component for an active corrosion cell. Current is now discharged from the zinc can anode into the electrolyte and the anode then corrodes. The carbon rod cathode is not affected.

In Figure 1-1 discussed earlier, a cell in the connecting circuit between anode and cathode caused current to flow in the cell between the similar-material electrodes. In the case of the zinc-carbon flashlight cell, however, there is a natural potential (voltage) between the dissimilar materials comprising the anode and cathode. In the case of a new zinc-carbon flashlight cell, this potential is approximately 1.6 volts.

The galvanic potential difference between zinc and carbon which is used to advantage in the flashlight battery is an example of the use of the practical galvanic series of metals from Table 2-1 of the Basic Course, shown as Table 1-2 in this chapter. This table lists metals and certain other conducting materials from least noble (or most likely to be anodic) to most noble (or most likely to be cathodic). Any two materials from such a table will (when connected together in an electrically conducting environment) form a corrosion cell in which the more noble of the two will be the cathode.

The practical galvanic series from the Basic Course as referenced above gives potentials with respect to a copper-copper sulfate reference electrode. A more complete listing is contained in Table 1-1. This table, refers to the listing as a “solution potential series" (synonymous with "electromotive series") with potentials shown with respect to a hydrogen electrode which has been arbitrarily set at zero. In both tables, materials listed higher in the table will be anodic (and will corrode) when connected in a corrosion cell to a more noble material which appears at a lower point in the table.

Although the principal of Tables 1-1 and 1-2 is the same, the voltage difference between any two materials appearing in one table may not agree with the voltage difference between the same two materials in the other table. There is a good reason for this. Whereas the practical series lists typical potential values measured with respect to a



COMMON ZINC-CARBON FLASHLIGHT BATTERY

FIGURE 1-2

TABLE 1-1

SOLUTION POTENTIAL SERIES (ELECTROMOTIVE SERIES) OF SOME BASIC METALS AND MATERIALS

Progressively more anodic ↑ (less noble) and more corrosive

Metal or Material	Potential (Emf, V)	Metal or Material	Potential (Emf, V)
Lithium	-2.96	Nickel	-0.23
Rubidium	-2.93	Tin	-0.14
Potassium	-2.92	Lead	-0.12
Strontium	-2.92	Iron (ferric)	-0.04
Barium	-2.90	**HYDROGEN**	0.00
Calcium	-2.87	Antimony	+0.10
Sodium	-2.71	Bismuth	+0.23
Magnesium	-2.40	Arsenic	+0.30
Aluminum	-1.70	Copper (cupric)	+0.34
Beryllium	-1.69	Copper (cuprous)	+0.47
Manganese	-1.10	Tellurium	+0.56
Zinc	-0.76	Silver	+0.80
Chromium	-0.56	Mercury	+0.80
Iron (ferrous)	-0.44	Palladium	+0.82
Cadmium	-0.40	Carbon	+0.84
Indium	-0.34	Platinum	+0.86
Thallium	-0.33	Gold (auric)	+1.36
Cobalt	-0.28	Gold (aurous)	+1.50

↓ Progressively more cathodic (noble) and less corrosive

NOTE: Polarities shown are applicable to the external circuit between materials.

TABLE 1-2

A GALVANIC SERIES OF CERTAIN METALS AND ALLOYS ARRANGED IN ORDER OF CORROSIVITY

ANODIC (LEAST NOBLE) END Material	Material (continued)
Magnesium	Brasses
Magnesium alloys	Copper
Zinc	Bronzes
Aluminum 2S	Copper-nickel alloys
Cadmium	Monel
Aluminum 175S	Silver solder
Steel or iron	Nickel (passive)
Cast iron	Inconel (passive)
Chromium-iron (active)	Chromium-iron (passive)
Ni-Resist	18-8 Chromium-nickel-iron (passive)
18-8 Chromium-nickel-iron (active)	18-8-3 Chromium-nickel-molybdenum-iron (passive)
18-8-3 Chromium-nickel-molybdenum-iron (active)	Hastelloy C (passive)
Lead-tin solders	Silver
Lead	Carbon and graphite
Tin	Platinum
Nickel (active)	Gold
Inconel (active)	CATHODIC (MOST NOBLE) END
Hastelloy C (active)	

copper-copper sulfate reference electrode in neutral soils or waters, laboratory determined values such as those in Table 1-1 are typically determined for each material with reference to hydrogen electrode when the material being tested is immersed in a solution of its own salts.

From the above it would appear that the practical series (Table 1-2) will be more useful to the corrosion worker dealing with underground structures than would a laboratory-determined series. But here again, the practical galvanic series should be used as a guide only because if there are local or general deviations from neutral soil or water conditions along a buried structure, there can be distortions in the potential values.

As further assistance in determining the anodic-cathodic relationship between materials, (from most anodic to most cathodic) Table 1-2 tabulates a series of metals and metal alloys that may be encountered. It will be noted that potential values with respect to a common reference are not given as is the case with Table 1-1. Table 1-2 is most useful in making an initial determination of the probable anodic-cathodic relationship. The general order of the probable potential between them may be estimated by using Table 1-2 and may be confirmed by test in the specific environment of the actual application.

DEMONSTRATION

Hearing and reading about various corrosion cells and how they operate gives an initial background. However, there is no better way to get the full impact of the manner in which these cells work than to see an actual demonstration of corrosion cells in action.

Colonel George C. Cox (deceased) developed a demonstration lecture for use at the Appalachian Underground Corrosion Short Course which illustrates effectively how various cells work. The following material describes how the demonstration is accomplished and details several experiments undertaken during the demonstration.

The problems involved with such demonstrations were, first, how to present them so that they could be seen equally well by all members of a large group and, second, how to show that areas which are supposed to be anodic in a given cell actually are performing in an anodic manner - and, likewise, how to show the cathodic areas.

The first problem was solved by placing the experimental corrosion cells in transparent containers filled with liquid electrolyte. Then, using optical projection equipment, the image of the corrosion cell could be projected on a screen so that all could see. This illustrates the corrosion cell framework but without some additions there would be little that could be seen during a reasonably short lecture time interval to show that there was anything going on in the corrosion cell.

This second problem was solved by the use of chemical indicators in the electrolyte solutions used in the corrosion cells. For the anodic indicator, 2 or 3 drops (not more than 3) of a saturated aqueous solution of potassium ferricyanide is added to each 100 milliliters of stock solution. The resulting precipitate will give a brilliant bluish green color by transmitted projector light in anodic areas. For the cathodic indicator, 5 milliliters of a 1% alcohol solution of phenolphthalein is added to (and well shaken into) each 95 milliliters of electrolyte solution just before placing in the projection cell. The measurements are critical. The phenolphthalein indicator will show a bright pink or crimson color by projected light in cathodic areas.

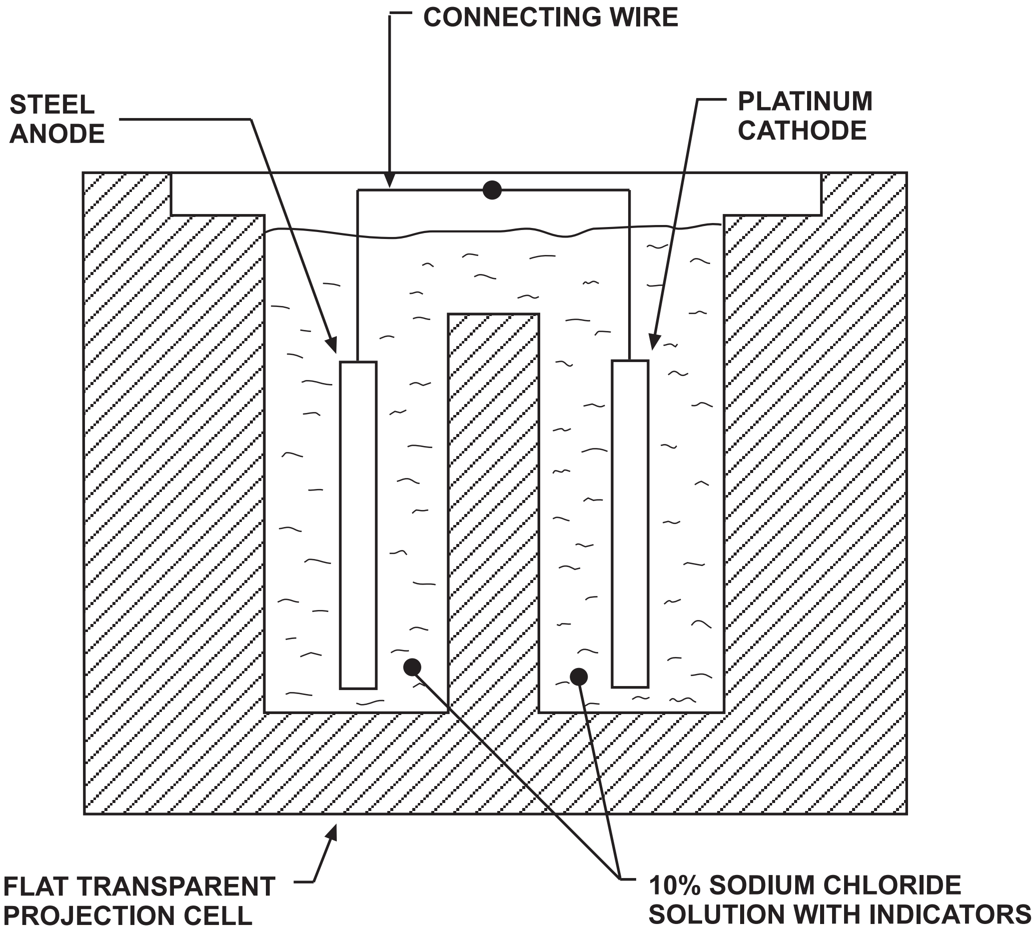
The combination of the on-screen projection capability plus the means of positively identifying anodic and cathodic areas makes it possible for classroom groups actually to see the action taking place in corrosion cells of various types.

The following sections will illustrate some of the corrosion cells which can be demonstrated using the Cox methods. It should be noted that demonstrations of this same nature can be used effectively for corrosion worker training purposes within company organizations. Additionally, such demonstrations can be a useful tool when conducting corrosion familiarization sessions for company management personnel.

Dissimilar Metal Corrosion Cell

This demonstration cell is used to show that when two dissimilar metals are connected together in a corrosion cell, one will be an anode (and will corrode) while the other will be cathodic and unaffected.

The demonstration cell to be used in this case is shown diagrammatically by Figure 1-3. Note that the two materials used are steel and platinum immersed in a low resistivity sodium chloride solution. Inspection of Table 1-1 indicates that we could expect a potential difference between ferrous iron and platinum of approximately 1.30 volt and that the iron should be the anodic (corroding) member. Accordingly, in the demonstration cell, the indicators should show a bluish-green coloration around the steel anode and a pink or crimson coloration at the platinum cathode.



DISSIMILAR METAL DEMONSTRATION CELL

FIGURE 1-3

The high galvanic voltage between steel and platinum permits fairly rapid action in the cell so that the indicator colors should develop in less than five minutes after the cell is activated by the demonstrator.

The demonstration visually indicates that corrosion can occur when dissimilar metals are in electrical contact with one another in a conducting electrolyte. There are quite a few dissimilar metal combinations that can be encountered when working on underground metallic structures.

Some of the more common are:

- Steel and cast iron
- Plain steel and galvanized steel
- Galvanized steel and cast iron
- Copper and steel or cast iron
- Brass and steel or cast iron
- Lead and copper

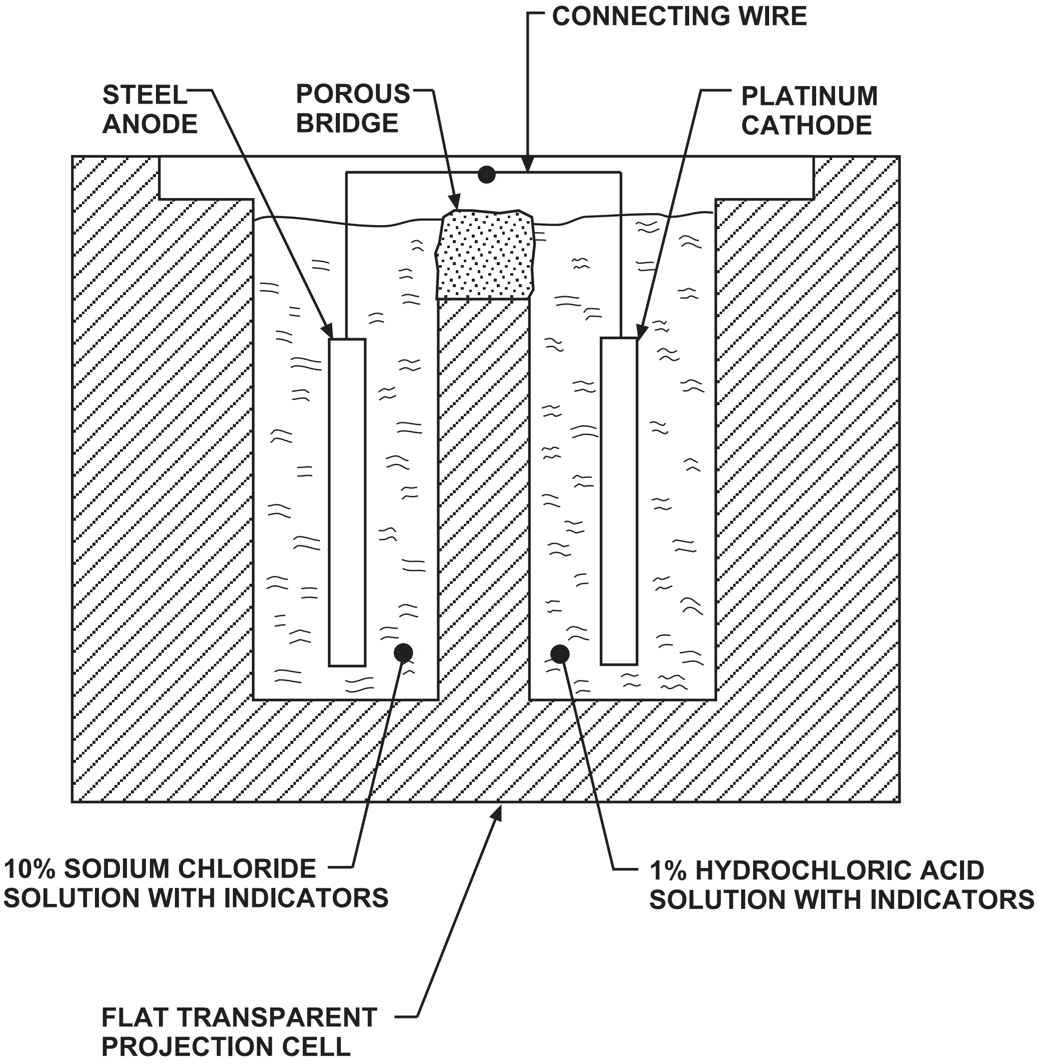
Plus other combinations involving stainless steel, aluminum, cinders (carbon), etc.

Corrosion Cell Showing Effect of Electrolyte pH Characteristics on Dissimilar Metal Corrosion

The objective of this demonstration cell is to show that a dissimilar metal corrosion cell will remain active under different pH conditions.

In the preceding demonstration, the electrolyte in the steel-platinum dissimilar metal cell was a uniform mixture of sodium chloride in contact with both elements of the cell. In this demonstration, as shown by Figure 1-4, the same two dissimilar metals are used but the steel is (for the first part of the demonstration immersed in a 10% sodium chloride solution (alkaline) while the platinum is immersed in 1% hydrochloric acid solution. A porous bridge separates the two electrolytes preventing free intermixing of the solutions. However, it becomes saturated with the solution and permits corrosion current interchange between the steel and platinum.

When the cell arranged as described above is placed in operation by the demonstrator, the color indicators will show the steel in the alkaline environment to be anodic and corroding as shown by a blue-green coloration while the platinum in the acid environment will



DEMONSTRATION CELL TO SHOW EFFECT OF PH ON DISSIMILAR METAL CORROSION

FIGURE 1-4

show the pink cathodic coloration.

Once the above demonstration is shown on the screen, the demonstrator will reverse the positions of the steel and platinum placing the steel in the acid solution and the platinum in the alkaline environment. Again the color indicators will show the steel to be anodic and the platinum cathodic with generally similar reaction times.

A successful demonstration as described shows that differing pH conditions along an underground structure do little to change the anode-cathode relationship of corrosion cells.

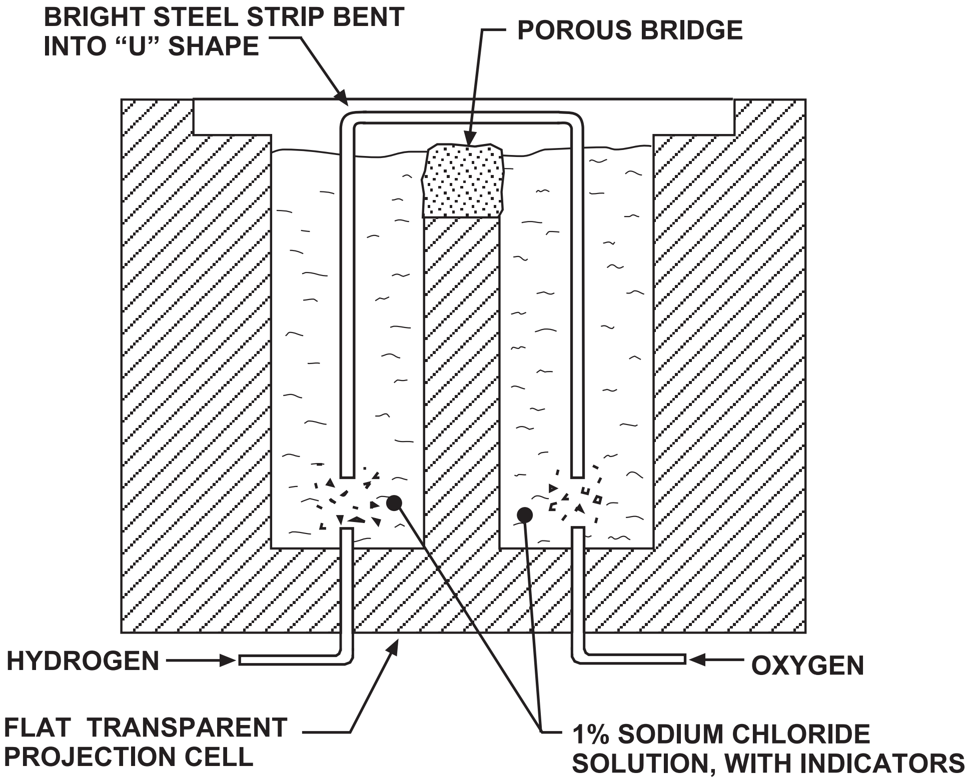
On underground structures, particularly long structures such as pipelines, it is not at all unusual to find alkaline, neutral, and acid conditions at different locations along the structure. Although some pipelines may be in predominantly neutral soils, they can pass through industrial areas where contamination can produce either alkaline or acid conditions.
Some soils can be naturally acid or alkaline.

Corrosion Cell Demonstrating Corrosion Caused by Differential Oxygen Concentration

The intent of this demonstration is to show that a single metal (such as steel) in an environment of uniform chemical composition, (such as uniform soil) can suffer corrosion if part of the metal surface receives a greater supply of oxygen than others. Further, it is intended to show that those areas having the least oxygen availability will be anodic and corroding.

The schematic arrangement of the demonstration corrosion cell is shown by Figure 1-5. Bright steel electrodes are placed in each of the two cell compartments; these are connected together to establish electrical continuity between the two. This can be accomplished with a single strip of steel bent into a U-shape as shown. Each compartment is filled with a uniform solution of 1% sodium chloride with color indicators added. A porous bridge is used between the two compartments to prevent free interchange of electrolytes from the two compartments but still provide electrical continuity between the two.

To obtain the differential oxygen concentration, oxygen is bubbled through one compartment (which will be the anodic side. In Figure 1-5 the means of accomplishing this is shown schematically for the demonstration cell which has been used in the



DIFFERENTIAL OXYGEN CONCENTRATION DEMONSTRATION CELL

FIGURE 1-5

classroom experiments. This is done by using a DC voltage (supplied by a variable transformer and AC to DC rectifier) between two platinum electrodes in a separate compartment of the demonstration cell. This separate compartment is filled with a 20% solution of sodium hydroxide (NaOH). Oxygen is evolved at the positive platinum electrode and is channeled, as shown on the figure, through the cathodic half of the demonstration cell. Likewise, hydrogen is evolved at the negative platinum electrode and is channeled through the anodic half of the cell. The DC applied voltage is adjusted by the demonstrator to obtain a good flow of gas from the two platinum electrodes. This will require approximately 18 volts DC.

The reaction time for the demonstration to show the anodic and cathodic indicator colorations (pink at the cathode and blue-green at the anode) may range from one to two hours. This necessitates the demonstrator placing the cell in operation prior to the start of the classroom demonstration so that the reaction can be shown during the classroom time period.

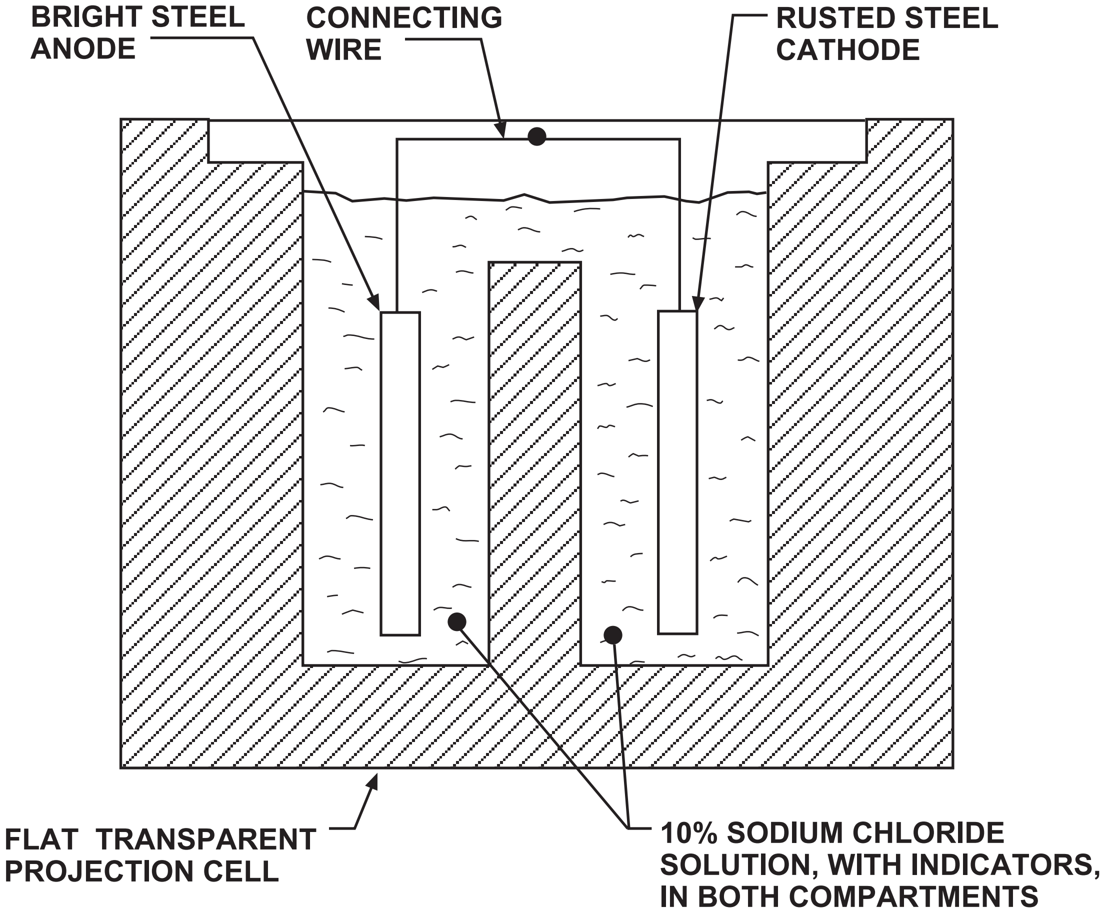
A successful demonstration will show that the steel strip in the oxygen-poor environment will be anodic while the steel strip in the oxygen-rich environment will be cathodic.

As discussed in the Chapter 2 of the Basic Course, differential oxygen concentration is referred to as "differential aeration". A typical example of such a corrosion cell is a pipeline in a relatively porous well aerated soil passing under a paved highway where the pavement restricts air (and thereby oxygen) access to the pipe. This causes relatively oxygen-poor environment around the pipe under the pavement - and this is where the corrosion occurs in the absence of adequate protective measures.

Corrosion Cell Demonstrating Corrosion Caused by Dissimilar Surface Conditions on Steel

The purpose of this demonstration is to illustrate that there is an anode-cathode relationship between new steel and rusted steel in electrical contact with each other in a conducting environment - even though both steels are of the same alloy. Further, it is the intent to show that the new steel is anodic and will corrode.

Figure 1-6 shows the schematic arrangement of the demonstration corrosion cell. A bright steel electrode is placed in one compartment of the cell and a rusted steel electrode is placed in the other. Both compartments are filled with a 10% sodium chloride solution with color indicators added. The two electrodes are electrically



DEMONSTRATION CELL TO SHOW CORROSION
CAUSED BY DISSIMILAR SURFACE CONDITIONS

FIGURE 1-6

interconnected to complete the corrosion cell.

Once the cell is placed in operation by the demonstrator, the time required to obtain color indications will be in the order of 30 to 60 minutes. When the reaction becomes apparent, the blue-green anodic coloration will be seen in the compartment containing the bright steel electrode. Similarly, the pink cathodic coloration will show in the compartment containing the rusted steel electrode.

A similar result would be obtained if the comparison were made between a bright steel electrode and a steel electrode coated with mill scale - with the bright steel electrode being anodic and corroding.

In pipeline work, the new steel-rusted steel relationship was learned the hard way before the advent of adequate corrosion control measures. Typically, when corrosion failures occurred in a "hot-spot" area necessitating replacement after, say, ten years, the pipe was replaced with a new piece of steel pipe of the same type as used originally. The expectation was that it would be another ten years before replacement would be required again. Then when it was found that the replacement section only lasted, for example, five years, the unusual reaction was, "they just don't make steel like they use to". Actually, the difference in performance time was not the fault of the steel itself, it was the anode-cathode relationship between new (bright) steel and old (rusted) steel as shown by the demonstration described above.

The steel to mill scale anode-cathode relationship may be encountered on steel from a hot rolling mill from which the mill scale has not been properly removed. The mill scale is strongly cathodic (more noble) with respect to the base steel. This gives rise to strong dissimilar-surface-condition corrosion cells at breaks in the mill scale coating. The base steel is anodic and corrodes at such breaks in the absence of adequate corrosion control measures.

Demonstration Showing the Corrosion Cell Resulting from Differences in Electrolyte Concentration

This demonstration is intended to show that a steel structure (such as a pipeline) passing through a similar electrolytic environment, but of differing concentration from point to point, can be affected by corrosion cells caused by the variations in concentration. Additionally, it is intended to show that the steel structure in the more highly concentrated electrolyte will be anodic (and corroding) with respect to those parts of the structure in less concentrated electrolyte.

A corrosion demonstration cell to illustrate the differential concentration effect is shown by Figure 1-7. A bright steel electrode is placed in each of the two cell compartments. They are electrically interconnected (a single strip bent into a U-Shape. as shown accomplishes this). One of the compartments is filled with a 1% solution (low concentration) of sodium chloride. The other compartment is filled with a 10% (higher concentration) of sodium chloride. Anodic and cathodic color indicators are added to the solution. A porous barrier between the two compartments prevents free intermixing of the two solutions but permits passage of electric current between the two compartments.

Once the cell is placed in operation by the demonstrator, time required to obtain anodic and cathodic color indications will typically range from 30 to 60 minutes. A successful demonstration will show the blue-green anodic reaction coloration at the steel electrode in the high concentration (10% sodium chloride) compartment and the pink cathodic reaction coloration at the steel electrode in the low concentration compartment.

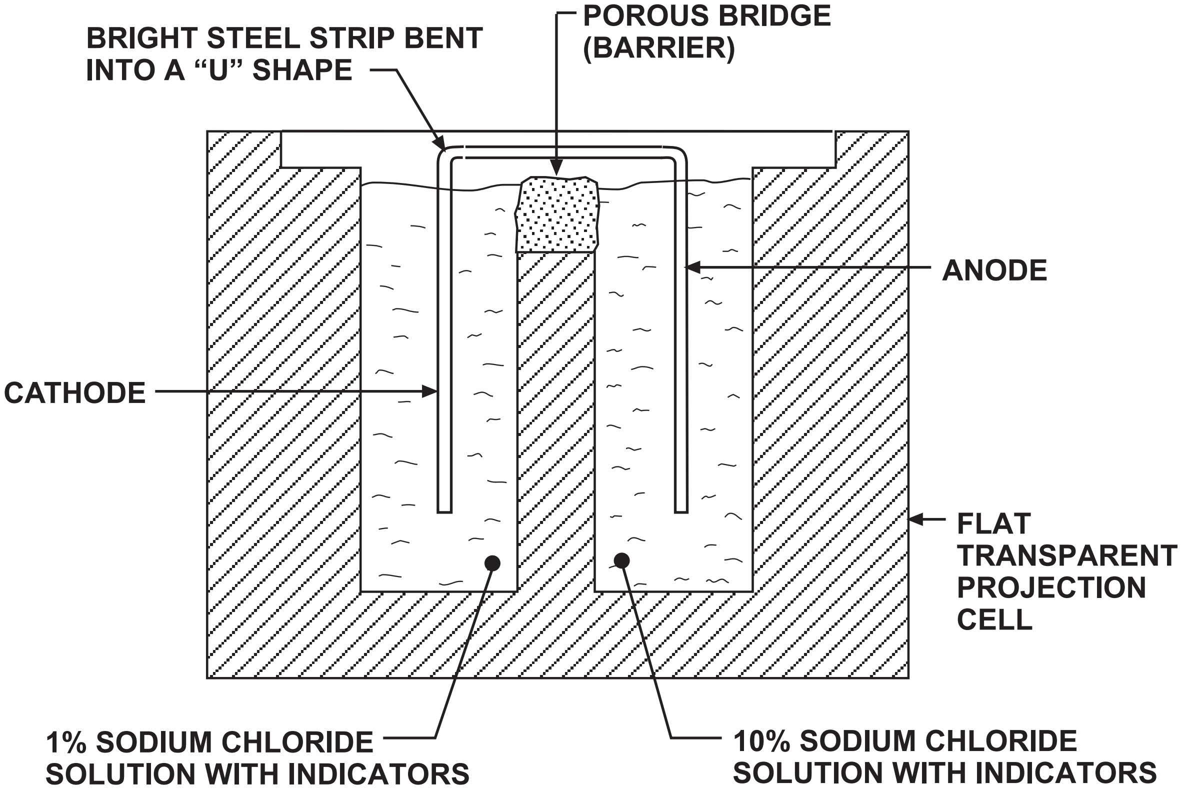
Various conditions can give rise to the differential-concentration corrosion cells on operating pipelines. An example is a pipeline crossing a marine tidal flat with some fresh water influx. At high tide, the entire structure may be covered with concentrated sea water but as the tide recedes, part of the structure will be in concentrated sea water while part will be in diluted sea water. Corrosion will be concentrated in that part of the structure still in the more concentrated sea water. This is a moving situation as the tide flows in and out.

Another example can be chemical contamination in industrial areas. Where such contamination occurs, the concentration will typically be greatest at the center of the spill area. This would be the area of greatest anodic effect. As the concentration tapers off as the edges of the spill area are approached, the structure becomes relatively cathodic.

Demonstration to Show the Effect of Anode-Cathode Ratio on Corrosion Rate

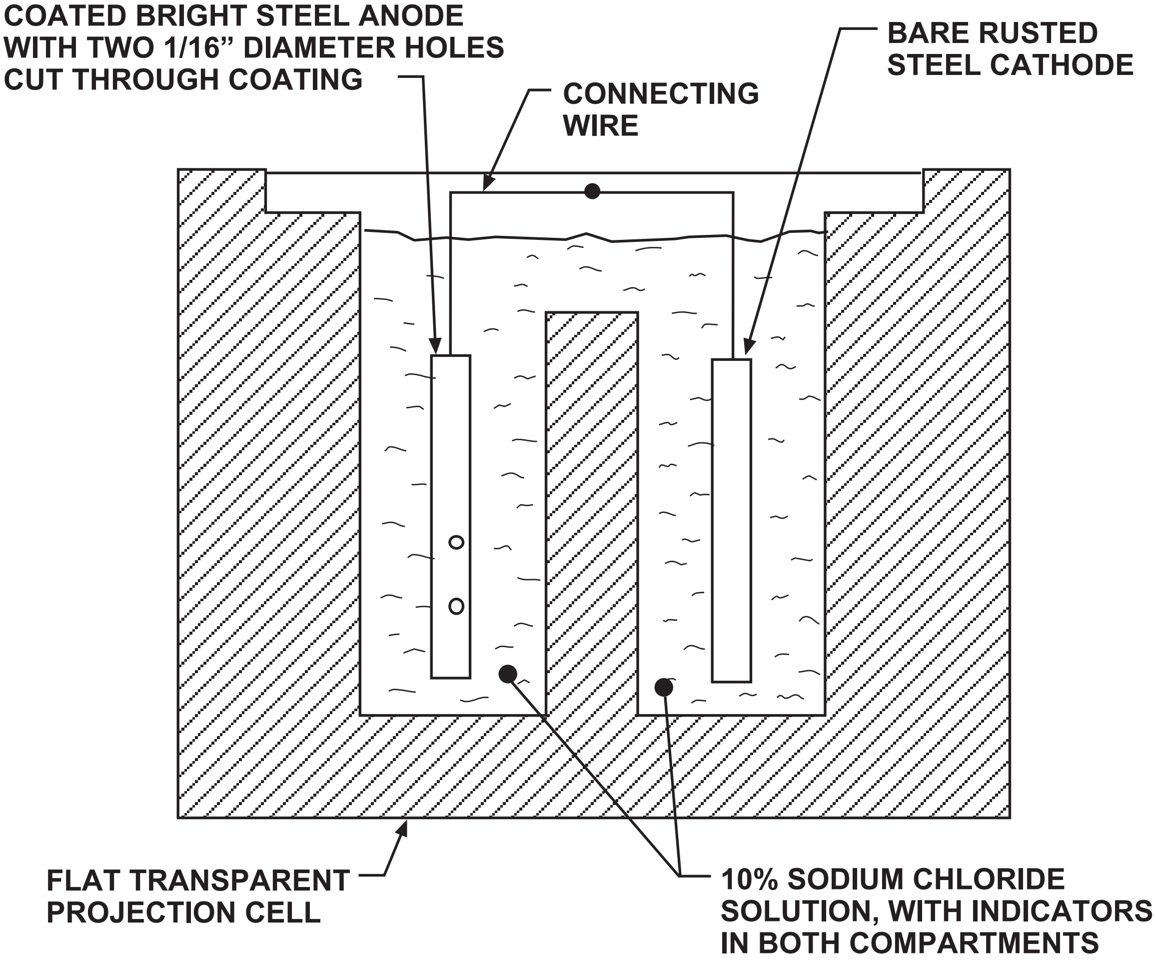
The purpose of this demonstration is to show that if a small anode is coupled to a large cathode in a corrosion cell, the rate of corrosion will be high at the small anodic area.

The demonstration cell arrangement to accomplish this is shown by Figure 1-8. In this cell, one compartment contains a bright steel electrode which has been given a paint coating with two pinholes (approx 1/16" in diameter) cut through the coating near one edge of the electrode. The other compartment contains a rusty steel electrode; a



DEMONSTRATION CELL TO SHOW CORROSION CAUSED BY DIFFERENCES IN ELECTROLYTE CONCENTRATION

FIGURE 1-7



DEMONSTRATION CELL TO SHOW EFFECT OF ANODE - CATHODE RATIO ON CORROSION RATE

FIGURE 1-8

preceding demonstration has shown that the bright steel will be anodic and the rusty steel cathodic. The two electrodes are electrically interconnected. Both compartments are filled with a 10% solution of sodium chloride to which the anode and cathode color indicators leave been added. Typically, with this arrangement, the ratio of cathodic area to the small anodic area will be in the order of 150:1.

Typically, a successful demonstration will show a relatively intense blue-green anodic coloration showing at the small anodic area pinholes before pink cathodic coloration appears at the larger rusty steel cathodic area. This is an indication that the corrosion rate at the anodic pin-holes is relatively intense as compared to that observed during the prior demonstration in which a bare bright steel electrode was coupled to a bare rusty steel electrode.

If the situation were reversed such that the anodic area is large and the cathodic area small by the same ratio, there would be an intense pink indicator appearing at the small cathodic area before the blue-green anodic coloration becomes apparent oil the large anodic area - an indication that the corrosion rate in the anodic area is much less intense than in the preceding case.

This all illustrates the basic rule that if anodic materials must be coupled to cathodic materials on an underground structure, a small cathode coupled to a large anode is much to be preferred to a small anode coupled to a large cathode. This rule does not, however, apply to cathodic protection installations where relatively small anodes (galvanic or impressed current) are connected to large cathodic areas being protected - but here the anodes are corroded in order to cathodically protect the working underground structure.

Some examples can be cited to illustrate the effects of anode-cathode ratio in underground piping systems.

As one example, if a brass valve is used in galvanized steel piping, there is a dissimilar metal corrosion problem. However, there is a small cathode (the brass valve) working against a relatively large anode (the galvanized piping). Under this condition, the corrosive effect is distributed over a large area of the galvanized piping. Further, the corrosion current from the galvanized piping can polarize the small brass cathode which acts to reduce the corrosion current interchange. Coating the brass valve can further reduce the current interchange to a negligible amount by reducing the already-small cathode to just any brass cathodic material exposed at defects in the valve coating. This emphasizes the wisdom of using the small cathode, large anode relationship on underground structures.

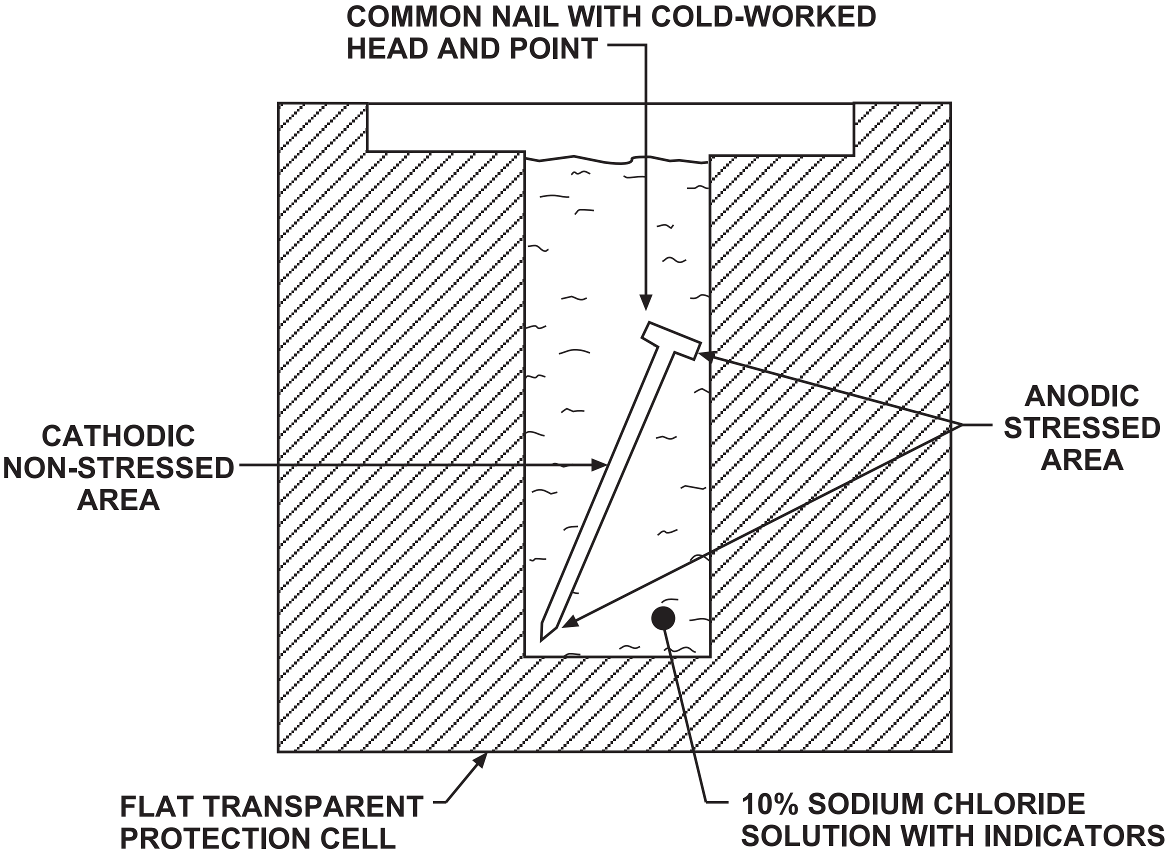
As a reverse-situation example, if a galvanized steel valve were to be used in underground copper piping, the undesirable small anode large cathode would result. Under this condition, there would be intense corrosion current discharge from the small anode (the galvanized steel valve). Further, this current flowing to the relatively large copper pipe cathodic area would have little expectation of polarizing the copper - so there would be little or no reduction in the corrosion current interchange from this source. Also, coating the galvanized valve anode in this situation would be the wrong thing to do since the ratio of large cathode to small anode would be made even greater. Current discharge from the anode surface exposed at defects in the coating would be even more intense than if the galvanized valve were left bare leading to even earlier corrosion penetration of the valve body. This emphasizes the wisdom of avoiding the small anode, large cathode relationship on underground structures wherever possible.

A final example relates to the use of coatings on non-cathodically protected underground structures. A good coating can prevent corrosion on more than 99% of the structure surface area. But the remaining surface area is exposed to earth at minor coating defects or pinholes inevitably exist or will develop on underground structures in practical applications. Some of the pinholes will be in naturally cathodic areas and some in naturally anodic areas. Where pinholes exist in a relatively small anodic area working against pinholes in large cathodic areas on either side of the anodic area, corrosion current discharge from the pinholes in the anodic area can be intense. This can result in the development of corrosion penetrations on the non-cathodically protected structure earlier than if the structure had been installed bare, even though the total metal loss is not so great.

Demonstration to Show the Corrosive Effect of Stress in Metal

It is the intent of this demonstration to show that residual stresses in metal are anodic with respect to non-stressed portions of the same metal sample.

Figure 1-9 illustrates the arrangement to show the effect. A single compartment demonstration cell is used. The compartment is filled with a 10% solution of sodium chloride to which anodic and cathodic color indicators have been added. A common iron nail is placed in the compartment. The cold worked nail head and point contain residual stresses from the cold working process. A successful demonstration will result in a concentration of the blue-green anodic coloration around the head and point of the nail



DEMONSTRATION CELL TO SHOW
CORROSIVE EFFECT OF STRESS IN METAL

FIGURE 1-9

with the pink cathodic coloration along the shank of the nail. Occasionally, depending on the surface condition of the nail shank, there may be secondary lesser anodic areas along the shank of the nail.

Because of the low driving potential between the stressed and non-stressed portions of the nail, the time required for the color development on on-screen projection may be from one to two hours making it necessary to place the cell in operation prior to the start of the lecture period.

Stress corrosion can occur on working pipelines where stress-induced corrosion can initiate cracking and pipeline failure. This is an involved study in itself but appears to be most apt to occur on the higher strength pipeline steels in the absence of adequate protective measures.

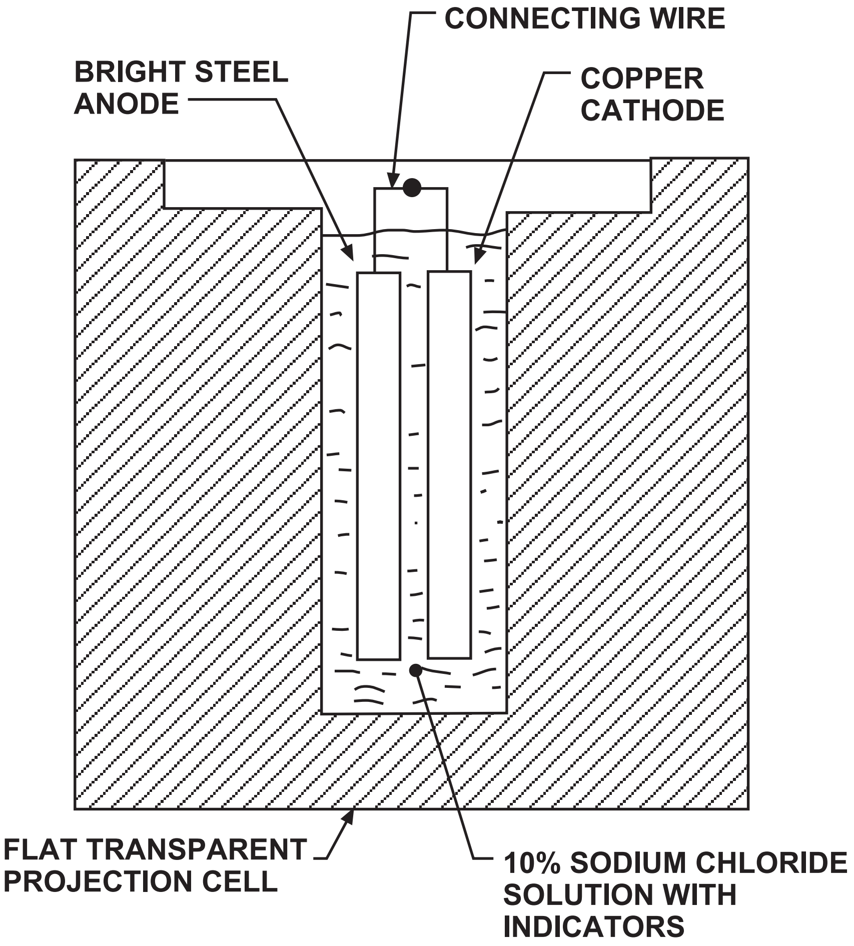
The use of rivets and bolts on structures in a conducting environment can be a problem. Stress is present in such fasteners but if rivet and bolt materials are selected such that the stressed material is slightly cathodic to the material in the body of the structure, the desirable large anode small cathode relationship will be attained. Under this condition, the stressed bolts or rivets will be cathodically protected to a degree by the structure itself. Since the anodic area (the body of the structure) is large, the corrosive impact on it will be slight as discussed in the preceding section.

Demonstration to Show Effect of Cathodic Protection on a Corrosion Cell

In this demonstration, the intent is to show the beneficial effect of cathodic protection on a known corrosion cell. This accomplished with a two-part demonstration.

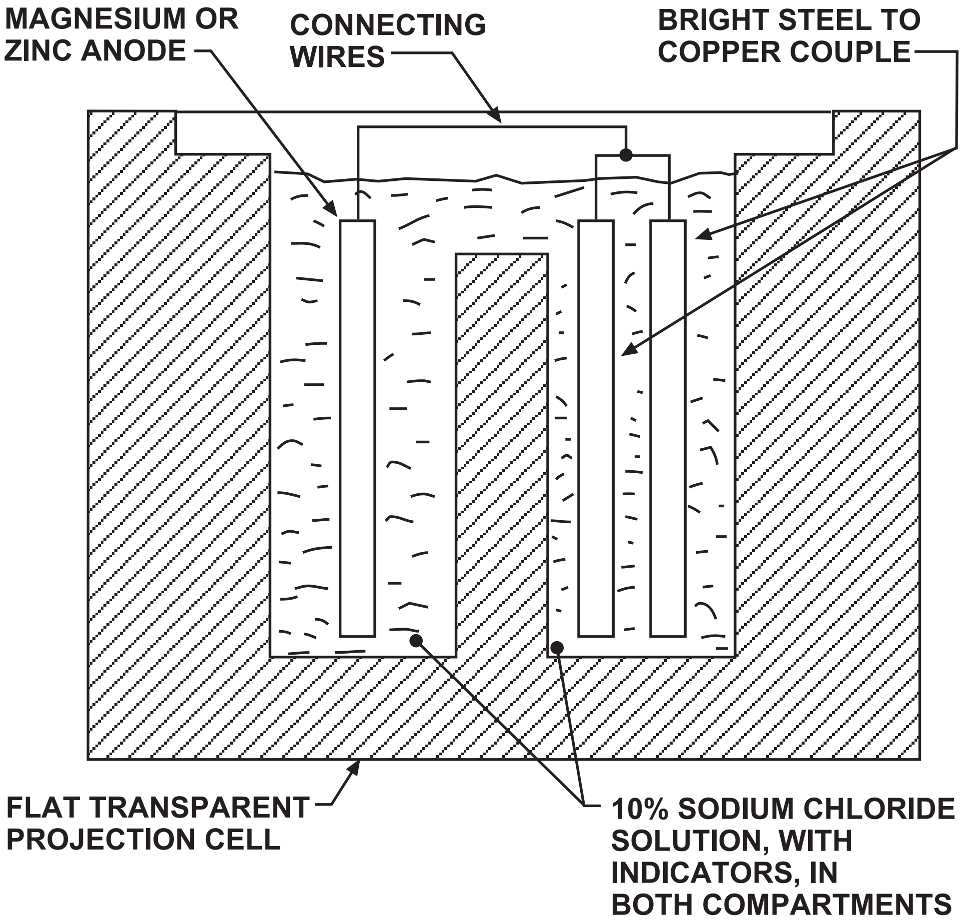
In the first part of the demonstration, a single-compartment cell is used as shown schematically by Figure 1-10. A dissimilar metal couple (bright steel anode and copper cathode electrically interconnected as shown) is placed in the compartment. The compartment is filled with a 10% solution of sodium chloride to which the anodic and cathodic color indicators have been added. Within five to ten minutes after placing the cell in operation, the bright steel anode should show the blue-green anodic coloration while the copper cathode shows the pink cathodic coloration. This establishes the corrosion pattern for a non-cathodically protected steel-copper cell.

In the second part of the demonstration, a two-compartment cell is used as illustrated by Figure 1-11. A bright steel-copper dissimilar metal couple (identical to that used in the first part of the demonstration) is placed in one compartment. Either a zinc or



CATHODIC PROTECTION DEMONSTRATION
PART 1
PRIOR TO APPLYING PROTECTION

FIGURE 1-10



CATHODIC PROTECTION DEMONSTRATION
PART 2
PROTECTION APPLIED

FIGURE 1-11

magnesium electrode is placed in the second compartment (either one is less noble than both steel and copper). The zinc or magnesium electrode is electrically connected to the steel-copper couple. Both compartments are filled with a 10% solution of sodium chloride to which the color indicators have been added. Within five minutes (if magnesium is used), both the steel and the copper in the other compartment will show the pink cathodic coloration. This demonstrates that the steel portion of the steel-copper couple is now collecting current from the environment (rather than discharging current as shown in the first part of the demonstration) and has changed from anodic to cathodic - and is thus cathodically protected.

This demonstration is a simple visual illustration of an effective application of cathodic protection using galvanic anodes. This procedure is used widely on pipelines and other underground structures. Further information on the use of galvanic anodes is included in Chapter 2.

Where impressed current cathodic protection systems are used, the principal is exactly the same. The only difference is the source of the cathodic protection current. Whereas with galvanic anode protection dissimilar metals are used as the source of current, impressed current cathodic protection systems use current from an outside voltage source to force current to flow from low-consumption-ratio anodes to the structure to be cathodically protected - but the result is the same.

Impressed current systems are discussed further in Chapter 3.

Demonstration Flexibility

Although the various demonstration cells which have been discussed show a number of examples of corrosion in action, the lecturer conducting the demonstration may choose to add to or modify some of them for further clarification where lecture time permits.

Demonstration Equipment

For those who may wish to prepare similar demonstrations, the following information is included in equipment and techniques that have been used for this purpose to date as developed by Colonel Cox.

The projector used is a 3¼ inch by 4 inch slide projector. The transparent plastic demonstration cells are made to fit the slide carrier slot in the projector. The cells are made of Plexiglass or Lucite. Two types are needed. The cell construction illustrated by Figure 1-12 includes two two-compartment cells and one single compartment cell. The unit can be moved, as needed, to place any one of the three cells in the path of the projection beam.

The cell construction used for the oxygen concentration demonstration cell is illustrated by Figure 1-13. This cell includes the hydrogen and oxygen generation compartment which is not needed for the other demonstration cells.

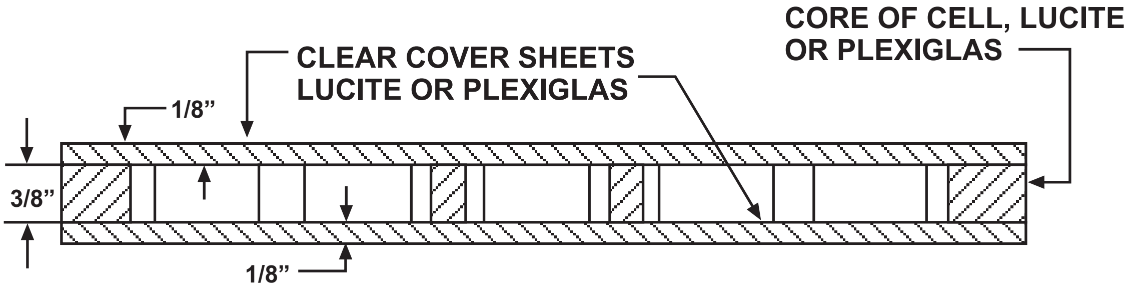
The various projection cells have to be placed in the projector in an upright position in order to prevent electrolyte spillage. When projected in the normal manner, the image on the screen will be upside down. Accordingly, the projector is pointed away from the screen and the image reversed (appears upright) by using the two front-reflecting-surface mirrors, one above the other, to deflect the projector toward the screen. Each mirror should be held in a frame which is mounted in a supporting bracket with pivots on the center horizontal axis so that the mirror angle can be adjusted and then held in position with thumb- screws or wing nuts.

The lower mirror should be 6 by 9 inches in size with the long axis horizontal. It should be placed directly in line with the projector beam with the center of the mirror approximately 3 inches from the projector lens.

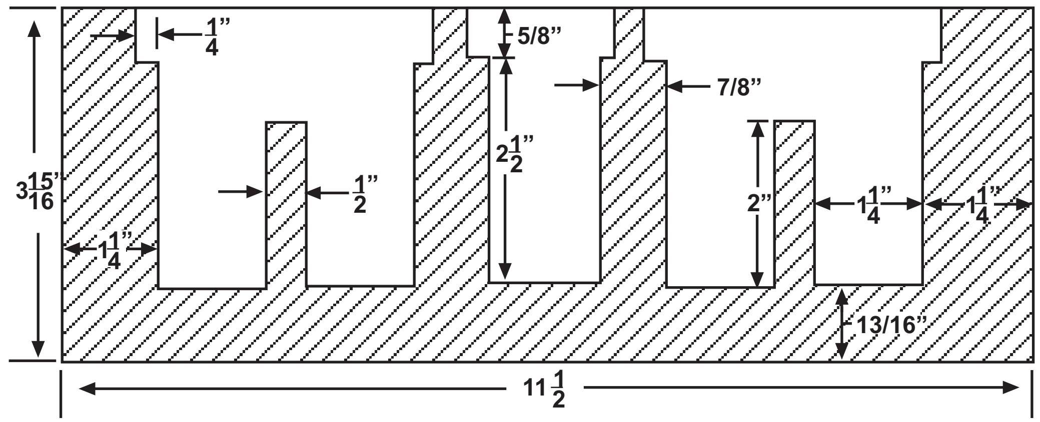
The upper mirror should be 9 by 12 inches and placed directly above the lower mirror. The center point of the upper mirror should be 10 to 12 inches (but not more than 12) above the center point of the lower mirror. By adjusting the angle of each mirror to about 45 degrees, the projector beam is deflected across the top of the projector toward the screen - and the image on the screen will be upright.

With appropriate modifications in the projection cells, it should be possible to utilize a standard overhead projector which would give the demonstrator added flexibility in changing cells during the presentation.

In those demonstration cells requiring a porous bridge between the two compartments of a two- compartment demonstration cell, cotton balls may be packed into the space between the compartments. These will become saturated with the electrolytes in the compartments and permit electric current to flow between the two without permitting free intermixing of the differing electrolytes. Nevertheless, both compartments should be filled at the same time



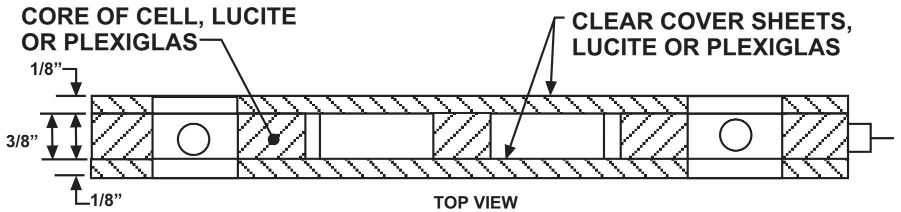
TOP VIEW



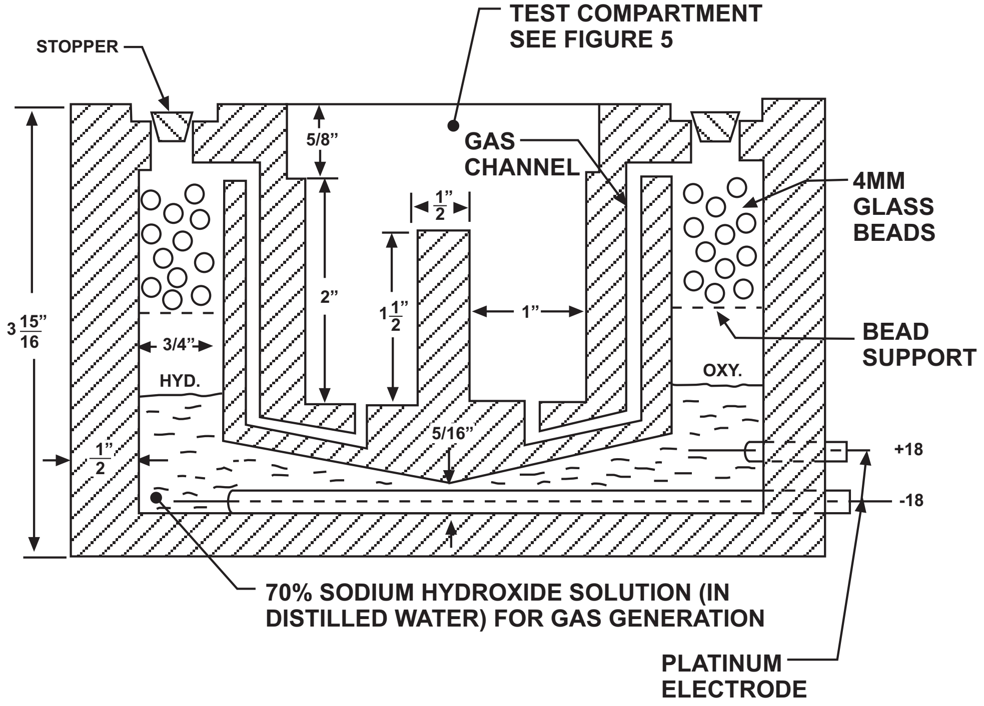
SIDE VIEW

CONSTRUCTION OF PROJECTION CELL SLIDE
FOR USE IN 3 1/4" x 4" PROJECTOR
SLIDE INCLUDES TWO DOUBLE-COMPARTMENT CELLS
AND ONE SINGLE COMPARTMENT CELL

FIGURE 1-12



TOP VIEW



SIDE VIEW

CONSTRUCTION OF PROJECTION CELL SLIDE FOR USE IN 3 1/4" x 4" PROJECTOR. SPECIAL SLIDE FOR OXYGEN CONCENTRATION DEMONSTRATION ILLUSTRATED BY FIGURE 1-5

FIGURE 1-13

and at the same rate in order to prevent seepage from one compartment to the other through the porous bridge.

Fresh solutions should be prepared for each demonstration. Aqueous solutions should be made using distilled water. Observe the instructions given earlier on the addition of anodic and cathodic color indicators. It is helpful to have solutions in small separate pouring bottles for easy handling during a demonstration. It takes approximately 20 milliliters to fill a single compartment of a demonstration cell.

When using the oxygen concentration demonstration cell, the lower compartment containing the 20% sodium hydroxide solution should be filled only as far as the bottom of the glass bead columns and the fill holes carefully stoppered to prevent escape of the gas. The function of the glass bead columns is to condense any entrained vapors and return the condensate to the reservoir.

The color indicators reach a peak of brilliance at which the projected effect is most satisfactory. The length of time required for this respect is given for the various demonstrations described herein but it is desirable that the first-time demonstrator make "dry runs" before an actual presentation in order to gain adequate experience with the cells.

Metal electrode strips should be about a quarter inch wide of approximately 20-gage material. These may be bent into "L" shape - or, in some cases, a "U" shape where the same material is used in both compartments of a two-compartment cell. Zinc or magnesium anodes need not be thin sheet but may be rods or strip that will fit into the ⅜" thick compartment of a cell. Platinum anodes, where used, are electrolysis demonstration electrodes stocked by chemical equipment supply houses.

CONCLUSIONS

In this chapter, we have reviewed the electrochemical features of the basic corrosion cell showing the consumption of steel (the most prevalent material used in underground structures). Based on this, fundamental corrosion formulas for iron are given.

The common flashlight battery was used as a good practical example of a corrosion cell based on dissimilar materials in electrical contact with each other in a corrosive medium. The anode- cathodic arrangement of dissimilar metals in tabular form was reviewed.

The various types of corrosion cells affecting an iron (or steel) structure were illustrated by visual demonstration to show that conditions which, in theory, should cause corrosion do, just that. The relative speed of reaction among the several demonstrations show that some conditions resulting in rapid reaction time tend to be more severe in effect than those having slower reaction times.

Finally, the visual demonstrations were concluded by showing that if cathodic protection is applied to a corrosion cell, the cathodic protection prevents the formation of the anodic areas, which would develop had the cathodic protection not been present. This demonstration showed also, that the material used as a source of the cathodic protection current is anodic and corrodes to provide cathodic protection for the protected structure.

REFERENCE

Col. George C. Cox "Demonstrating Electrochemical Corrosion Reactions by the Use of Transparent Cells in an Optical Projector." Proceedings of the 3rd Annual Appalachian Underground Corrosion Short Course (1958).

Chapter 2 - Installation of Galvanic Anodes

INTRODUCTION

This chapter is concerned with the use of galvanic anodes for cathodic protection on underground structures. Although use on pipelines is the major application, galvanic anodes may be used on many other types of underground metallic structures.

Within the framework of this chapter, it is intended that the following general categories of information will be covered:

1. A brief review of the fundamentals applying to this specific subject.

2. The normally accepted applications where galvanic anodes can be used economically and advantageously for cathodic protection of underground structures.

3. General data on the physical and electrical characteristics of galvanic anodes made from magnesium, zinc, and aluminum.

4. Guideline material on field installation practices for various types of cathodic protection installations using galvanic anodes as the source of electrical energy.

REVIEW OF FUNDAMENTALS

The Galvanic Corrosion Cell

The galvanic corrosion cell was discussed in detail in the Basic Course (Chapter 2 - Corrosion Fundamentals) and has been reviewed in Intermediate Chapter 1 - Corrosion Cell in Action.

The galvanic corrosion cell includes four basic parts:

1. An anode
2. A cathode
3. A metallic path between the anode and cathode
4. A conducting electrolyte in which both the anode and cathode are immersed

The fact that there is an anode and a cathode implies that there is a driving voltage (potential or emf) between the anode and cathode which will cause corrosion current to flow between the two. There will be no corrosion unless current flows between the anode and the cathode.

Galvanic Anodes and Cathodic Protection

The cells established between steel and magnesium, zinc or aluminum are stronger (they have a higher driving voltage) than the usual galvanic corrosion cell encountered on a steel structure. Accordingly, the higher driving voltage of the galvanic anode cell overcomes the lower driving voltage of the corrosion cell. The points which had been anodic (discharging current and corroding) are forced by the galvanic anode cell to collect current and become cathodic. Corrosion is therefore stifled. This is the basic concept of cathodic protection with galvanic anodes. Figure 2-1 illustrates this concept.

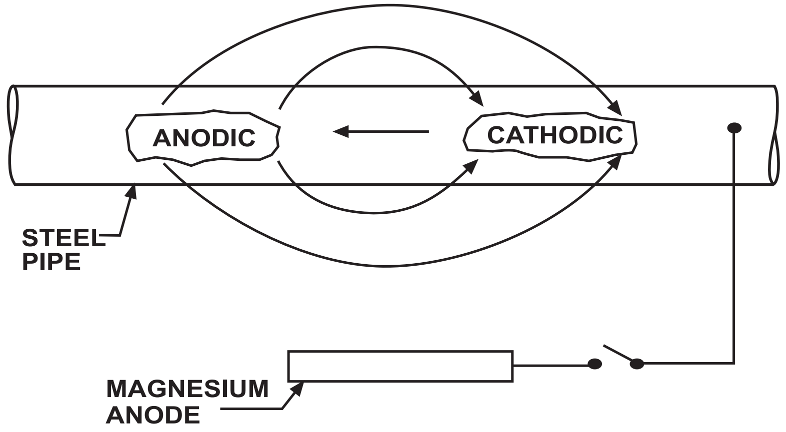
Galvanic Anodes Plus Coatings and Electrical Isolation

Although, as will be described later, galvanic anode cathodic protection can be used on bare underground structures, it is most efficiently used on well coated structures which are electrically isolated from all other structures. Here's why.

In Chapter 3 of the Basic Course text, Introduction to Pipeline Coatings, coatings are described as insulating barriers that prevent current discharge from areas that tend to be anodic on underground structures. It is also pointed out that, from a practical standpoint, one can always expect that there will be "holidays" (scrapes, gouges, pinholes, rock penetrations, etc.) which will expose small areas of the structure surface to the surrounding environment. The current flow from a galvanic cathodic protection installation will seek out and flow onto the underground structure at the holidays and provide cathodic protection. Typically, there will not be a significant measurable amount of the galvanic anode current flowing through sound coating onto the structure.

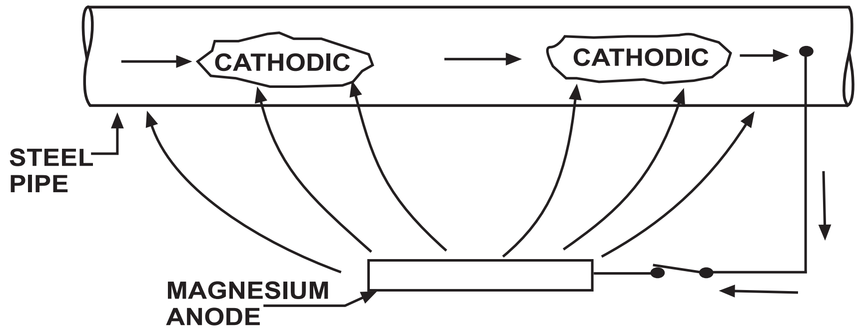
Assuming a reasonably good coating carefully applied and handled, the actual exposed metal structure surface area could be less than 1% of the total surface area. This simply means that the amount of current from a galvanic anode cathodic protection installation needed to protect one square foot area of bare metal (such as on a bare steel pipeline) could cathodically protect several hundred square feet of coated structure.

Electrical isolation of a coated structure (or portion of such a structure) to be cathodically protected with galvanic anodes may be necessary for an effective system. The current output of galvanic anode installations on underground structures is typically



CONDITION 1:

SWITCH OPEN IN MAGNESIUM ANODE CIRCUIT. NO CATHODIC PROTECTION. CORROSION CURRENT FLOW FROM ANODIC AREA TO CATHODIC AREA OF CORROSION CELL SHOWN BY LINES AND ARROWS. RETURN CIRCUIT THROUGH PIPE.



CONDITION 2:

SWITCH CLOSED IN MAGNESIUM ANODE CIRCUIT. CATHODIC PROTECTION APPLIED. CATHODIC PROTECTION CURRENT FLOW SHOWN BY LINES AND ARROWS. PREVIOUSLY ANODIC AREA HAS BECOME CATHODIC.

BASIC CONCEPT OF CATHODIC
PROTECTION WITH GALVANIC ANODES

FIGURE 2-1

much less than that which can be obtained from impressed current cathodic protection systems (See the following Chapter). For this reason, the current output of galvanic anode installations on coated structures needs to be confined to that part of the structure which is to be cathodically protected.

As an example, if a one-mile section of a ten-mile-total-length coated pipeline were to have galvanic anodes installed, and if the installations were designed to provide only enough current to protect the one-mile section, it would not be cathodically protected unless it were electrically isolated from the other nine miles in the pipeline. This is because, without electrical isolation, much of the galvanic anode current would flow to the other nine miles of pipe rather than to the one-mile section to be protected. In view of the limited current available from the galvanic anode installations, the result could be that no part of the one-mile section and no part of the remaining nine miles in the pipeline would receive full and adequate cathodic protection.

Although galvanic anodes are most efficiently used on electrically isolated coated structures, they can be used on bare structures. Such use has been very extensive on bare pipelines. The difference is that, in most applications, enough current for cathodic protection will reach the structure surface only in the immediate vicinity of the anode (within its potential gradient field). Galvanic anodes (normally magnesium) used in this manner are said to provide "hot spot" protection. This type of protection and the gradient field concept will be discussed in more detail later in this Chapter.

GALVANIC ANODE APPLICATIONS

General Uses

As has been indicated in the preceding material, galvanic anode installations tend to be used mostly on underground structures in applications where cathodic protection current requirements are small and where soil resistivities are acceptably low. The importance of the soil resistivity is that the current output of a galvanic anode cathodic protection installation is primarily controlled by two factors: the anode-to-structure potential (driving voltage) and the resistance to earth of the galvanic anode installation. The former is restricted within narrow limits whereas the latter is a function of the soil resistivity. The lower soil resistivities permit obtaining a low enough resistance to earth to permit the flow of an economically acceptable driving voltage.

Specific Uses

There are numerous ways in which galvanic anodes are used on underground structures. The following descriptions comprise a representative listing of uses.

1. For sections of piping in distribution systems having a small cathodic protection current requirement, galvanic anode installations can be more practical (less expensive, less complicated, and easier to maintain) than an impressed current installation (rectifier or other impressed current power source).

2. Galvanic anodes (usually magnesium) are used for "hot spot" protection on bare pipelines. Typically, these are installed at locations where leaks are repaired or at locations where corrosion surveys indicate that corrosion is active.

3. Galvanic anodes can be used to supplement impressed current cathodic protection systems. If the overall protection afforded by an impressed current installation has some deficient areas (not quite enough current reaching them to attain full protective potentials), galvanic anodes can be used in such areas to provide the additional current needed. This can be less expensive than reinforcing the impressed current installation and can lead to fully adequate overall protection.

4. Galvanic anodes frequently are well suited to providing cathodic protection to short pipeline replacement sections. This is true where soil conditions are favorable and where the replacement pipe is well coated and is electrically isolated from the remainder of the pipeline system and from any other underground metallic structure

5. Galvanic anodes can be used to prevent stray current discharge from underground structures (particularly pipelines) where the degree of interference is not severe. This is accomplished in the interference area by so placing and installing the anodes that the galvanic voltage difference between the anode metal and structure metal (steel for example) will force the stray current interference current to discharge from the anode material rather than from the structure.

   Where stray current interference effects are stronger, the voltage drop across the structure-to-ground resistance caused by the stray current discharge in the interference area may be greater than the counter polarity galvanic voltage between galvanic anode metal and the structure. In such instances, the interference effect may be reduced but not eliminated unless unusually elaborate galvanic anode installations are used.

6. Where pipelines are buried in the ocean bottom or in other sea-water-covered areas, galvanic anode "bracelets" (usually zinc) are attached to the well-coated pipeline as it is assembled on the lay barge and fed off into the water and underwater trench or simply laid on the ocean floor. The very low resistivity marine environment permits high current output, when needed, from individuals anodes. The anode bracelets are typically placed at close intervals along such lines. This permits excellent uniformity of protective current distribution along the pipeline and permits making available enough weight of galvanic anode material to ensure long anode life. The relationship between anode weight and useful life is discussed later in this Chapter.

7. Well coated warm pipelines (such as oil pipelines) in a permafrost arctic environment can be cathodically protected effectively with continuous strip galvanic anodes (ribbon anodes). A warm oil pipeline creates a thaw zone in the permafrost along the pipeline. By placing the strip galvanic anode material parallel to the pipeline in the surrounding envelope of thawed earth, uniformly distributed protective current is attained. Anode life can be adjusted by selecting the size and number of paralleling continuous strip galvanic anodes.

   It should be noted that this does not work on a cold pipeline in a permafrost environment where there is no thawing of the environment surrounding the pipeline. This is because earth which is below the freezing point has a very high resistivity (even though low resistivity when thawed); accordingly, anode-to-earth resistances are so high that the limited driving voltage available with galvanic anodes will not force the flow of a significant amount of current.

8. Continuous strip galvanic anodes can be used for the coated internal surfaces of pipelines carrying a corrosive material. In this case, the anodes are best attached to the interior of each pipe length as it is laid and welded (or otherwise joined) to the pipeline being built. Again, the amount of anode material can be adjusted to give the desired installation life.

9. An adaptation of Item 8 involves the use of continuous strip anodes to serve as a source of backup cathodic protection for the carrier pipe inside a casing at a road or railroad crossing. As long as the casing pipe remains electrically isolated from the carrier pipe, current from the overall pipeline cathodic protection system will pass through the casing wall (and any electrolyte enclosed by the casing) to reach the

carrier pipe and afford protection. Should, however, the casing pipe become electrically short circuited to (develop a direct metallic contact with) the carrier pipe, any cathodic protection current from the overall system collected by the casing will flow directly to the carrier through the point of metallic contact between the two. No protection will then be available to the carrier pipe throughout the length enclosed by the casing.

When contact develops as described, strip galvanic anodes attached to the carrier inside the casing (if such anodes were installed) will automatically provide cathodic protection to the carrier pipe where covered with any conducting electrolyte which has accumulated in the annular space between carrier and casing.

10. A highly specialized application is the use of two or more galvanic anodes, closely spaced, used as a high voltage dissipation gap (or grounding cell) connected across pipelines isolating joints. High voltages are possible across isolating joints during electrical storms or as a result of faults on paralleling high voltage electrical systems. If these high voltages are not controlled, the isolating joints may arc across and become short circuited necessitating expensive repair or replacement.

    The galvanic anode dissipation gap is made up with sets of anodes rigidly held mechanically, at close spacing (½ to 1 inch). The anode assembly is packaged in a low resistivity special backfill. Half the anodes (typically one or 2) are connected to the pipe on one side of the isolating joint while the other half are connected to the opposite side.

    In normal operation (assuming a DC voltage across the isolating joint as a result of different cathodic protection levels on the two electrically separated systems), current will tend to flow from the system having less (or no) protection through the low internal resistance of the anode gap to the system having a higher level of protection. However, the anode or anodes which tend to collect current polarize in the negative direction. This causes a “back voltage” which opposes the flow of current through the anode gap. Because of this characteristic, there is little loss of cathodic protection current through such anode gaps.

    When a high voltage is impressed across an isolating joint equipped with an anode gap, the high voltage overcomes the back voltage (which restricts current loss under normal conditions) and passes current in an amount primarily determined by the impressed high voltage and the circuit resistance.

As an example, assume that a high voltage is impressed across an isolating joint equipped with a dissipation gap grounding cell having a gap resistance of 0.3 ohms and that 1000 amperes passes through the anode gap. The current flow through the anode gap restricts the voltage drop across the isolating joint, by Ohm's Law (E = IR), to 1000 amperes x 0.3 ohms = 300 volts. In the absence of the anode gaps, the voltage drop across the isolating joint could be, easily, thousands of volts.

Advantages and Disadvantages

Although some of the advantages and disadvantages of galvanic anodes are undoubtedly apparent from the preceding material, the more significant items in each category are summarized below:

Advantages

1. Since galvanic anodes are “self-powered,” they require no external power source.

2. Installations may be designed with sufficient weight of anode material to produce the desired current output for many years before replacement is necessary.

3. The field installation of galvanic anodes is simple. Relatively little training is required to attain acceptable construction skills.

4. Maintenance requirements are very low. Out ages on commercial power supplies do not affect them. They cannot be short circuited.
   As long as they are in electrical contact with the protected structure, they will continue to provide protective current until the anode material has been consumed.

5. Galvanic anodes tend to be more economical than impressed current installations where small amounts of protective current are needed and where earth resistivities are low.

6. Galvanic anodes are less likely to cause stray current interference on other structures than is the case with impressed current systems. Such interference is possible with galvanic anodes if there is not sufficient clearance between the anodes and foreign structures. Typically, five feet or more will be sufficient to prevent significant interference in most instances.

Disadvantages

1. Galvanic anodes have a low driving voltage. This driving voltage is limited by the galvanic voltage difference between the metal of the structure being protected and the metal of the galvanic anode.

2. Because of the low driving voltage, galvanic anodes normally are limited to use in low resistivity soil. This is so that the anode-to-earth contact resistance will be low enough to permit the flow of useful amounts of cathodic protection current.

3. The usual galvanic anode installations have insufficient capacity for controlling dynamic stray current effects on protected structures.

4. Except in unusual situations, galvanic anodes are not an economical source of large amounts of cathodic protection current.

GALVANIC ANODE CHARACTERISTICS

It is to be noted at the outset of this section that there are different alloys available of the various galvanic anode metals and that manufacturers offer many sizes and shapes of anode material. Accordingly, the corrosion control worker should keep informed of the latest catalog information on the available galvanic anode materials.

Galvanic Anode Materials

The following three metals are the most common galvanic anode materials:

Magnesium
Zinc
Aluminum

The characteristics of these anode metals are included in the following section along with comments on their limitations, energy content, efficiency, and backfill requirements.

Magnesium Anodes

The technical data applicable to magnesium anodes is included in Table 2-1.

TABLE 2-1

COMMON ALLOY SPECIFICATIONS - MAGNESIUM

Element	High Potential	Grade A	Grade B	Grade C
Al	0.010% max	5.3 to 6.7%	5.3 to 6.7%	5.0 to 7.0%
Mn	0.50 to 1.30%	0.15 to 0.70%	0.15 to 0.70%	0.15 to 0.70%
Zn	0	2.5 to 3.5%	2.5 to 3.5%	2.0 to 4.0%
Si	0.05 % max	0.10% max	0.30% max	0.30% max
Cu	0.02% max	0.02% max	0.05% max	0.10% max
Ni	0.001% max	0.002% max	0.003% max	0.003% max
Fe	0.03 % max	0.003% max	0.003% max	0.003% max
Other	0.05% each or 0.30% max total	0.30 % max	0.30 % max	0.30 % max
Magnesium	Remainder	Remainder	Remainder	Remainder
Solution Potential	-1.80 V	-1.55 V	-1.55 V	-1.55 V

Magnesium anodes are used to a greater extent than zinc for earth burial installations on pipelines and other underground metallic structures. This is because the galvanic cell driving potential is higher, permitting practical amounts of cathodic protection current in higher resistivity soils.

There are many different sizes and shapes of magnesium anodes available from manufacturers. The corrosion worker should obtain up-to-date catalogs so that correct information will be available to permit matching the optimum anode weight and shape to specific design needs.

The most popular magnesium anode for general use is the 17-pound anode packaged in special chemical backfill. Most of the magnesium weights and shapes can be obtained either bare or packaged in special backfill. The advantages of special chemical backfill for use with galvanic anodes is covered in a separate section.

Approximately similar weights of magnesium may be available in short chunky shapes or in long slender shapes. There is a reason for this. The resistance-to-earth of a galvanic anode determines the current output at the fixed galvanic anode cell potential. A long slender anode has a lower resistance-to-earth in a given soil resistivity than does a short chunky anode. This means that long slender anodes can be the better choice in the higher soil resistivities.

Although either zinc or magnesium installations may be designed for use in any soil resistivity, various considerations tend to dictate that zinc anodes have their best usage in low resistivity soils with lesser advantage as the resistivity increases up to a rule-of-thumb maximum (which may be exceeded in special cases) of about 1500 ohm-cm. Allowing for some range overlap, a guide for magnesium usage could be between 1000 and 5000 ohm-cm. Again, both limits can be exceeded where design conditions warrant.

Zinc Anodes

The technical data applicable to zinc anodes is included in Table 2-2.

As was the case with magnesium anodes, zinc anodes can be obtained in many different weights and shapes. They may be obtained packaged in special backfill. Again, the corrosion worker should obtain the latest catalog information on currently available zinc anodes.

TABLE 2-2

COMMON ALLOY SPECIFICATIONS - ZINC

Zinc (Mil-A 18001)		Zinc (ASTM B418-67 Type II)	
Seawater Use		Underground Use	
Element	Percent	Element	Percent
Aluminum	0.1 to 0.3%	Special high-grade Zinc	99.99% pure
Cadmium	0.025 to 0.06%		
Iron	0.005% max		
Special high-grade zinc	Balance		
Solution potential	-1.10 V	Solution potential	-1.10 V

As indicated earlier, zinc anodes work best in very low resistivity environments such as sea water, salt marshes, and similar low resistivity material. In such environments, short chunky zinc anodes work best. As the resistivity gets higher, the long anodes would be preferred. This could, for example, be in the general range of 750 to 1500 ohm-cm resistivity.

A later section in this Chapter will discuss the advantage of using a lower potential anode such as zinc in low resistivity environments.

Aluminum Anodes

Although investigated extensively in the past, there is not currently a type of chemical backfill that is in common usage to permit the practical and economical installation of aluminum anodes in earth burial applications. They do not work well directly buried in the usual earth environments.

Proprietary aluminum alloy anodes are available which work very well in a sea water environment. Cathodic protection current from anodes so located but connected to buried pipelines or other underground structures can protect such structures effectively.

Table 2-3 contains technical data pertaining to aluminum anodes.

Use of Special Chemical Backfill

For best performance over the long term, magnesium or zinc anodes are best used with a special chemical backfill surrounding the anode. As indicated earlier, suitable chemical backfills are not commonly available for use with aluminum anodes in earth burial applications.

The special backfills have the following advantages:

1. The chemical backfill provides homogeneous mixture contacting the anode surface as opposed to, typically, heterogeneous earth backfill contacting the anode if the chemical backfill is not used. This uniform environment reduces the amount of self corrosion on the anode surface with improved anode current efficiency.

2. The chemical backfill isolates the anode from soil chemicals which could have a passivating effect - an effect which can reduce or even completely stifle useful cathodic protection current output from the anode.

TABLE 2-3

COMMON ALLOY SPECIFICATIONS - ALUMINUM

Element	Seawater Galvalum I	Saline Mud Galvalum II	Seawater Brackish Saline Mud Galvalum III
Zinc	0.35 to 0.50%	3.5 to 5.0%	3.0%
Silicon	0.10% max	-	0.1%
Mercury	0.035 to 0.048%	0.035 to 0.048%	-
Indium	-	-	0.015%
Aluminum	Remainder	Remainder	Remainder
Solution Potential	-1.10 V	-1.10 V	-1.10 V

3. Typically, chemical backfills used with magnesium or zinc anodes have low resistivity compared to most soils in which the anodes are installed. Assuming that an anode is to be installed in earth having a resistivity higher than that of the envelope of chemical backfill being used around it, the net effect will be an apparent increase in anode size. This means that the anode resistance to earth will be lower than would be the case if the anode were installed without chemical backfill. This lower resistance in turn means higher current output at the fixed galvanic anode cell potential.

4. The chemical backfills commonly used with zinc and magnesium anodes have the ability to absorb and hold moisture. This characteristic is valuable in that it resists early anode drying out which would increase anode resistance to earth and decrease useful current output.

Chemical backfills are made with various mixtures of gypsum ($CaSO_4$), Bentonite clay, and sodium sulfate (Na_2SO_4). A simple mix that works well with zinc consists of 50% Plaster of Paris (calcined gypsum) and 50% Bentonite clay. The resistivity of this mixture after water wetting is in the order of 250 ohm-cm.

Another chemical backfill mixture commonly used with packaged anodes from suppliers consists of 75% hydrated gypsum, 20% Bentonite clay, and 5% sodium sulphate. The resistivity of this mixture after water wetting is in the order of 50 ohm-cm. This mixture can be used both with zinc and magnesium anodes. The low resistivity is a distinct advantage in reducing anode-to-earth resistance as indicated earlier.

Purchasing galvanic anodes of zinc or magnesium complete with attached connecting wire and chemical backfill in a bag or porous container surrounding and centered on the anode is an advantage from the standpoint of convenience and speed of installation.

The disadvantage of using anodes complete with packaged backfill, particularly long (5 ft.) anodes in vertically augered holes, is the possibility that voids may be left unintentionally below or around the package. After the backfill bag or porous container deteriorates with time, the chemical backfill can then settle into the voids leaving part of the anode surface without the benefit of the chemical backfill. In turn, less than optimum anode performance will occur.

The above-described hazard may be offset by construction methods and practices that will ensure proper backfilling of the packaged anode.

Chemical backfills may be purchased separately from galvanic anodes. Some operators prefer this, particularly when installing multiple anode beds with long anodes.

GALVANIC ANODE INSTALLATION PROCEDURES

Single Anode Installation

Where a single anode such as a 17-pound standard size magnesium anode is to be used, general practice is to use a packaged anode. This would typically be installed as shown on Figure 2-2. Care is taken when backfilling the anode to be sure that there are no voids which will cause later trouble after the package container deteriorates.

If longer packaged anodes are used, the auger hole in which the anodes are installed, as shown also in Figure 2-2, should be large enough so that when the packaged anode is placed in position in the hole, the backfill may be placed and tamped to prevent voids.

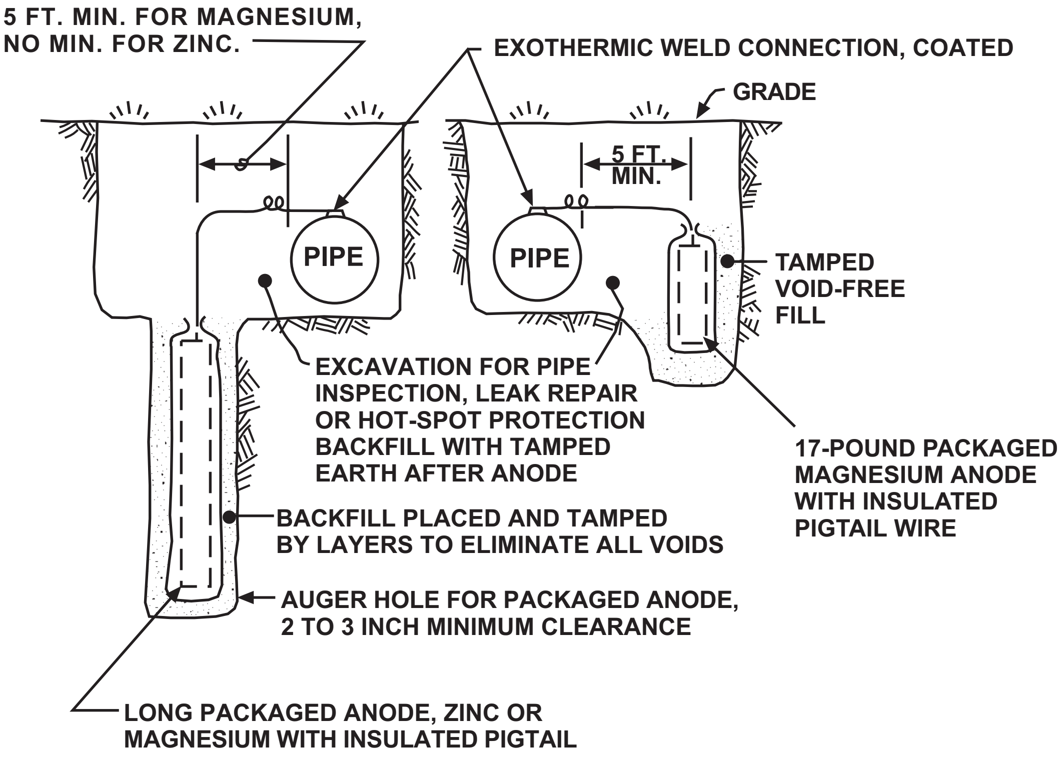
If, in specific situations, anodes are installed in congested areas where they cannot be placed at an adequate lateral distance from the pipeline or other structure, they may be placed in deeper holes below the protected structure with the required clearance between the bottom of the structure and the top of the anode. This is illustrated by Figure 2-3.

The installation of a single bare anode and separate chemical backfill is illustrated by Figure 2-4. Using separate backfill with long vertical anodes makes it possible to place the anode centrally in the hole and place and tamp the chemical backfill powder (which is installed dry) so that the entire annular space surrounding the anode is filled completely with no voids.

Multiple Anode Installation

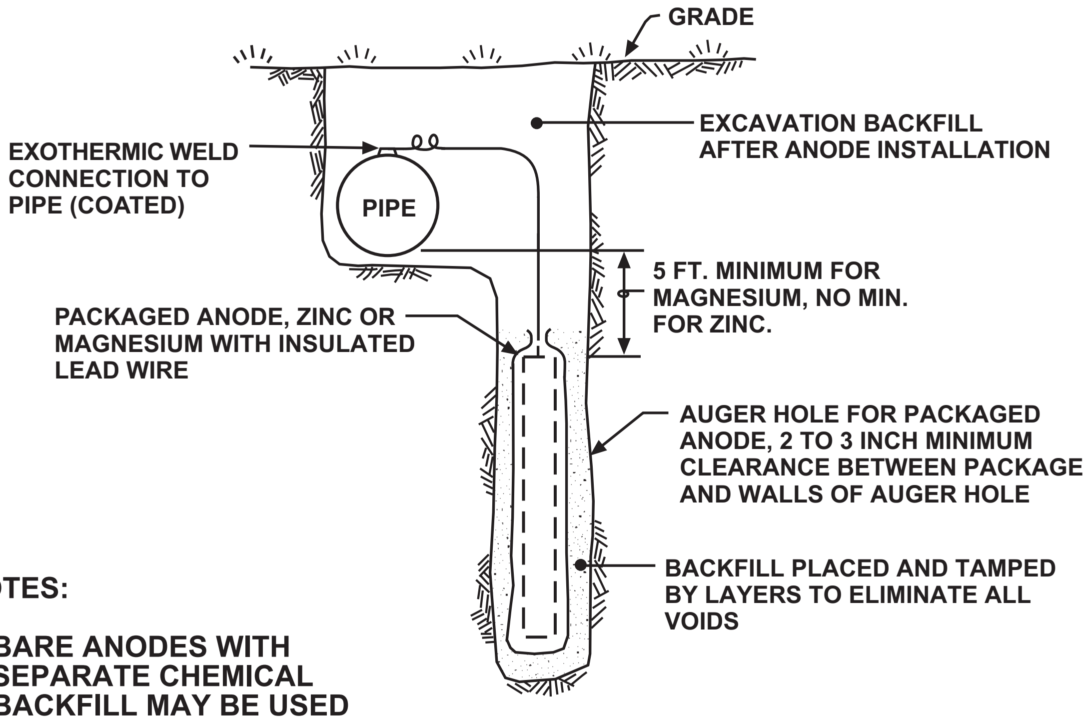
Where amounts of cathodic protection current are needed at one location which are larger than available from a single anode, multiple anode installations may be used. Such an installation is illustrated by Figure 2-5.

Anodes in a multiple anode installation may be either packaged or bare with separately installed chemical backfill. The latter method is less likely to involve later problems with voids, particularly when using long anodes. Separate chemical backfill is preferably installed dry. It can either be wet down from the top after installation to start anode activation or allowed to take up moisture from the earth. As the backfill mix becomes



TYPICAL INSTALLATION OF
PROTECTION WITH GALVANIC ANODES

FIGURE 2-2



NOTES:

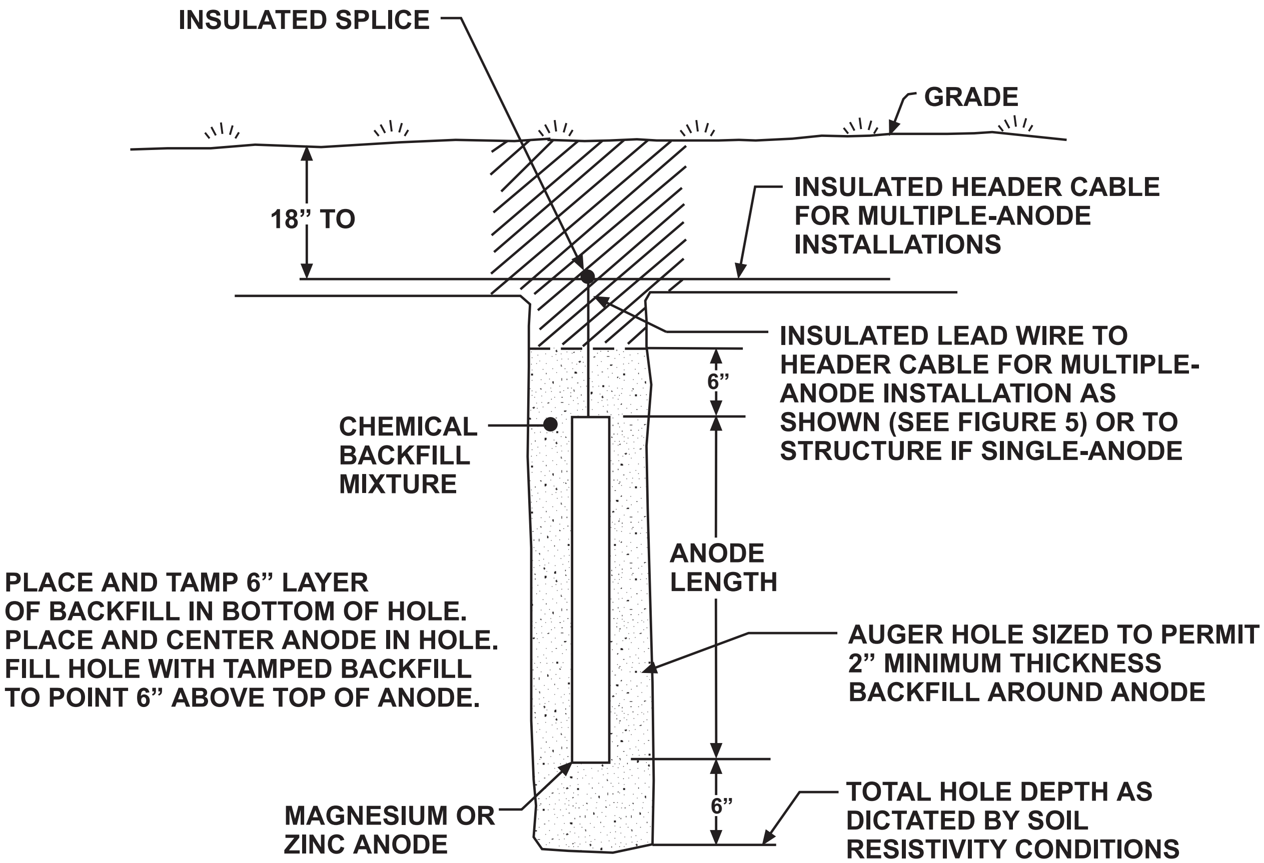
1. BARE ANODES WITH SEPARATE CHEMICAL BACKFILL MAY BE USED PER FIGURE 2-4.

2. MULTIPLE ANODE INSTALLATIONS MAY ALSO BE MADE WITH ALL ANODES BELOW PIPE BUT OTHERWISE IN GENERAL ACCORD WITH FIGURE 2-5.

3. IF NECESSARY, AUGER HOLE MAY BE ANGLED SLIGHTLY

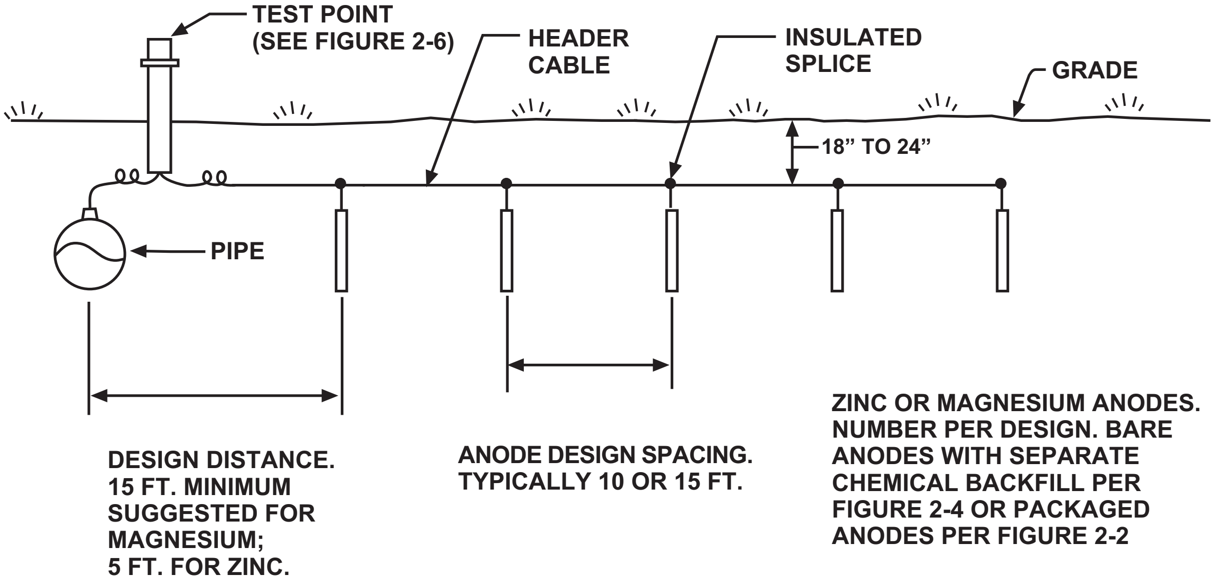
TYPICAL INSTALLATION OF GALVANIC ANODES WHERE LATERAL SPACE IS LIMITED

FIGURE 2-3



TYPICAL INSTALLATION OF BARE GALVANIC ANODES WITH SEPARATE CHEMICAL BACKFILL

FIGURE 2-4



MULTIPLE INSTALLATION OF GALVANIC ANODES

FIGURE 2-5

water saturated it tends to swell which further ensures good contact with the sides of the anode auger hole.

Anode Lead Attachment

The insulated lead wire from the anode may be connected to the pipeline or other underground structure by some form of exothermic welding process to ensure long term low resistance in the connection. Welding kits are available which permit making a copper wire-to-steel connection quickly and economically. The copper metal nub at the points of connection must be thoroughly insulated with suitable coating material to avoid having a copper-to-steel galvanic corrosion cell at the junction between the two metals.

Test Points

Test points may be desired or required to permit periodic testing of galvanic anode performance. In order to accurately determine IR drop considerations, the anode installations should be installed to allow testing of current output and interrupted potential readings. This type of testing necessitates surface test point installation.

Ready made terminal box test points of various designs are available from suppliers. A typical test point installation is illustrated by Figure 2-6.

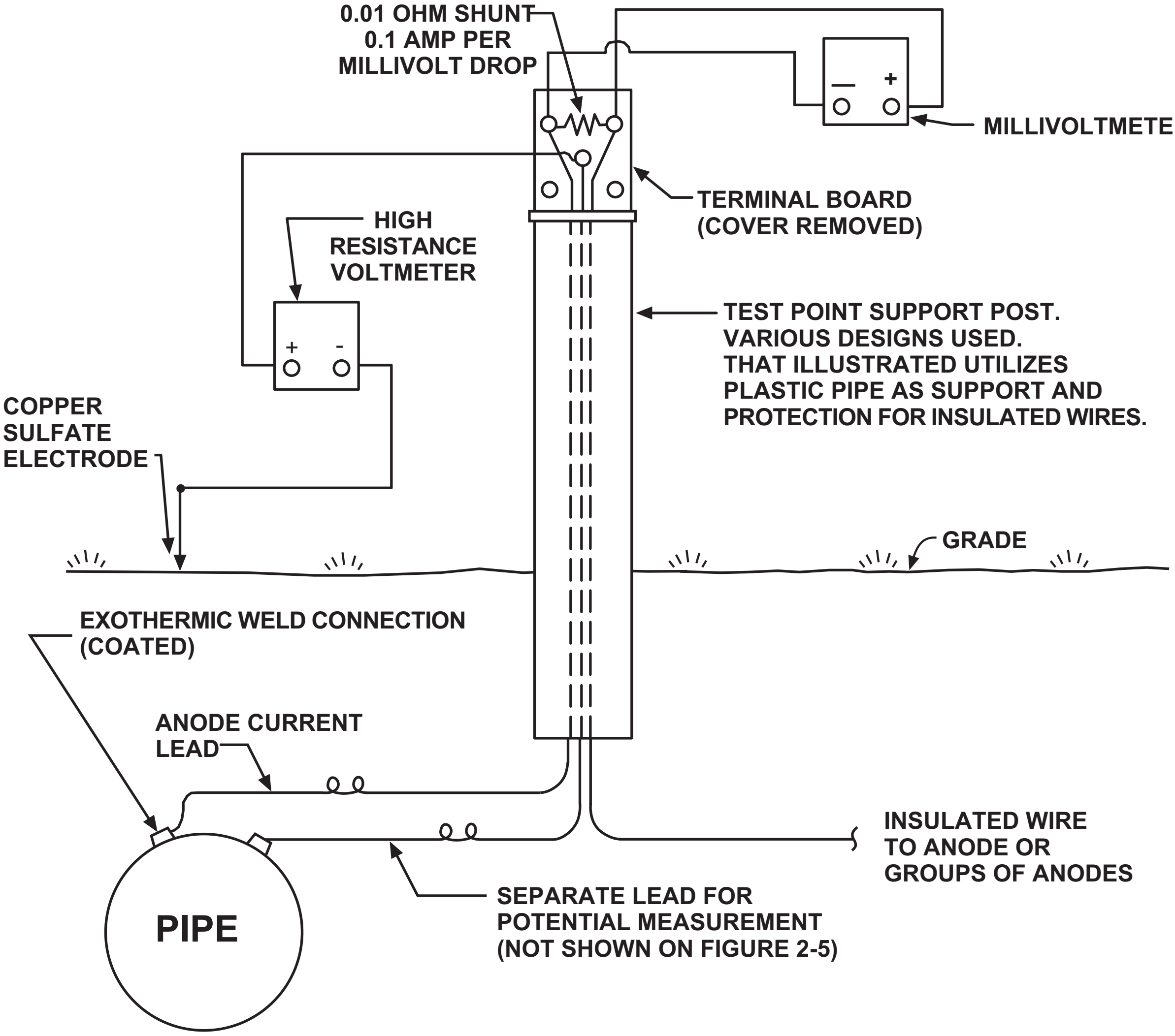
CONCLUSIONS

This Chapter has described the different types of galvanic anodes used for cathodic protection and their general and specific uses. It also lists some of the advantages and disadvantages as they relate to impressed current systems.

The Chapter also includes some installation suggestions.

REFERENCE:

Peabody, A. W., “Control of Pipeline Corrosion”, National Association of Corrosion Engineers.



TYPICAL TEST POINT INSTALLATION

FIGURE 2-6

Chapter 3 - Installation of Impressed Current Cathodic Protection Systems

INTRODUCTION

The objective of this chapter is to describe the different types of impressed current anode beds, the materials and equipment used, and the installation procedures followed, to insure adequate performance of the installed systems.

This chapter will cover the three basic types of impressed current anode beds:

- Remote Anode Bed
- Distributed Anode Bed
- Deep Anode Bed

It will also discuss materials and installation practices. The advantages and disadvantages of each type of anode bed will also be reviewed.

In Chapter 2, Installation of Galvanic Anodes, the parameters for galvanic anode systems were discussed. The main difference between the two systems is that galvanic anode systems make use of the difference in potential between the anode material and the structure while the impressed current system uses an outside DC power source.

DEFINITIONS

The following definitions are pertinent to the text of this Chapter:

Impressed Current Cathodic Protection System

An impressed current cathodic protection system is a cathodic protection system that utilizes an external source of DC power in order to force current flow off an anode bed and onto an underground structure, hence mitigating the discharge of corrosion current from the structure to the electrolyte and reducing the loss of metal from the structure.

Remote Anode Bed

Sometimes referred to as a “conventional anode bed” or a “point-type” anode bed, a remote anode bed is a group of anodes installed remote (usually 100 feet or more) from the structure and spaced on 10 to 30 foot centers. The individual anodes can be installed vertically or horizontally. Some remote anode beds are installed with anodes placed horizontally, end to end, in a continuous bed of coke breeze backfill.

Distributed Anode Bed

A group of anodes, or one long anode, installed close to and parallel to the structure to be protected. The anode bed can be installed on one or both sides of the structure at a distance of 5 to 20 feet from the structure. Distributed anode beds are used to protect sections of pipelines which have poor coating or which are bare. They are also used for localized protection and in areas where shielding does not allow the current from a remote anode bed to reach the structure. For the latter reason, distributed anode beds are very often used to protect structures within plant complexes, especially when the structure may not be electrically isolated.

A distributed anode bed can be a group of individual anodes, installed on 25 to 500 foot centers, connected by a continuous header cable.

A distributed anode bed can also be one long continuous anode. This is referred to as a “linear anode”.

The distributed anode bed is laid out or distributed along the entire length of the structure. As a result, installation costs are usually more expensive than for a remote anode bed. Because of the long cable runs associated with distributed anode beds, large gauge cables are required to reduce the voltage drop along the cable runs. A distributed anode bed used to protect a long pipeline may require the installation of two rectifiers, one at each end of the anode bed, to reduce the voltage drop on the cable. The installation of the distributed anode bed requires more care than the remote anode bed because the anode bed is located close to the structure being protected and care must be taken to avoid damage to the structure.

An advantage of a distributed anode bed, over a remote anode bed, is that it can be installed within a complex underground network with little or no stray current problems being caused on the foreign metallic structures in the area, due to the close proximity of the anode bed to the structure and the relatively low current output per unit length.

One disadvantage of the distributed anode bed system is that due to its close proximity to the protected structure, the possibility of damage to the anode bed during excavation of the structure for maintenance or during construction activity is greatly increased.

Deep Anode Bed

A group of anodes, a continuous pipe, or wire anodes, installed in a vertically drilled hole at selected points along the route of a structure, or between several structures in a plant area. The holes normally range from 100 to 600 feet deep; individual anodes are usually located on 10 to 30 foot centers. One variation of this type of anode bed is the semi-deep anode bed where the depth of the hole ranges from 50 to 150 feet. When it is desirable to install an anode bed system which has many of the operating characteristics of a remote anode bed but for which there is no space available at the desired site location, the only way to install the anodes at a distance from the pipeline/structure is to install them deep below the pipeline/structure.

Deep anode beds are also used when the soil strata are so arranged that the upper layers of soil are of high resistivity with underlying layers of lower resistivity.

A deep anode bed is usually more expensive to build than a remote anode bed of comparable capacity. In addition, the anodes of a deep anode bed are well below grade level and are therefore inaccessible for maintenance should failure occur in the anode material used or in the connecting cables. It is often more economical to abandon a malfunctioning system in place and install a new anode bed close to the original one than to attempt system repairs.

POWER SUPPLIES FOR IMPRESSED CURRENT CATHODIC PROTECTION SYSTEMS

There are several types of equipment that can be used as power sources for impressed current cathodic protection systems. Among these are rectifiers, solar cells, engine-generator sets, wind powered generators and turbine-generators. Although rectifiers are by far the most commonly used source of DC power for impressed current systems, a general basic description of each of the sources is given in the following paragraphs.

Rectifiers

A device which takes alternating current from a power distribution system and converts it to direct current. Rectifiers have as their major components:

- a transformer to step down AC line voltage, which has taps on the secondary winding to allow selecting a wide range of voltages

- a rectifying element which converts the AC to DC
- a cabinet.

Other components normally found in rectifiers are AC circuit breakers, DC output meters, lightning arresters (on both AC and DC sides) and current measuring shunts.

Rectifiers are manufactured with many different ratings for single-phase and three-phase AC service. The rectifying element consists of either selenium stacks or silicon diodes. Figure 3-1 shows a wiring diagram for a single-phase rectifier and Figure 3-2 shows a wiring diagram for a three-phase rectifier.

Rectifiers are manufactured with air cooled or oil cooled enclosures. For hazardous areas, oil cooled explosion-proof cabinets are available. Rectifiers can be of the conventional type (manual tap changing arrangement) or of the automatic type: 1) constant potential which maintains a preset potential between the structure and permanent reference electrode, and 2) constant current which maintains a preset current output. Figure 3-3 shows a wiring diagram for a constant potential rectifier.

Solar Cells

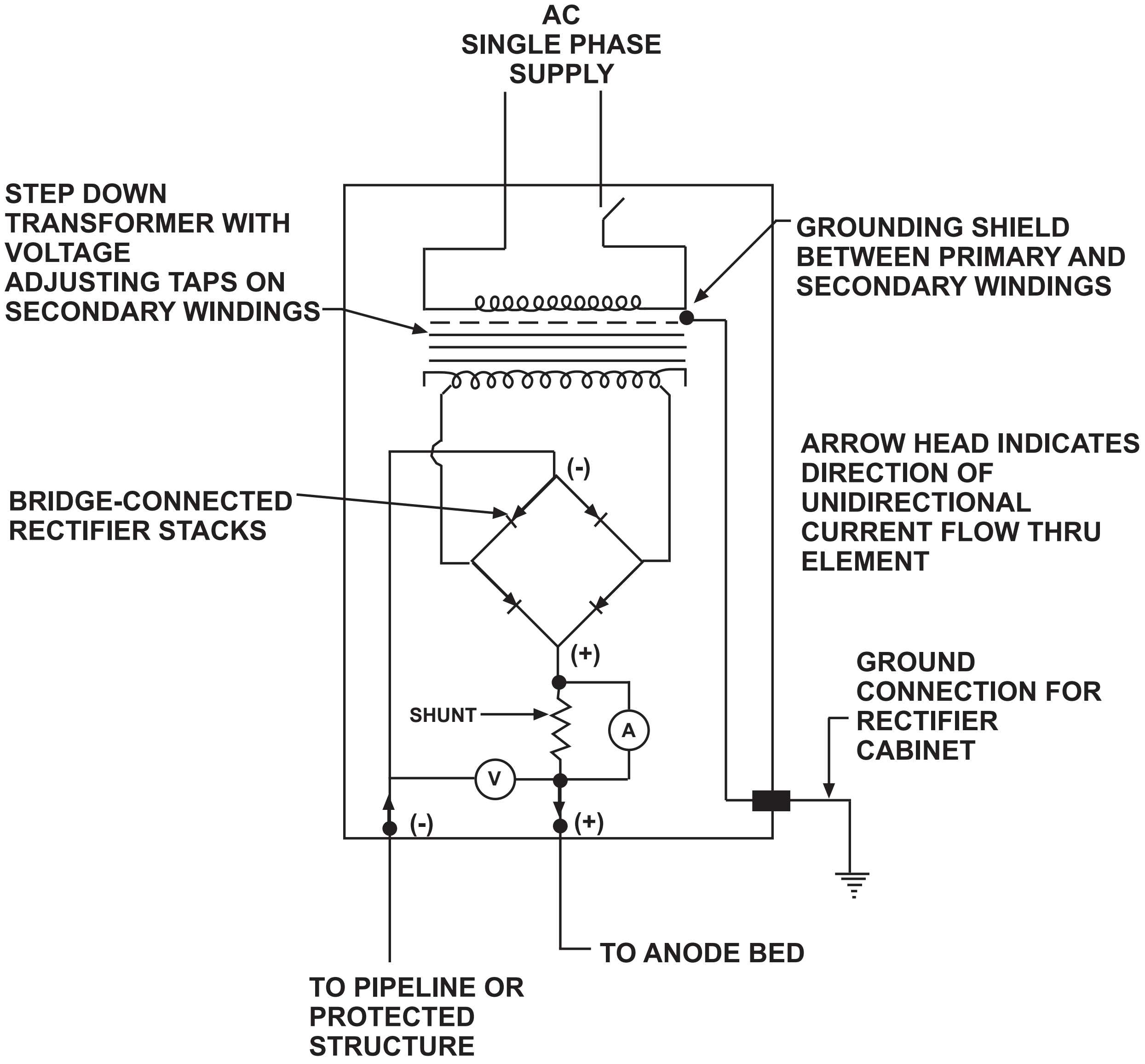
In areas where sunlight is available for a large percentage of the time, solar cells in combination with storage batteries can be used to produce a steady flow of direct current. Silicon solar cells are made by coating silicon crystals with phosphorus (produces negative charge carriers) and with boron (produces positive charge carriers). When light hits the silicon slices, a photocurrent flows, voltage develops, and electricity is generated.

The cathodic protection unit consists of the solar panels, storage batteries and a control cabinet. Panels are connected in series to increase the voltage output and in parallel to increase the current output.

Solar cells are a viable power source where regular AC power is not available. Figure 3-4 shows a schematic of a cathodic protection solar cell.

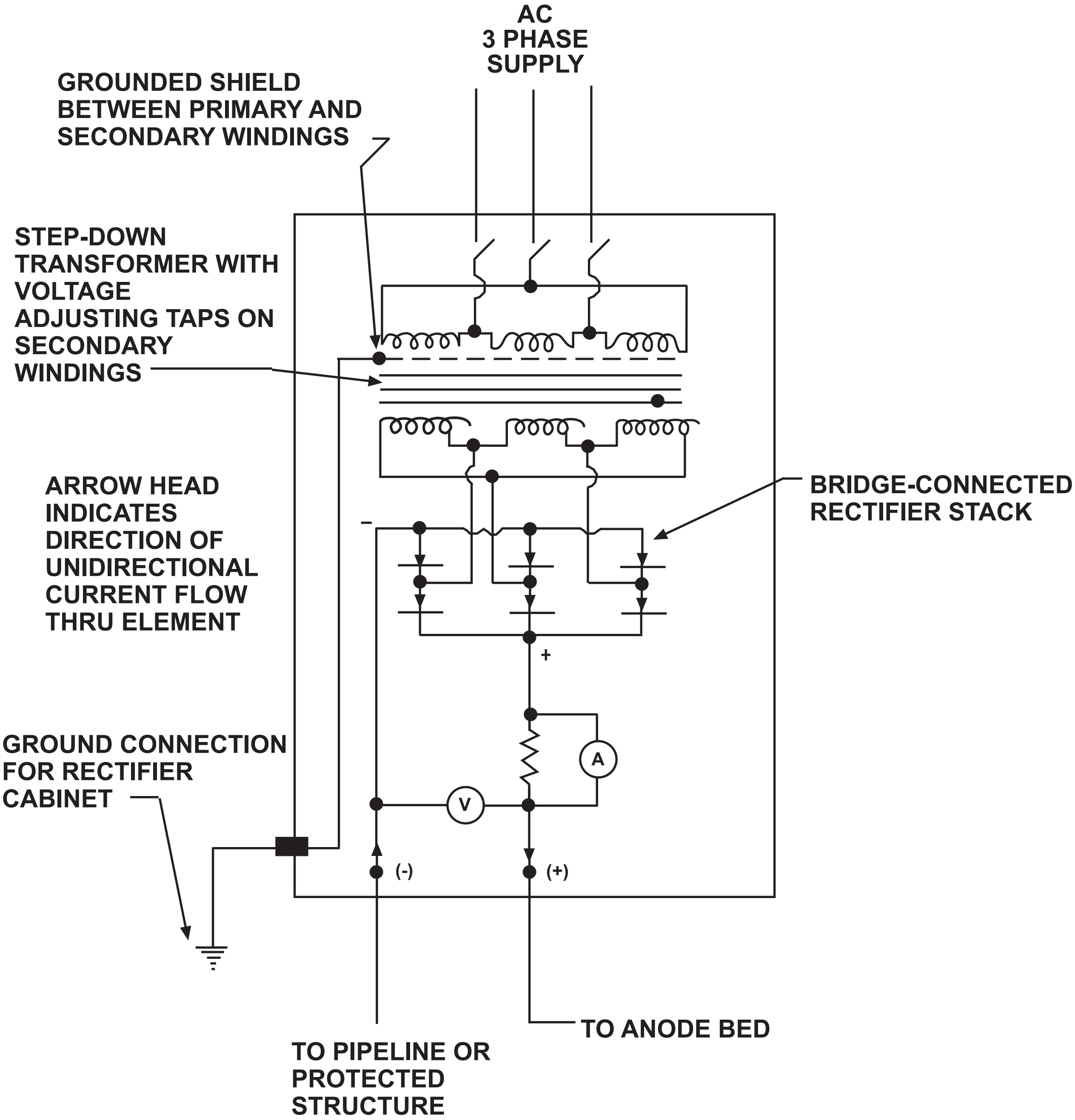
Thermoelectric Generators

Thermoelectric generators produce power by the direct conversion of heat into electricity. Power is produced by maintaining a temperature difference across a



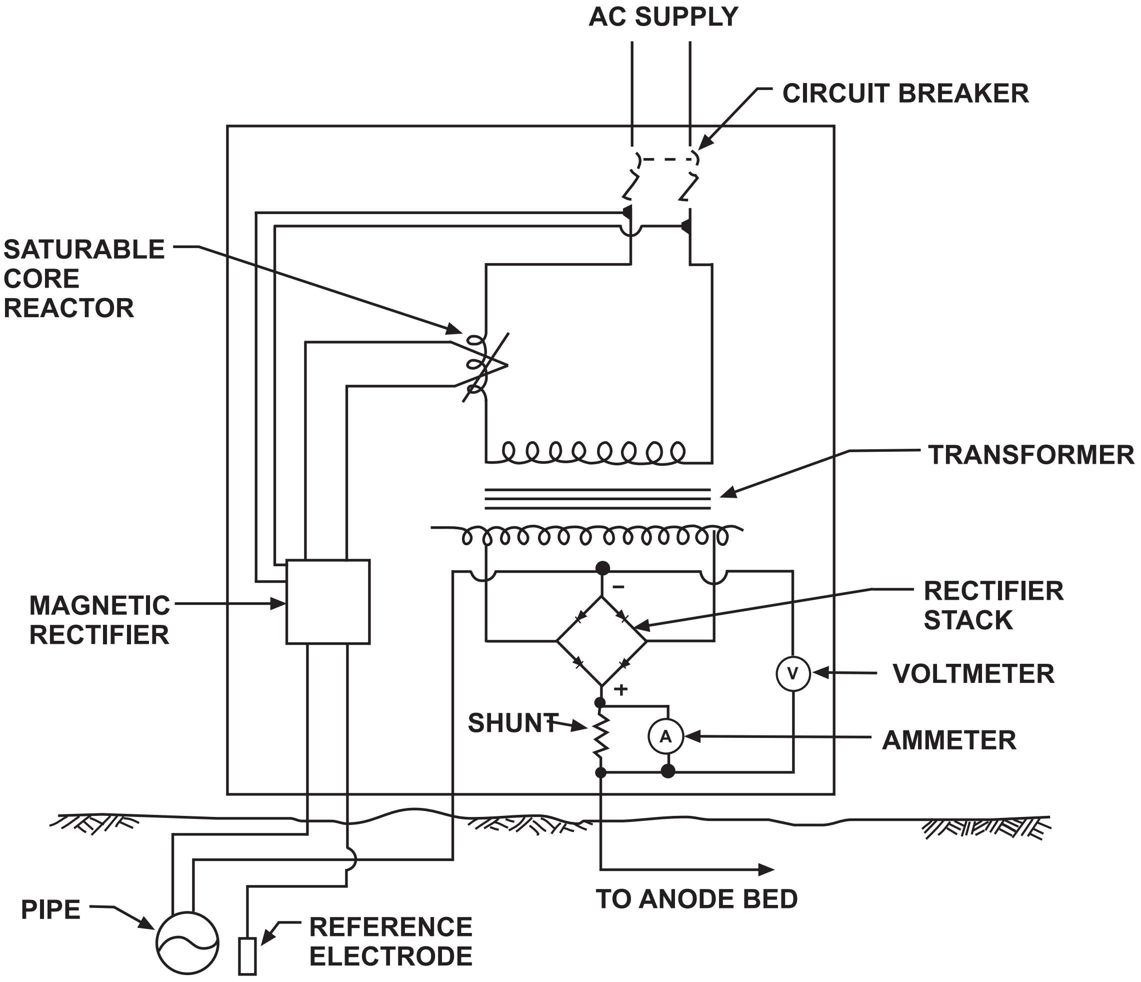
SINGLE PHASE RECTIFIER UNIT
SCHEMATIC DIAGRAM

FIGURE 3-1



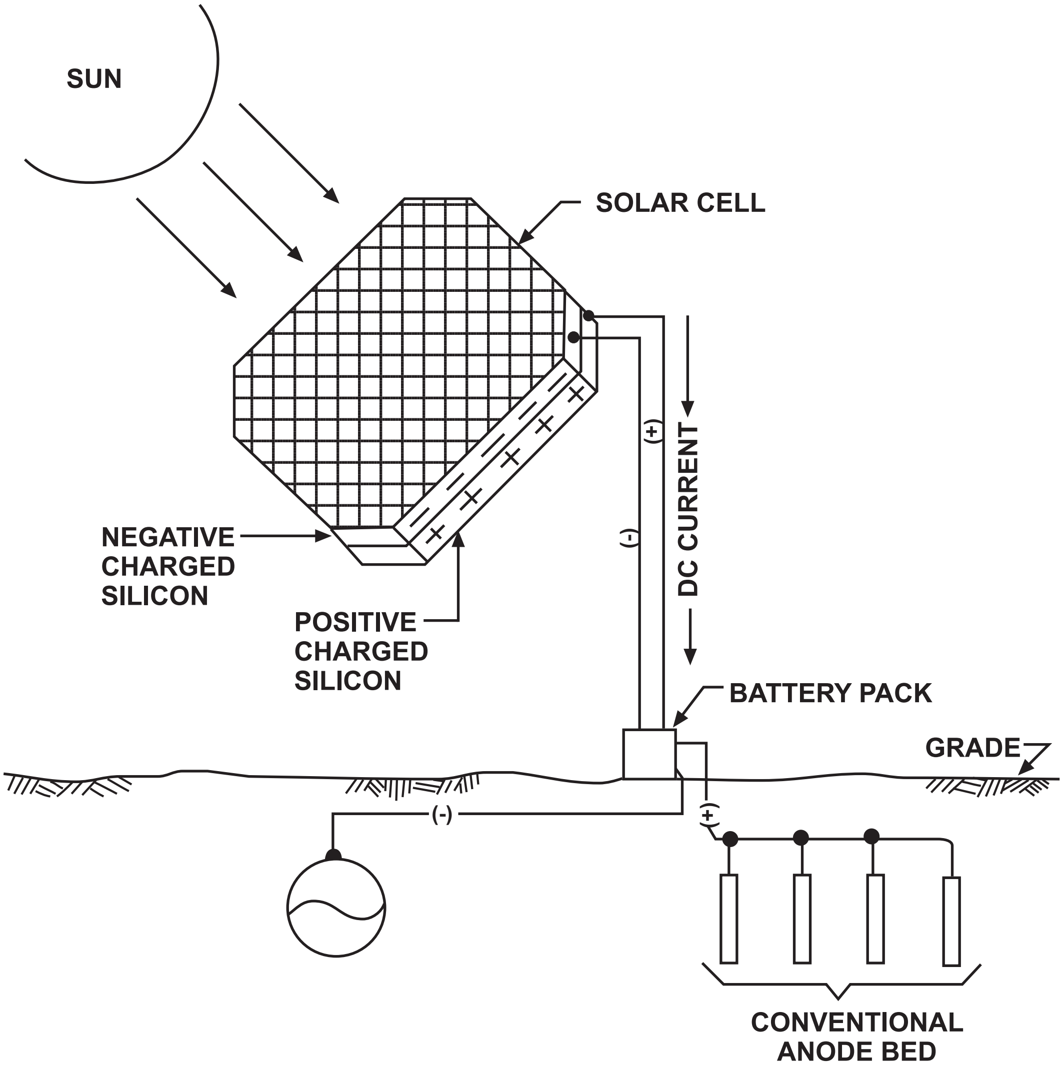
THREE-PHASE RECTIFIER UNIT
SCHEMATIC DIAGRAM

FIGURE 3-2



TYPICAL CONSTANT POTENTIAL RECTIFIER SCHEMATIC DIAGRAM

FIGURE 3-3



SOLAR POWERED DC POWER SUPPLY
FOR CATHODIC PROTECTION INSTALLATION

FIGURE 3-4

thermopile, an assembly of semi-conductor thermoelectric elements. Combustion of Natural Gas or Propane provides the heat while natural convection provides the cooling required to create this temperature differential**.**

Engine - Generator Sets

These units consist of a fuel-powered engine and an AC generator used to provide the input power for a rectifier unit. The fuel required to operate the engine can be tapped from the pipeline as shown in Figure 3-5, if the product can be utilized as a fuel source. An alternative source of engine fuel could be a storage tank installed in the area. A typical engine-generator set may require 1500 gallons of diesel fuel to operate for about a month.

Turbine - Generator Sets

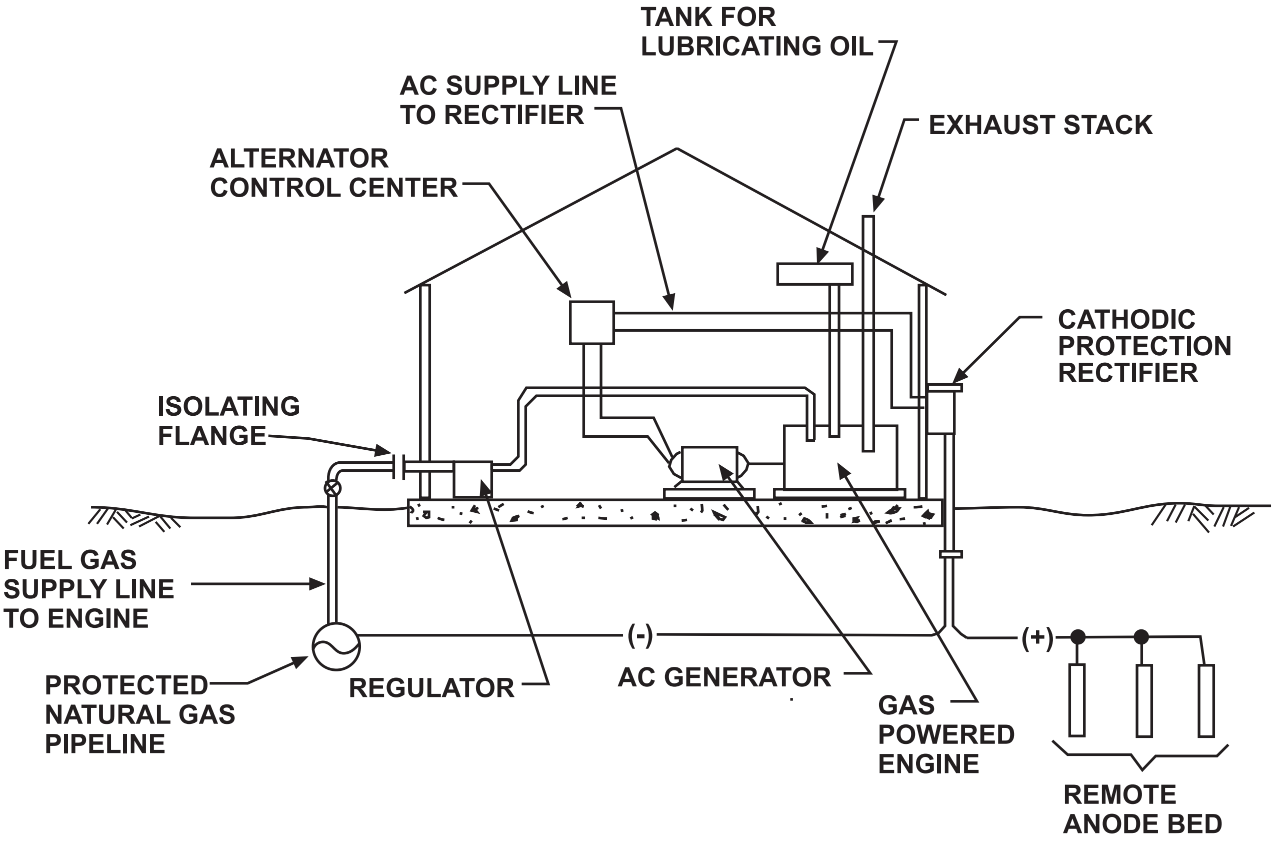
Turbine generator sets utilize the product or gas flow to drive a small turbine which in turn drives a DC generator which supplies the cathodic protection current for the anode bed.

Figure 3-6 shows a typical turbine-generator set for a natural gas pipeline. The gas is diverted to the turbine through a bypass line, installed across a delivery station where a drop in gas pressure is present, and returned to the system. Note the application of this system can only be used at locations where there is reasonably constant gas pressure drop or decrease in available product flow.

Wind Powered Generators

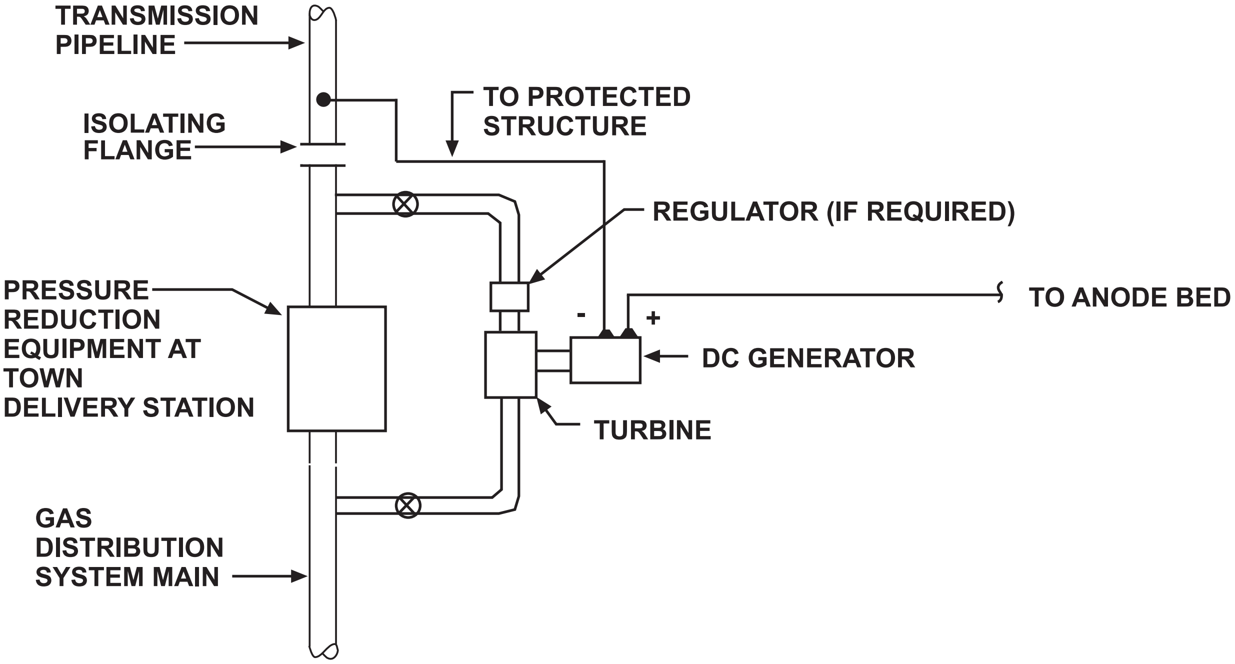
These systems provide a practical and very economical electrical power supply for cathodic protection installations which require a completely independent power source.

A typical wind-powered generator consists of a turbine assembly, generator assembly, rectifying unit and a battery. The turbine assembly, which usually consists of three blades, approximately 15 feet in length, is directly coupled to a slow speed generator which can produce 200 watts at wind speeds of 20 mph and can maintain a 700 watt continuous load at a location with average winds of 12 mph. The AC voltage from the generator is converted to DC voltage via a rectifying unit. This DC voltage is used to charge batteries which supply the required cathodic protection current. Figure 3-7 shows a typical wind powered generator set.



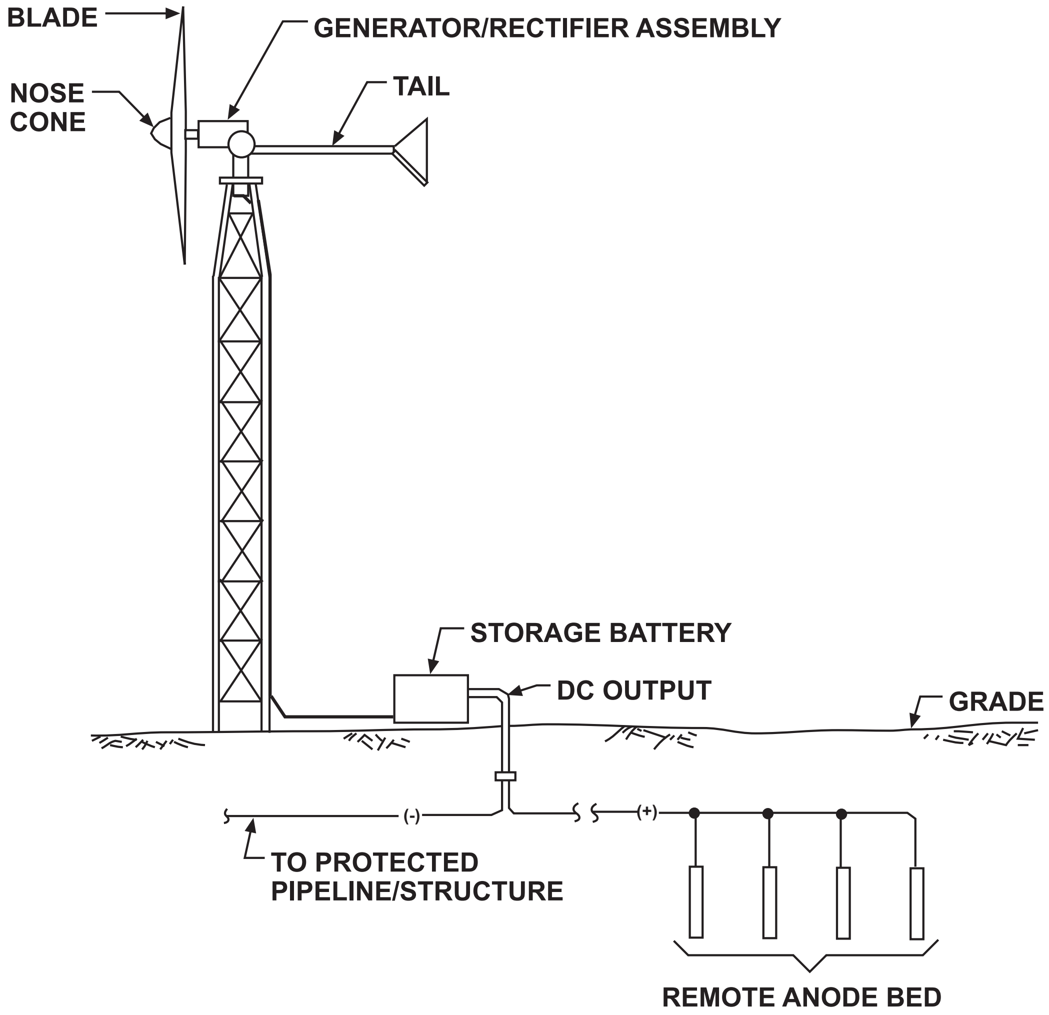
ENGINE GENERATOR SET
DC POWER SUPPLY
CATHODIC PROTECTION INSTALLATION

FIGURE 3-5



TYPICAL TURBINE GENERATOR SET INSTALLATION

FIGURE 3-6



WIND-POWERED DC POWER SUPPLY
FOR CATHODIC PROTECTION INSTALLATION

FIGURE 3-7

ANODE BED MATERIALS

Anodes

Various types of materials are available for use as impressed current anodes. The following paragraphs present a list of some of the materials used and some of their characteristics:

a. Scrap Iron

Scrap iron in the form of an old pipeline was the original impressed current anode used to protect an underground structure. Scrap iron anodes are still used today, particularly in areas where regular anode materials are expensive or hard to obtain.

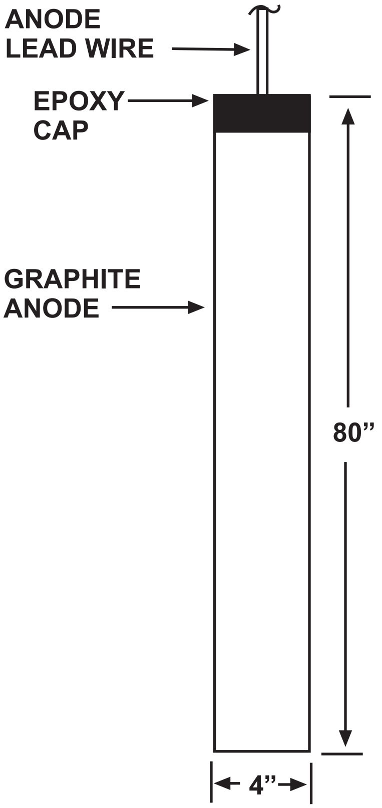
Impressed current systems have been designed utilizing anything from scrap railroad car wheels welded together to form an anode for protection of an underground structure to a half-sunken barge used as a remote anode to protect a dock structure. Some of the disadvantages of using scrap iron are the high consumption rates, nonuniform consumption, and colored corrosion products which may cause discoloration of the surroundings.

b. Graphite

Graphite anodes are manufactured from petroleum coke particles. The process from coke particles to an almost pure graphite can take as long as 16 weeks because of the many steps involved in it. Graphite anodes are normally impregnated with hot linseed oil or microcrystalline wax to inhibit moisture from penetrating the anode and causing mechanical and chemical decomposition. Disadvantages of the graphite anode are its softness and brittleness. Therefore, they must be handled with care during shipping and installation. Figure 3-8 shows a typical graphite anode. These anodes are manufactured in different sizes.

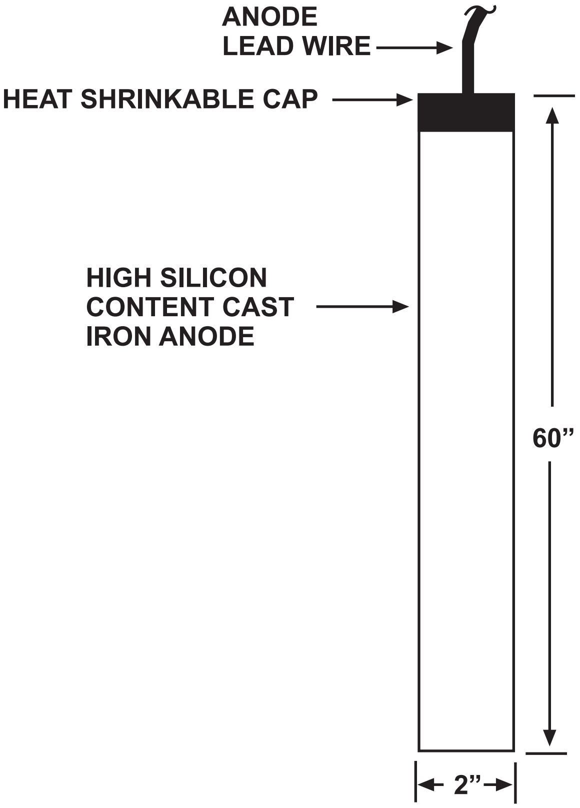
c. High Silicon Cast Iron

The typical alloy for cast iron anodes is ASTM A518 Grade 3. They contain approximately 15% silicon and 4.5% chromium. Like graphite anodes, they are very brittle and must be handled with care. Figure 3-9 shows a typical high silicon cast iron anode. These anodes are also manufactured in different sizes.



TYPICAL GRAPHITE ANODE

FIGURE 3-8



TYPICAL HIGH SILICON CONTENT
CAST IRON ANODE

FIGURE 3-9

d. Platinized Titanium

Platinum works very well as an impressed current anode because of its extremely low consumption rate and high current density. Because of the cost of platinum, it is usually applied in a very thin layer onto a less expensive material. Titanium is used as such a material. These anodes are manufactured by either electrodepositing the platinum on the metal substrate or by the cladding process. If there are voids in the platinum surface, current can discharge from the titanium substrate. Titanium is generally passivated at low DC potentials and does not discharge current to the electrolyte. At voltages in excess of 10 volts, the passivation film breaks down rapidly and current flows to the electrolyte from the titanium resulting in rapid corrosion of the titanium in the form of pitting. This can lead to failure of the anode. Some engineers recommend that the voltage at the surface of the titanium substrate be kept below 10 volts. It is important to note that this 10 volt limit is the voltage at the titanium substrate, not necessarily the rectifier output voltage. With a packaged anode, the voltage across the titanium/backfill interface is much less than the output voltage measured at the rectifier terminals.

e. Platinized Niobium/Tantalum

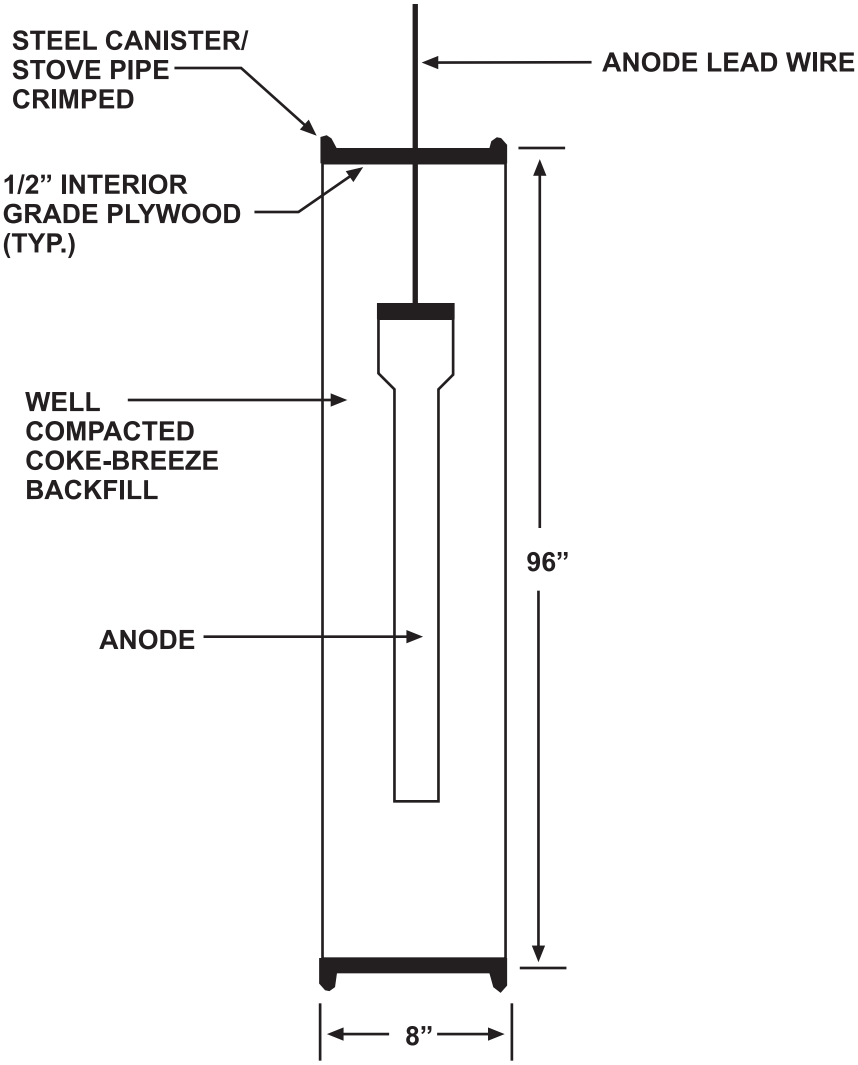
These anodes are used where there is concern over the use of platinized titanium anodes because the system design requires a driving voltage greater than 10 volts. Niobium or tantalum as base metals can withstand higher driving voltages. (The breakdown voltage of niobium oxide film is approximately 120 volts). These types of metal substrates are the most commonly used for anode bed anodes installed in the soil. Figure 3-11 shows one type of anode detail and specification for a platinized niobium anode.

f. Mixed Metal Oxide Anodes

These anodes consist of a titanium substrate with a dimensionally stable mixed metal oxide coating. Like platinum, mixed metal oxide anodes have an extremely low consumption rate and can be used at very high current densities. Like platinized titanium anodes, the voltage limitations of the titanium substrate must be considered in the design process.

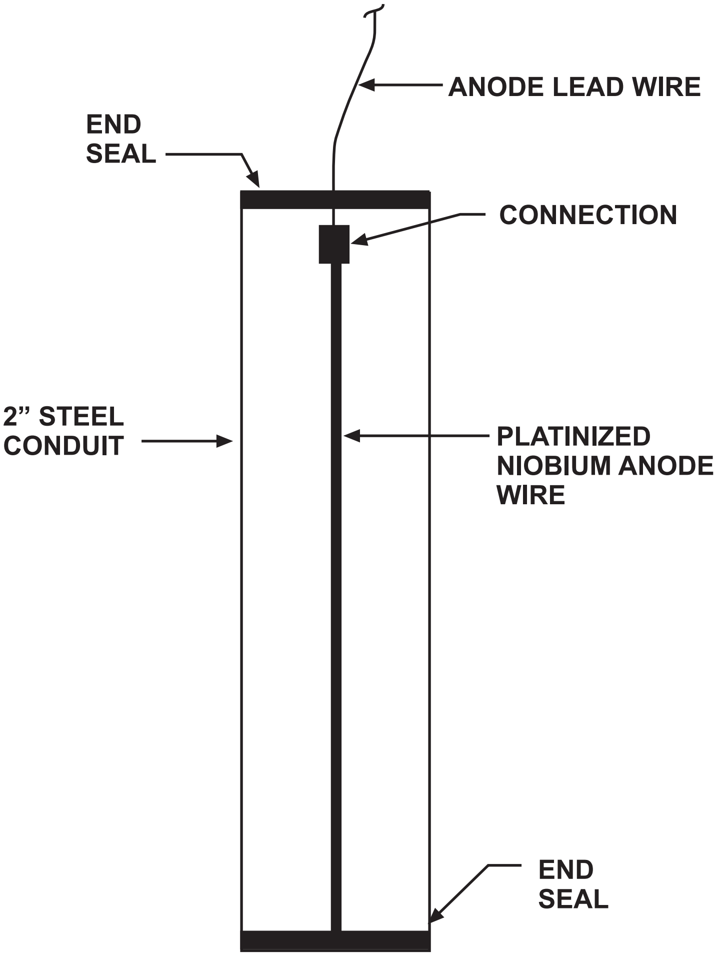
g. Magnetite

These anodes have been used in Europe for many years. Magnetite anodes have been



TYPICAL PREPACKAGED CANISTER ANODE

FIGURE 3-10



PLATINIZED NIOBIUM WIRE ANODE

FIGURE 3-11

improved in recent years and are now readily available in the western hemisphere for underground and marine use.

Magnetite (Fe_3O_4) is a corrosion product itself therefore, there is little or no corrosion involved with the discharge of current from the surface of the anode. Although these anodes are expensive, their long life expectancy makes them an economical choice in some applications. See Figure 3-12 for typical magnetite details and specifications.

Packaged Anodes

With the exception of scrap iron anodes, all of the anodes describe above are available in prepackaged form. The anodes are centered in a galvanized "stove pipe type" container or electrical conduit, which is filled with low resistivity backfill such as coke breeze. Figure 3-10 shows a typical prepackaged anode and canister specification.

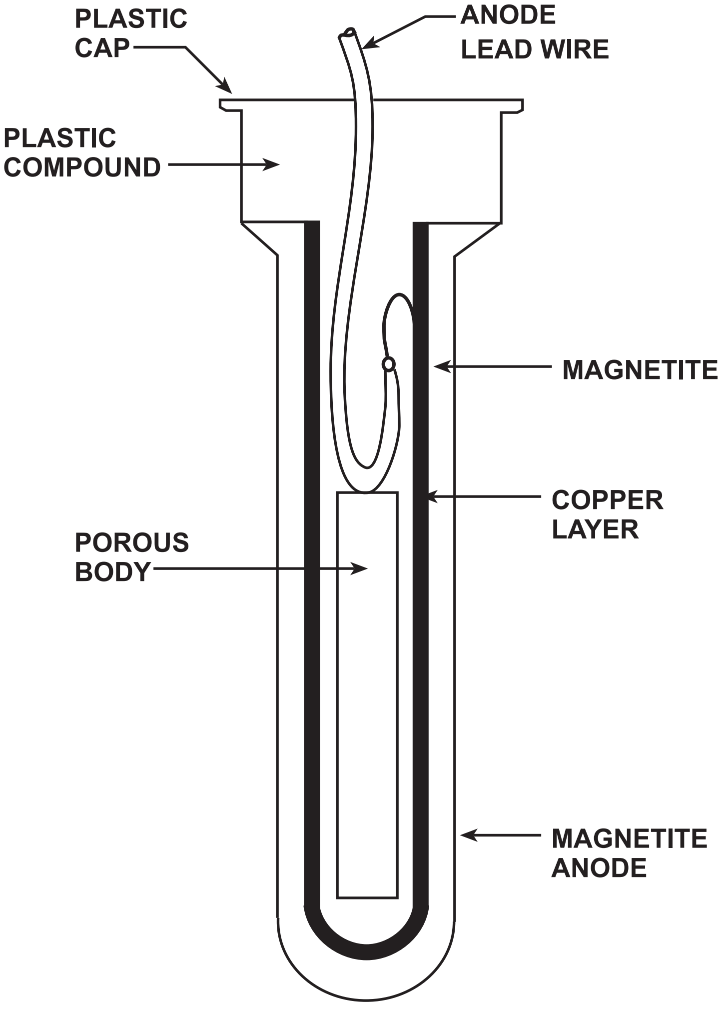
Anode-Lead Connection Insulation

It is good practice to specify anodes with some type of epoxy, polyethylene, or Kynar® cap to protect the lead end of the anode from current leakage which could lead to premature anode failure. Figures 3-8, 3-9, 3-11 and 3-12 outline typical details of anode/lead connection insulations used to prevent these types of problems.

Cables

Impressed current cathodic protection systems normally require the installation of considerable lengths of direct buried cables. The primary insulation material used is high molecular weight low density polyethylene insulation (HMWPE). This insulation material has outstanding dielectric strength and moisture resistance. It also has a high resistance to corrosive chemicals (mineral acids, fixed alkaline petroleum oils, etc.) usually existing in environments requiring cathodic protection.

Where severe conditions exist and polyethylene insulated cables are not suitable, special insulated cables such as Kynar® and Halar® are used. These insulations are resistant to chlorine and therefore are usually recommended for use in deep anode beds where chlorine is usually present. Selecting a cable size has both a practicable and economic aspect. The cable should be large enough to carry the intended current based on one of the many ampacity tables that are available. The cable should also be large enough to limit the voltage drop which would require a bigger power source. In addition, the cable should also be large enough to withstand mechanical stresses encountered during



TYPICAL MAGNETITE ANODE

FIGURE 3-12

system installation.

Cable Connections

Impressed current cathodic protection system negative return cables are normally connected to the pipeline/structure using an exothermic weld process. Exothermic weld connections are made by filling a graphite mold (see Figure 3-13) which houses the conductor and the weld metal (copper oxide and aluminum), and by igniting the powder with a flint gun. The exothermic reaction which results produces molten copper which flows into the weld cavity and welds the conductor to the pipe. The molds are specified based on conductor size and on surface type/pipe size.

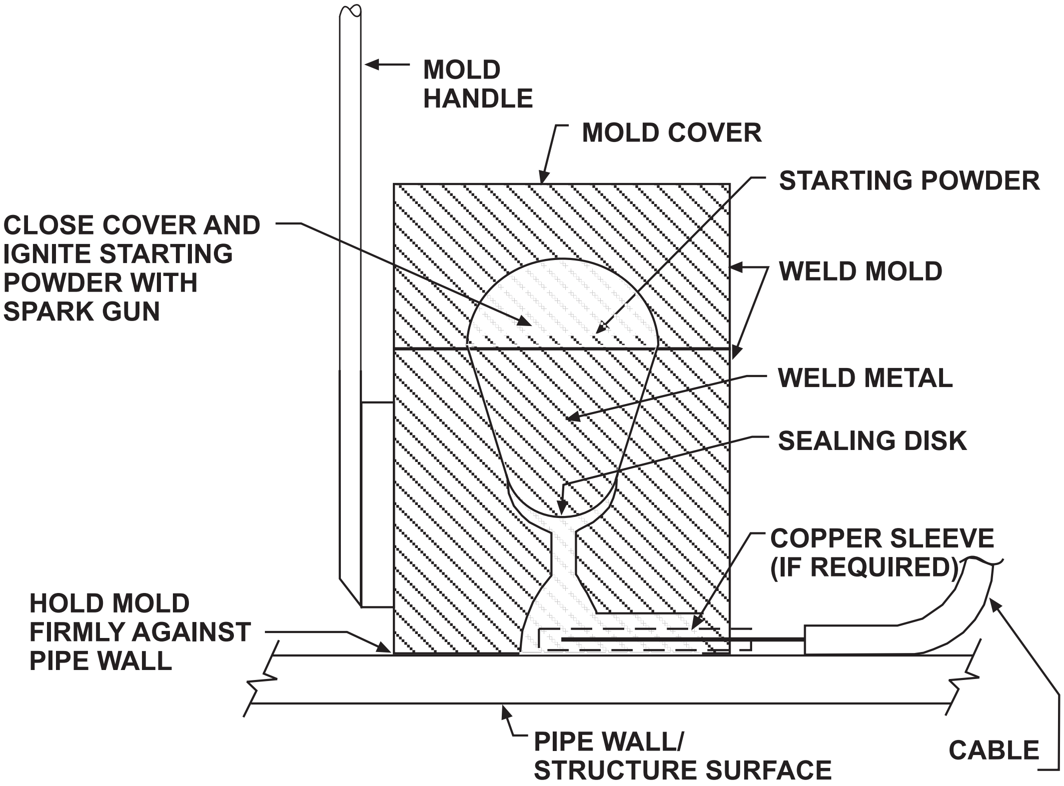
Exothermic weld connections should be adequately coated using a minimum of two layers of coal tar and glass fiber or equal. Patch coating should overlap existing pipeline coating a minimum of 2 inches.

When making header cable to header cable or anode lead to header cable connections various methods can be used, among them are solder, exothermic weld, and compression type and split bolt connectors. The compression type connection is probably the most recommended method because the connection is made without heat and there is no danger of damage to the cable insulation or wire at the connection. The compression connector is applied with a special tool which lets the user know that adequate compression has been reached, assuming that the proper tool and dies have been used. This is an advantage over the split bolt connector where it is up to the user to estimate if sufficient torque has been applied.

Cable Splices and Repairs

The cables associated with the anode bed, connected to the positive terminal of the DC power supply, are the most anodic part of the impressed current system. Taking voltage drops in the cables into consideration, the cables operate at a higher voltage than the anodes themselves. The impressed current anode material is formulated for low consumption rates, but copper wires are not. One can readily see that any damage to cable insulation or splices in an impressed current system can cause a relatively large amount of current to discharge to earth from a small area. Rapid corrosion leading to cable failure would occur.

Splice insulation and cable insulation repair must be absolutely waterproof; otherwise current will discharge to the electrolyte and cable failure will occur. The insulation



TYPICAL EXOTHERMIC WELD PROCESS

FIGURE 3-13

material use must also have high resistance to corrosive chemicals. For this reason, a poured two-part epoxy system has been used with good success on impressed current cable splices and repairs. The two-component epoxy system is poured into a special mold which is placed around the splice. The connection and adjacent cable insulation must be cleaned and abraded with emery cloth. Hardening of the epoxy usually takes one-half hour depending on ambient temperature. Backfill or immersion should not take place until the epoxy is fully hardened. Figure 3-14 shows a typical epoxy splice process for connection of anode lead wire to anode header cable.

An alternative method used to insulate a connection is a hand wrapped joint. In order to achieve a good joint insulation, the connection and surrounding area of insulation must first be cleaned and abraded using emery cloth. The next step is to fill all voids with a soft rubber splicing compound and then wrapping connection with several layers of rubber tape followed by several layers of PVC electrical tape. Taping should start in the center of the collection and end in the center. The first layers of tape should be stretched while being applied and the tension should be relaxed on subsequent layers to achieve a smooth surface. The final step is painting the taped joint completely with electrical shellac compound. Note: Shellac must be allowed to dry completely before allowing joint to contact earth.

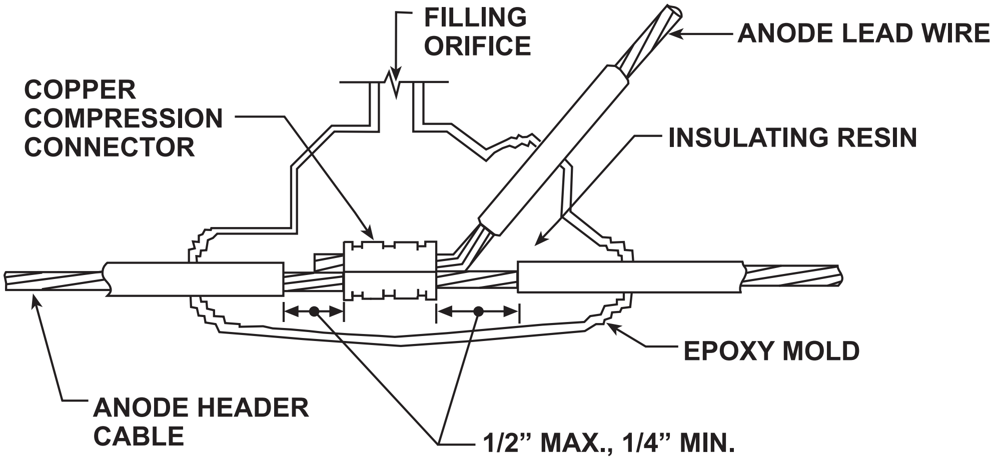
SELECTING AN ANODE BED SITE

The corrosion control professional should take the following factors into account when considering an anode bed site:

- Soil Resistivity
- Soil Moisture
- Interference with Foreign Structures
- Power Supply Availability
- Accessibility for Maintenance and Testing
- Vandalism
- Purpose of Anode Bed and Site Availability

Soil Resistivity

Soil resistivity is one of the most important factors to consider when selecting an anode bed site location. The number of anodes required, the DC voltage output rating of the rectifier and the resulting AC power costs are all directly related to the soil resistivity. In theory, the lower the soil resistivity, the fewer the number of anodes required and the



TYPICAL ANODE LEAD WIRE TO
ANODE HEADER CABLE
EPOXY INSULATED SPLICE

FIGURE 3-14

lower the rectifier DC voltage output required. Ideally, the area with the lowest soil resistivity should be considered for the anode bed site.

Soil Moisture

Another factor to consider in the selection of an anode bed site is the soil moisture at the proposed anode depth. In most cases, the resistivity of the soil decreases as the moisture content increases until the soil becomes saturated. When possible, anodes should be installed below the water table (assuming the water resistivity is not too high), or in areas of high moisture content such as swamps, ditches, creek beds, etc.

One factor that should be considered when analyzing the moisture content of the soil, is the seasonal variations. Moisture content and water table elevation vary at different times of the year and these variations would have an impact on the performance of the anode bed. When anode beds are to be installed near the ocean or a river, tidal variations could have an effect on the water table elevation.

One phenomenon that affects the moisture content of the soil around the anodes is called electro-osmosis. This phenomenon will be dealt with in the Advanced Course and is just mentioned in this Chapter to make the corrosion control worker aware of it. When DC current is discharged to the soil from an anode, this current pushes the water away from the surface of the anode and could result in an increase of the anode bed resistance. In the case of an anode bed being installed in high clay content soil, the removal of moisture from the clay may seriously reduce the conductivity of the soil, possibly rendering the anode bed ineffective.

Interference with Foreign Structures

Before selecting an anode bed site, local utilities should be contacted and area system maps should be obtained to determine if any underground metallic structures exist in the area. Structures such as pipelines, underground metallic sheathed electrical cables, or well casings may be subjected to stray current interference problems therefore, whenever possible, anode beds should be located away from foreign structures.

When the anode bed must be located in the vicinity of foreign structures, tests should be conducted before the installation of the anode bed to determine the possibility and magnitude of interference problems that could be expected and whether corrective action, if required, is feasible. Subsequent to the installation of the anode bed, cooperative interference testing should always be conducted to ascertain remedial measures required.

Impressed current interference testing will be discussed in detail in Intermediate Chapter 5.

Power Supply Availability

The selection of an anode bed site may be influenced by the availability of an economical source of power to be used to provide the required cathodic protection DC current.

Accessibility for Maintenance and Testing

The anode bed site selected must be accessible to construction vehicles for anode bed installation, testing and repairs. When possible, the anode bed should be located near public roadways or where right-of-way can accommodate vehicular traffic to facilitate periodic testing and maintenance. If the anode bed is located in an area which is not easily accessible due to the environmental conditions, such as in swampy areas, the rectifier and test stations should be located away from the anode bed in some more accessible location.

Anode bed inaccessibility may promote a lack of maintenance/testing which could result in undetected anode bed malfunctions and lack of protection for the pipeline/structure.

Vandalism

Anode bed sites near schools and playgrounds should be avoided due to the possibility of vandalism.

If system design required the installation of an anode bed in an area which may be considered a problem area as far as vandalism is concerned, precautions should be taken to protect the above ground system components. Some steps that could be taken include installing rectifiers in locked sheds, behind fenced areas or where possible at pumping stations or at terminals. Test stations can be installed in underground vaults or in locked flush mounted test enclosures.

In establishing the need for vandalism prevention measures, the corrosion control worker should ascertain if the area is one where test equipment would have to be installed later on for extended periods of time (such as overnight). One such area would be where variable stray currents are prevalent and 24-hour recordings may be required during periodic surveys. Steps could be taken during the construction stages of the anode bed to provide protective enclosure for the test equipment.

Purpose of Anode Bed and Site Availability

Two additional factors that have to be considered in the process of selecting an anode bed site are the intended purpose of the anode bed and the possibility of acquiring the required right-of-way for the installation. Is the intent of the anode bed to protect a long section of a pipeline (assuming the pipeline is well coated) or is it the intent to afford localized protection to a short section of a pipeline (poor coating) or a small structure? In the first case, the approach could be the installation of one remote type anode bed near the midpoint of the pipeline section or perhaps the installation of a deep anode bed near the midpoint area.

In the second case, the approach could be the installation of a distributed anode bed.

Once a determination has been made as to the intent and purpose of the installation and the most suitable type of installation, the land availability should be investigated.

If the installation consists of a distributed anode bed or even a deep anode bed, it is very possible that the installation can be made within the existing right-of-way agreement in which case, the only requirement may be to notify the land owner (through the company's Right-of-Way Department). If on the other hand, a remote type of anode bed is contemplated, the company's Right-of-Way Department should be requested to investigate availability of land at the desired and at possible alternate locations. It is desirable to select a location where the entire installation can be within one property.

INSTALLATION PRACTICES

Anodes - General

Before installing anodes, the decision to install anodes either vertically or horizontally must be made. The decision usually depends upon various factors such as soil resistivity and equipment availability.

Regardless of the type of installation, graphite and cast iron anodes are brittle and have to be handled with care. Do not handle anodes by the lead as this could put too much stress on the anode-lead connection, causing the loss of the anode.

Vertical Installation

After determining that the area is suitable for this type of installation (no shallow underlying rock), a typical vertical anode can be installed as shown in Figure 3-15. Generally, fewer vertical anodes are required than horizontal anodes to protect the same structure. The main reason for this is that vertical anodes can usually be placed in permanently moist soil which generally results in lower anode resistance.

When installing a vertical anode system, the first step is to install the anode header or feeder cable. The next step is to auger a hole for the anode. The depth of the hole is based on design calculations and type of anode being used. An extra foot or more of depth is required when installing an anode which is not prepackaged to allow coke breeze to be installed and compacted below and above the anode. After augering the anode hole and installing and compacting a layer of coke breeze, if required, the anode should be lowered into hole using support rope tied around the anode. Center the anode in the hole and backfill with coke breeze or native soil as required. Native soil backfill should be tamped above anode and coke breeze backfill taking care not to damage anode lead wire.

After completing the anode hole backfill, the anode lead wire should be spliced to the header cable. Sufficient slack should be left on the lead wire to prevent damage due to soil settlement.

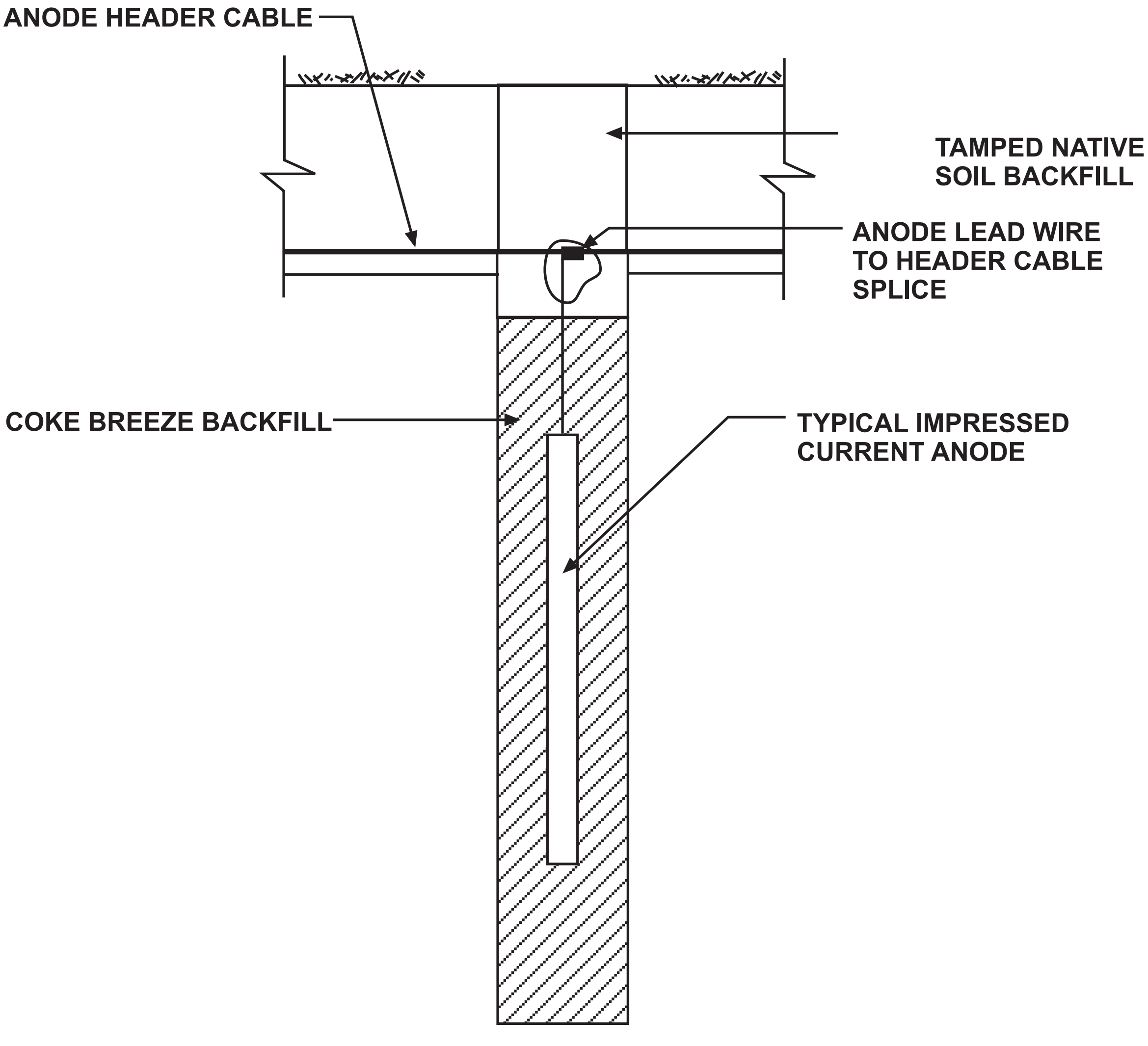
See Figure 3-16 for a typical prepackaged vertical anode.

For a distributed anode bed system, the exact location of the installed anodes and splices should be noted on the design drawings for future reference.

Horizontal Installation

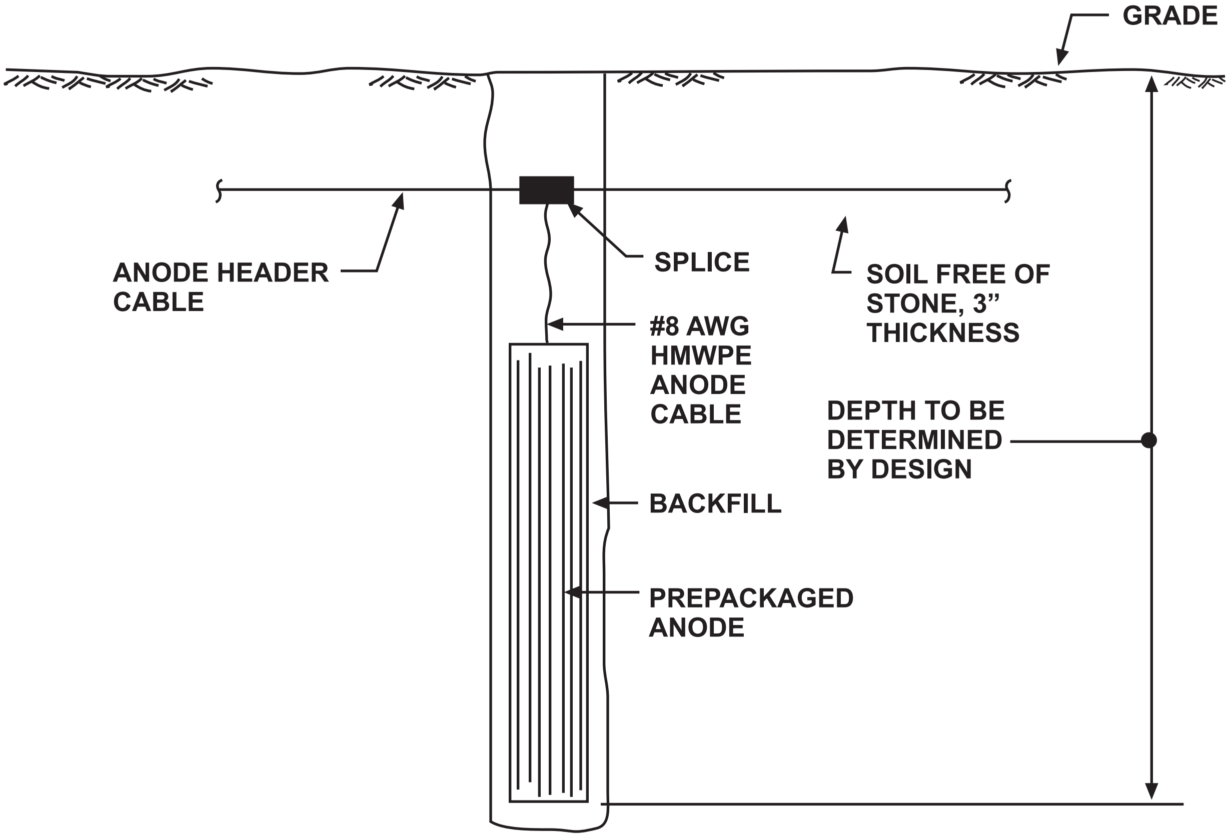
Where it is necessary to horizontally install anodes because of soil resistivity or equipment limitations, the first step, as with the vertical anode installation, is to install the anode header cable. The next step depends on the spacing required between the anodes. If the anode spacing is larger than 10 feet, a separate excavation may be required for each anode to be installed. If however, the spacing is less than 10 feet, it may be more economical to dig one continuous trench for the length of the anode bed installation.

Prepackaged anodes can be simply lowered into the trench by hand or by means of



TYPICAL VERTICAL ANODE INSTALLATION

FIGURE 3-15



TYPICAL VERTICALLY INSTALLED PREPACKAGED ANODE

FIGURE 3-16

support ropes and backfilled with native backfill tamping periodically as required.

Anodes requiring the placement of coke breeze backfill during installation require a trench deep enough to allow the placement of at least 6 inches of compacted coke breeze on all sides of the anode. Figure 3-17 shows a typical horizontally installed prepackaged anode.

Deep Anode Installation

Installation of a deep anode bed such as the one shown in Figure 3-18 begins with the drilling of a hole to the required anode depth. In the case shown in Figure 3-18 this would be a 10-inch x 100 foot hole. The next step in this installation is to install the 40-foot section of PVC casing followed by the installation of the 10-inch diameter, 60 foot long steel pipe through the PVC casing. The anodes are securely fastened to the 2 inch perforated PVC support/vent pipe using straps. Similarly, the anode lead wires are fastened to the pipe and run to the top of the pipe. The PVC support/vent with the anodes is then installed and centered in the hole. The next step is to pump fluidized coke breeze backfill into the first 60 feet of the hole, using the PVC support/vent pipe or a separate hose and pipe inserted into the hole. A plug of cement or clay is normally used to seal off the deep anode. The top 40 feet of the hole is backfilled with native backfill tamping periodically as required.

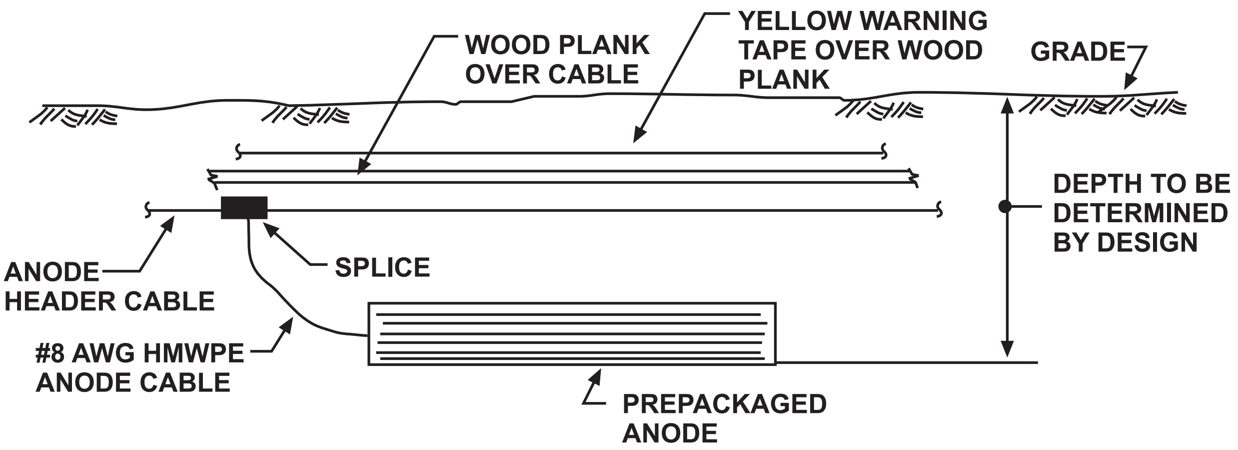
Figure 3-19 shows a similar installation using an uncased hole. A deep anode using a platinized anode wire is shown in Figure 3-20. Figure 3-21 shows a capsule type of installation that can be used to contain one of a number of types of anodes.

The last step in the deep anode bed installation would be the installation of an anode distribution box and the termination of the anode lead wires therein.

Cable Installation

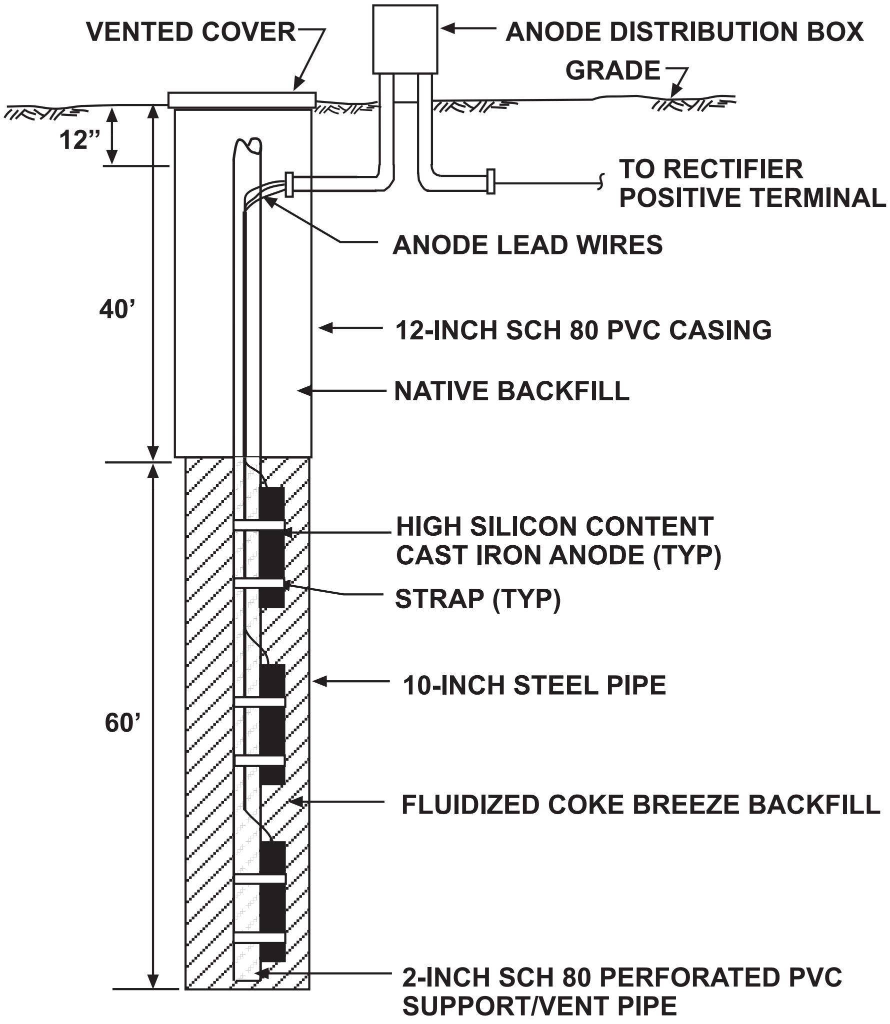
Anode header cables and system negative return cables are normally installed by excavating a trench and installing the cables at a minimum depth of 2 feet below grade. Before laying cables in the trench, remove any large stones or foreign material which may damage the insulation of the cable. The first three or more inches of backfill around the cables should be free of stones and foreign material and thoroughly tamped. The rest of the trench is backfilled with native soil tamping periodically as required.

When installing anode header cables for a distributed anode bed system, it is



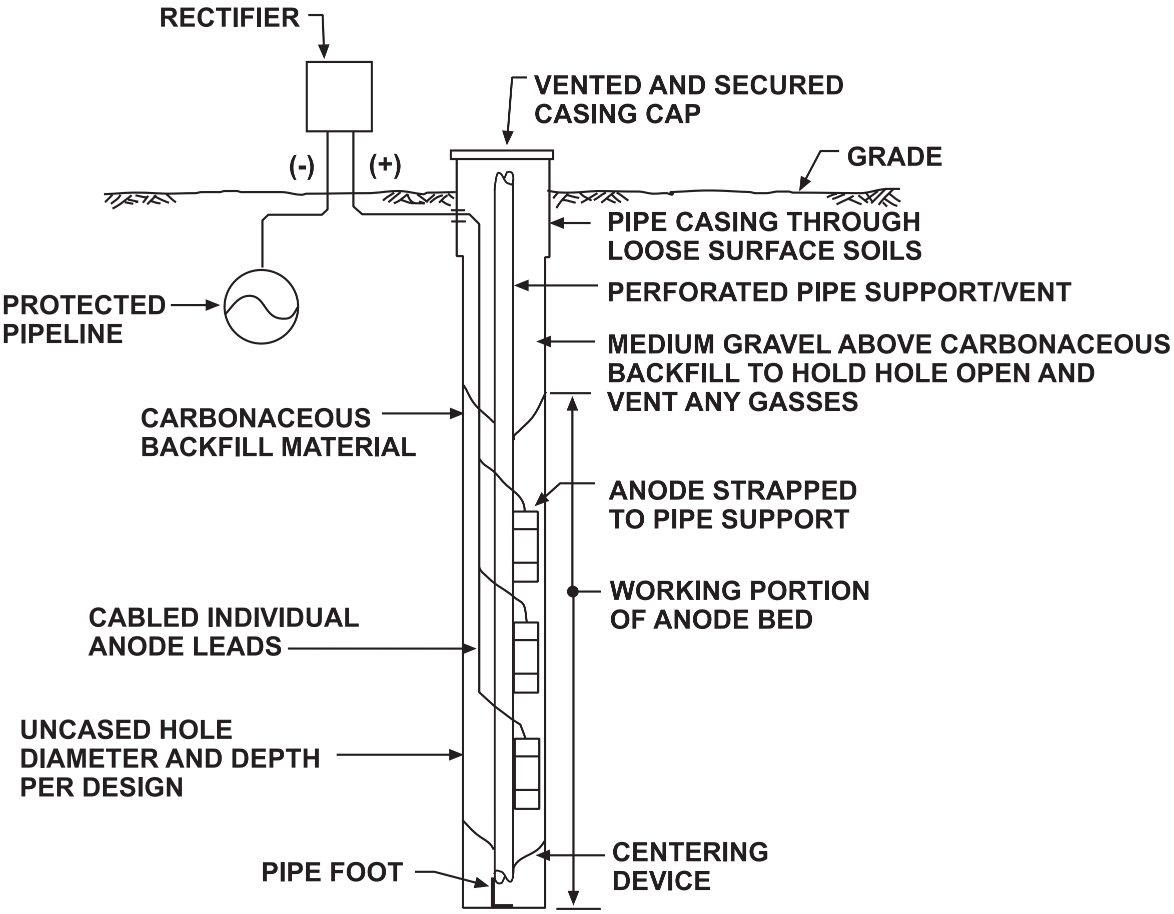
TYPICAL HORIZONTALLY INSTALLED PREPACKAGED ANODE

FIGURE 3-17



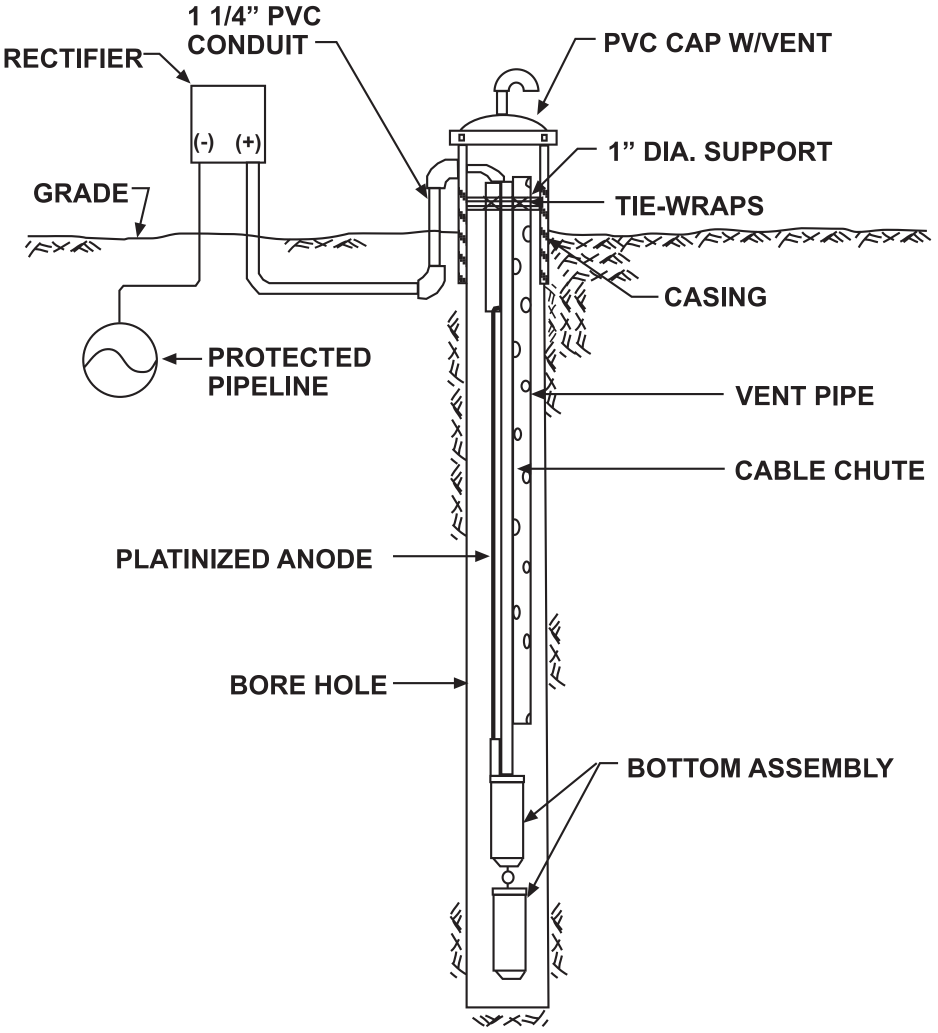
TYPICAL DEEP ANODE BED INSTALLATION DETAIL

FIGURE 3-18



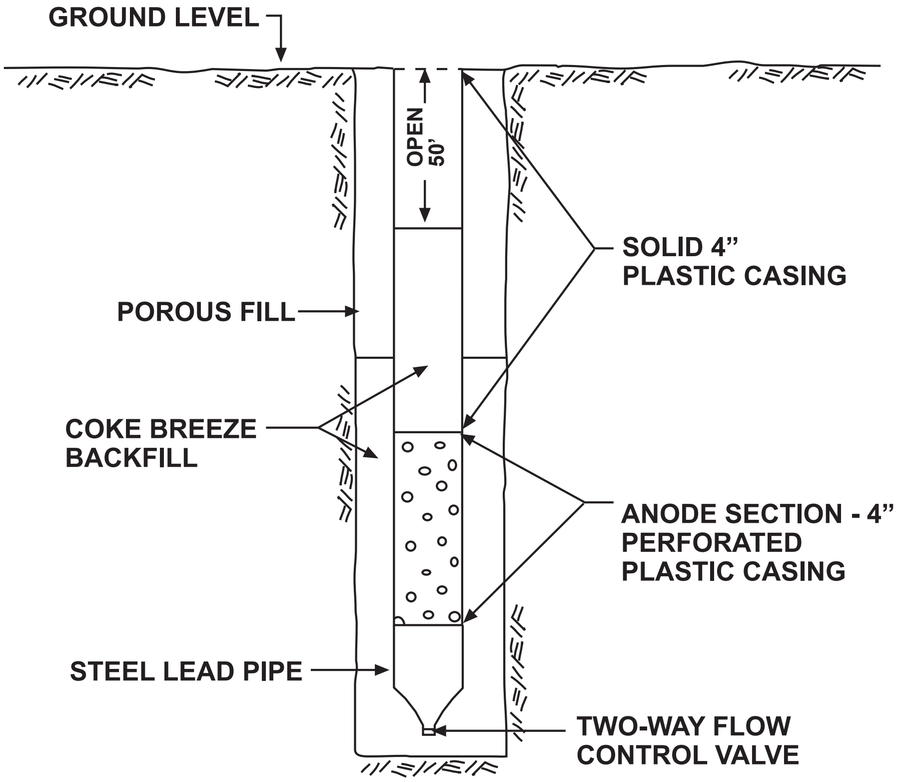
DEEP ANODE BED DESIGN USING PERFORATED PIPE SUPPORT/VENT AND CARBONACEOUS BACKFILL

FIGURE 3-19



TYPICAL PLATINIZED DEEP ANODE BED INSTALLATION

FIGURE 3-20



CAPSULE TYPE DEEP ANODE INSTALLATION

FIGURE 3-21

recommended that wood planks or plastic warning tape be installed over the cable as shown in Figure 3-17 to afford some protection to the ground during later construction in the area or excavation of the protected structure.

Distributed anode bed header cables, where the installation of the wood plank or warning tape is not deemed necessary, can be plowed in. When this is done, extreme care must be taken so as not to damage the cable insulation and more importantly, care must be taken to avoid possible damage to the pipe due to the close proximity of the header cable to the pipe.

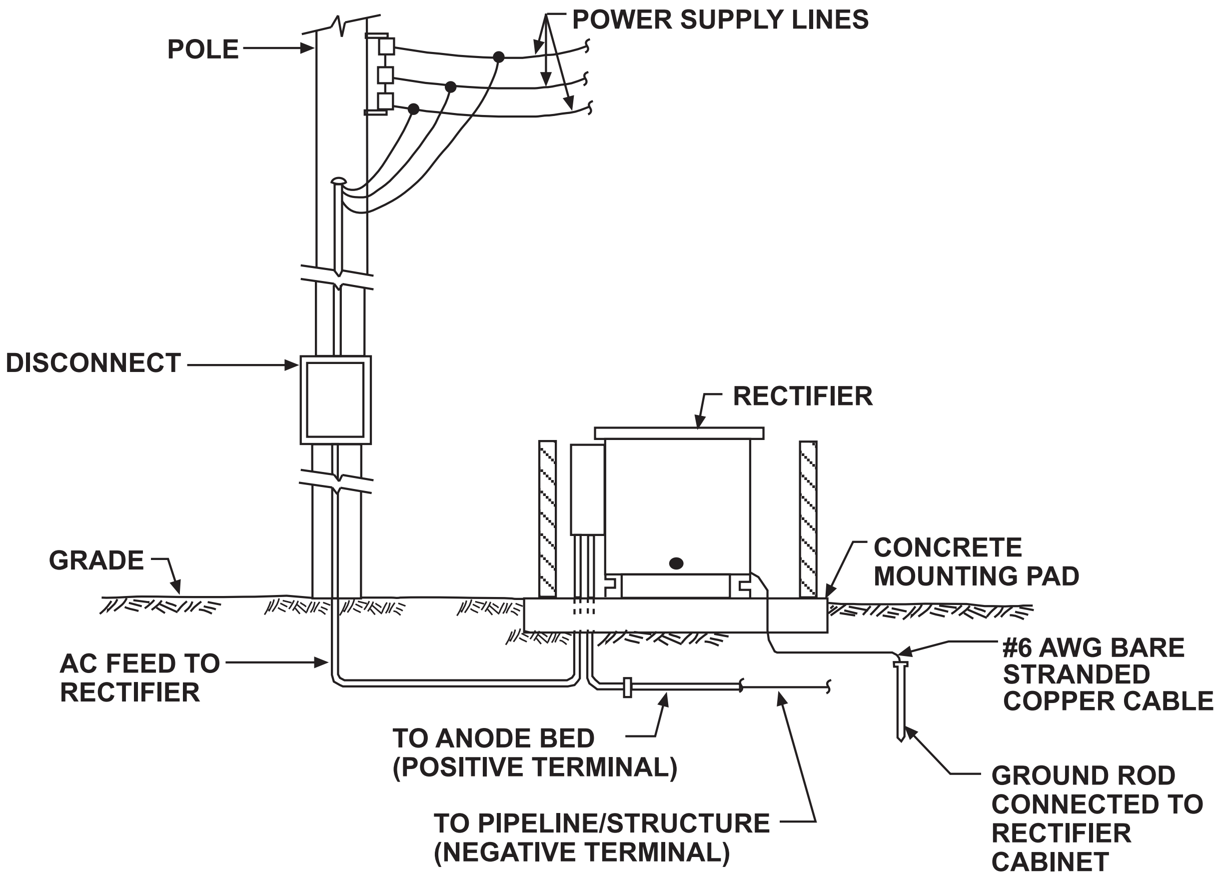
Any damage to the anode header cable or its insulation shall be repaired in accordance with one of the methods described in the previous section, Cable Splices/Repairs. Repairs to damaged negative return cables, shall also be made as described in that section.

Rectifier Installation

When selecting a rectifier location, efforts should be made, when possible, to select a location which is accessible for periodic inspection and maintenance. Rectifiers are typically either pole mounted, wall mounted, or pedestal mounted as shown in Figures 3-22, 3-23 and 3-24 at the end of this Chapter. Type of mounting used depends on the size and location of the unit. Units weighing in excess of 450 lbs. are normally pedestal or pad mounted, as shown in Figure 3-22. If the rectifier is to be located in an area which is prone to flooding problems the unit should preferably be either wall or pole mounted above the maximum water level. When wall or pole mounting a rectifier it should be installed, if possible, at a convenient working height, for maintenance and periodic testing.

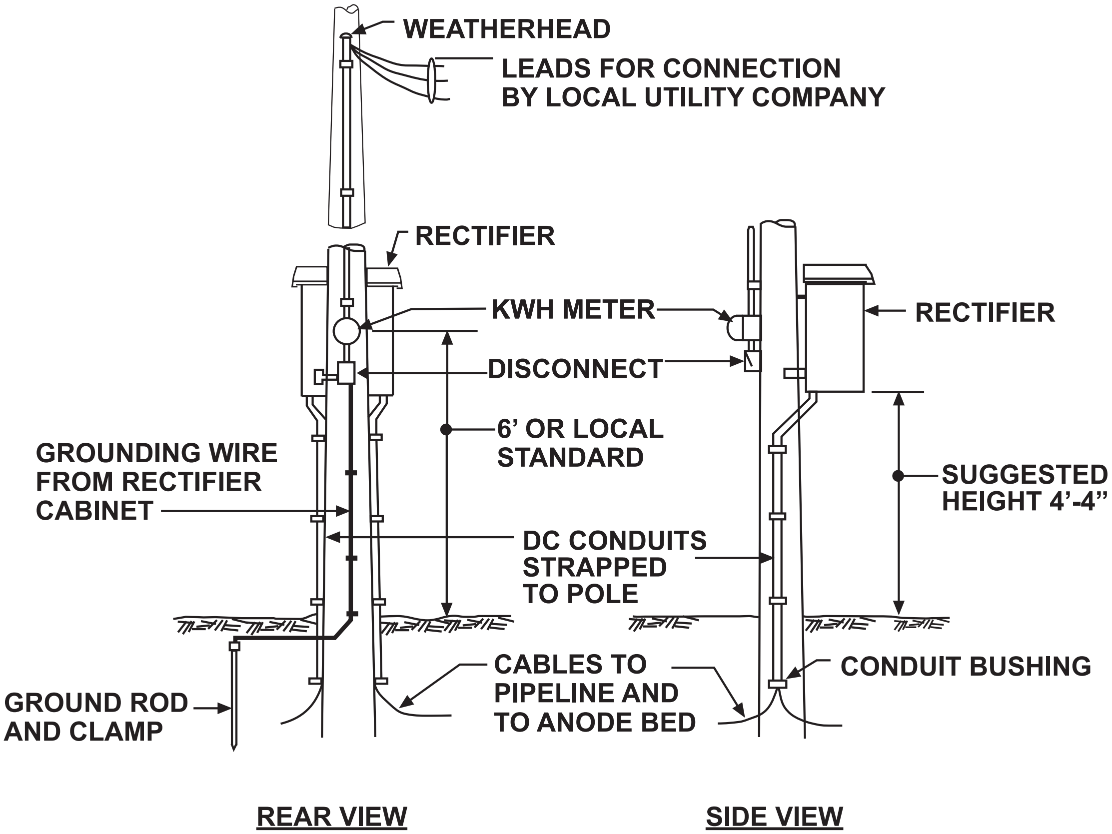
Before installing a rectifier unit, local electrical codes should be checked. By conforming to local code requirements during installation, time and possibly money may be saved in areas where local electrical inspector's certification is required before the local utilities will supply AC power.

The rectifier cabinet should be grounded for safety reasons. Rectifiers located near an existing grounding system should be tied into it if possible. Where no grounding system exists in the area, a ground grid should be installed and the rectifier connected to it using AWG #4 stranded copper cable.



PAD MOUNTED RECTIFIER

FIGURE 3-22



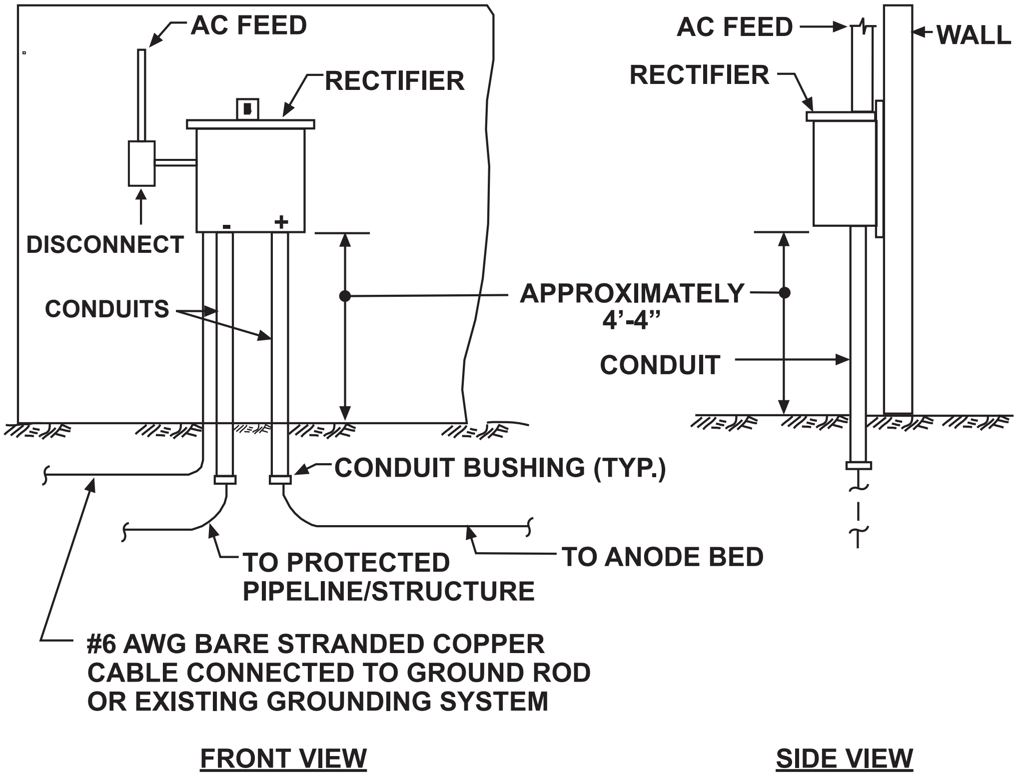
POLE MOUNTED RECTIFIER

FIGURE 3-23

CONCLUSIONS

The Chapter has described the different types of impressed current anode beds and has also described the steps that the corrosion control worker has to take to obtain the necessary data to install an impressed current anode bed.

In addition, the different anode materials and DC Power sources have been described as well as other miscellaneous items such as backfill, splice and insulation materials, etc. The chapter concluded with some installation suggestions for the different types of anode beds.



WALL MOUNTED RECTIFIER

FIGURE 3-24

Chapter 4 - Criteria for Cathodic Protection

INTRODUCTION

In Chapter 3 of the Basic Course, the theory and principles of how cathodic protection works were presented and discussed. To assure that cathodic protection is applied in accordance with these principles, criteria and methods of assessment are required. This chapter describes the industry accepted criteria. The discussion found below is a review of the NACE criteria presented in NACE Standard Practice SP0169-2007 "Control of External Corrosion of Underground or Submerged Metallic Piping Systems." This document "lists criteria and other considerations for cathodic protection that will indicate, when used either separately or in combination, whether adequate cathodic protection of a metallic piping system has been achieved." The document goes on to state that "persons responsible for external corrosion control are not limited to the primary criteria listed below." It states that "Criteria that have been successfully applied on existing piping systems can continue to be used on those piping systems. Any other criteria used must achieve corrosion control comparable to that attained with the criteria herein" referring to the three primary criteria described below. Some examples of other criteria that have been used in the past for underground piping include the 300 mV Shift, the E-log I Curve, and the Net Current Flow Criterion.

As mentioned, this text presents the criteria as specified in SP0169-2007. There is a more current version now, SP0169-2013. However, since many regulators still refer to SP0169-2007 for enforcement, it is that version we will discuss in this chapter. The principles in both versions are very similar.

CRITERIA FOR STEEL AND CAST IRON PIPING

Three primary criteria for cathodic protection of underground or submerged steel or cast iron piping systems are listed in Section 6 of SP0169-2007:

(1) *-850 mV (Cu-$CuSO_4$) with the Cathodic Protection Applied*

(2) *A Polarized Potential of -850 mV (Cu-$CuSO_4$)*

(3) *100 mV of Polarization*

The Net Protective Current Criterion is also listed in Section 6 under a special conditions section, for bare or poorly-coated pipelines where long-line corrosion activity is the primary concern. The application and limitations of each are given below.

-850 mV with the Cathodic Protection Applied Criterion

The full criterion states that adequate protection is achieved with "A negative (cathodic) potential of at least 850 mV with the CP applied. This potential is measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte. Voltage drops other than those across the structure-to- electrolyte boundary must be considered for valid interpretation of this voltage measurement."

> "Consideration is understood to mean application of sound engineering practice in determining the significance of voltage drops by methods such as:
>
> Measuring or calculating the voltage drop(s),Reviewing the historical performance of the cathodic protection system,
>
> Evaluating the physical and electrical characteristics of the pipe and its environment, and,
>
> Determining whether or not there is physical evidence of corrosion."

Application

Of the three criteria listed above, the -850 mV with the Cathodic Protection Applied Criterion is probably the most widely used for determining if a buried or submerged steel or cast iron structure has attained an acceptable level of cathodic protection. In the case of a buried steel or cast iron structure, an acceptable level of protection is achieved, based on this criterion, if the potential difference between the structure and a saturated copper-copper sulfate reference electrode contacting the soil directly above and as close as possible to the structure is equal to or more negative (larger in absolute value) than -850 mV. As described above, voltage drops other than those across the structure-to-electrolyte boundary must be considered for valid interpretation of this voltage measurement. These voltage drops are a result of current flow in the electrolyte (soil) and are generally referred to as ohmic or IR voltage drops. Voltage drops are more prevalent in the vicinity of an anode bed or in areas where stray currents are present and generally increase with increasing soil resistivity.

For bare or very poorly-coated structures, voltage drops can be reduced by placing the reference electrode as close as possible to the structure. For the majority of coated structures, most of the voltage drop is across the coating and the measurement is less affected by reference electrode placement. The voltage drop can also be minimized or eliminated by interrupting all of the DC current sources of the cathodic protection system and measuring the instantaneous "off" potential. The off-potential will be free of the voltage drop errors if all of the current sources, including sources of stray currents, have been properly interrupted and if long-line currents are negligible. Long-line currents occur on a structure as a result of the presence of macro-cells. The difference between the on- and the off-potential indicates the magnitude of the voltage drop error when the measurement is made with the protective current applied.

This criterion was originally adopted based on the observation that the most negative native potential observed for coated underground steel structures was about -800 mV Cu-$CuSO_4$. The assumption was made that macro-cell corrosion would be mitigated if sufficient CP current is applied to raise (in the negative direction) the potential of the entire structure to a value that is more negative than the native potential of the local anodic sites. A potential of -850 mV was adopted to provide a 50 mV margin of protection. The effectiveness of the criterion has been demonstrated over many years of application.

Limitations

There are a number of limitations with this criterion. The potential reading should be taken with the reference electrode contacting the electrolyte directly over the structure, to minimize ohmic voltage drop errors in the measurement and to minimize the extent of averaging over large areas of the structure. Alternative criteria may be required where the reference electrode cannot be properly placed, such as at river crossings or road crossings. The criterion also is most commonly used for well coated structures, where it can be economically met. For poorly-coated or bare structures, the high CP currents required to meet this criterion can be prohibitive, such that alternative criteria are typically used.

Potentials can vary significantly from one area of an underground structure to another as a result of varying soil conditions, coating damage, interference effects, etc. This creates the possibility that potentials less negative than -850 mV Cu-$CuSO_4$ exist between the measurement points. This problem can be addressed for pipelines by means of close-interval surveys. If the close-interval survey establishes that this problem exists, it is possible to maintain more negative potentials at the test stations to insure that adequate protection is achieved on the entire structure. However, the more negative potentials required will result in increased power consumption.

More negative potentials than -850 mV Cu-$CuSO_4$ also are required in the presence of bacteria or with a hot pipeline. In the latter case, the current required for CP can increase by a factor of two for every 10º C (18º F) increase in temperature of the pipe. The potential criterion is adjusted to compensate for the increased anodic current kinetics. Typically, a potential of -950 MV Cu-CuSO$_4$ is used for hot pipelines. In the case of microbes, the kinetics of the corrosion reaction and the environment at the pipe surface are altered such that a more negative potential is typically required to mitigate corrosion. Where the presence of microbes are confirmed or suspected, a minimum potential criterion of -950 mV Cu-CuSO$_4$ is typically used.

Care should be exercised to avoid overprotection, which can result in coating damage and may promote hydrogen damage of susceptible steels. The potential above which coating damage can occur is a function of many variables, including the soil composition and moisture content, temperature, coating type, the quality of the coating application, and the presence of microbes. The general consensus in the industry is to avoid polarized (instant off) potentials more negative than -1.05 to -1.10 V Cu-CuSO$_4$.

The older steels generally contain higher levels of impurities, such as sulfur and phosphorus, and exhibit higher susceptibility to hydrogen damage than the newer cleaner steels. In these older steels, the microstructures associated with hard spots and welds typically are much more susceptible to hydrogen damage than the microstructure of the wrought base metal. Again, the general consensus in the industry is to avoid polarized (instant off) potentials more negative than -1.05 to -1.10 V Cu-CuSO$_4$ in order to minimize hydrogen damage in these steels.

Potentials also can vary on a seasonal basis as a result of variation in the soil moisture content. Thus, some pipeline companies perform annual surveys at the same time each year, such that trends in the behavior can be properly interpreted. It should be cautioned that this approach does not preclude the possibility that the criterion is not being met on some parts of the structure during portions of the year.

Limitations also exist in the ability to accurately measure the potential of the structure in the presence of telluric currents and where shielding by disbonded coatings, rocks, thermal insulation, etc. has occurred. Similarly, the accuracy of the potential measurement is compromised by the presence of multiple pipelines in a right-of-way where the pipelines have varying coating conditions, and by stray currents that cannot be interrupted.

Dynamic stray currents, from sources such as DC transit systems and mining activities, pose a significant challenge in applying this criterion. Where dynamic stray currents are suspected, it is generally necessary to obtain potential values over the duration of the stray current activity, typically twenty-four hours or longer. For example, for DC transit systems, it is often possible to obtain fairly stable on-potentials of the structure in the early morning hours when the transit system is not operated. These potentials can provide base-line data for which to evaluate other measurements. Of course, significant interpretation of such data is required. DC stray currents not only affect the ability to obtain accurate off-potentials, they also influence the polarized potential of the pipe. Nevertheless, the -850 mV with the Cathodic Protection Applied Criterion is the most common criterion used in areas of significant dynamic stray current activity. It is generally accepted that the structure is protected at a test location if the potential of the structure remains more negative than -850 mV at all times, even with significant fluctuations associated with the dynamic stray currents. It may be necessary to increase the number of test points and the frequency of surveys in areas of dynamic stray DC currents over those used on other parts of a system to insure that adequate protection is being achieved.

Polarized Potential of -850 mV Criterion

This criterion states that adequate protection is achieved with "A negative polarized potential of at least 850 mV relative to a saturated copper/copper sulfate reference electrode." The polarized potential is defined as "The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization." The polarized potential is measured directly following interruption of all current sources and is often referred to as the off or "instant off" potential. The difference in potential between the native potential and the off or polarized potential is the amount of polarization that has occurred as a result of the application of the cathodic protection. As previously stated, the difference in potential between the on-potential and the off-potential is the error in the on-potential introduced as a result of voltage drops in the electrolyte (soil) and metallic return path in the measuring circuit.

Application

This criterion is more direct than the previous criterion (-850 mV with the Cathodic Protection Applied Criterion) in that it clearly defines the method by which voltage drops errors in the on- potential are considered; in this criterion they are minimized or eliminated. The voltage drop errors, which are often referred to as ohmic potential drop or IR drop errors, occur as a result of the flow of cathodic protection or stray current in the electrolyte (soil) or in the structure. They are measurement errors in that the cathodic polarization at the structure-to- electrolyte interface is the only part of the on-potential measurement that contributes to a reduction in the rate of corrosion of the structure. As described above, polarization is defined as the difference in potential between the native potential and the off- or polarized potential. It is referred to as cathodic polarization if the potential shift is in the negative direction.

This criterion is most commonly applied to coated structures where the sources of DC current can be readily interrupted. An example would be a fusion bonded epoxy (FBE) coated gas transmission pipeline in a rural area with an impressed current cathodic protection system.

Limitations

A significant limitation of this criterion is the requirement that all sources of DC current be interrupted. For standard survey techniques, the interruption must be performed simultaneously on all current sources. On gas transmission pipelines, interrupting all current sources may require the use of a large number of synchronous interrupters for all rectifiers, sacrificial anodes, and bonds affecting the section of pipeline that is being evaluated. In some cases, the number of rectifiers affecting a test section is not known without experimental verification. On gas distribution systems, sacrificial anodes are more commonly used for cathodic protection and the electrical leads for the anodes are usually bonded directly to the pipe with no means available to interrupt the current. For these situations, this criterion cannot be used. Achieving the criterion also may require the application of high CP currents, resulting in over-protection of some portions of the structure, and related problems such as cathodic disbondment of coatings, and hydrogen embrittlement of susceptible steels. As described above, a more negative potential than -850 mV Cu-$CuSO_4$ may be required to mitigate corrosion on hot pipelines or in the presence of MIC, further increasing the likelihood of over-protection.

Many of the difficulties of accurately measuring structure-to-electrolyte potentials, described under limitations to the -850 mV with the Cathodic Protection Applied Criterion apply to the Polarized Potential of -850 mV Criterion as well. These include access to the structure, seasonal fluctuations in the potential between testing times, spatial fluctuations in potential between test stations, the presence of multiple pipelines, having varying coating conditions, in a right-of-way, telluric current effects, and shielding of the structure surface by disbonded coatings, rocks, thermal insulation, etc.

100 mV of Polarization Criterion

This criterion states that adequate protection is achieved with "A minimum of 100 mV 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 criterion." Of the three criteria, this criterion has the most sound fundamental basis. As described in previous chapters, the corrosion rate decreases and the rate of the reduction reaction on the metal surface increases as the underground structure is polarized in the negative direction from the native potential. The difference between the corrosion rate (expressed as a current) and the rate of the reduction reaction is equal to the applied cathodic protection current. These processes can be shown graphically in an E versus Log I diagram, referred to as an Evans diagram. The slope of the anodic (corrosion) reaction is referred to as the anodic Tafel slope and typically has a value of about 100 mV per decade of current. With this Tafel slope, the corrosion rate of a structure decreases by a factor of ten (order of magnitude) for every 100 mV cathodic shift in the polarized potential. An order of magnitude decrease in the corrosion rate of an underground structure typically is more than adequate to effectively mitigate corrosion.

The cathodic polarization also promotes beneficial changes in the environment at the pipe surface, such as reducing oxygen, increasing the pH, and moving halides such as chlorides away from the metal surface, further decreasing the corrosion rate. These beneficial changes in the environment at the metal surface are referred to as environmental polarization in that the environmental changes typically result in a shift in the free corrosion potential of the pipe in the negative direction. Thus, the total potential shift from the native potential (excluding voltage drops in the soil), includes components due to environmental polarization and cathodic polarization.

As described in the criterion, the magnitude of the polarization shift can be determined by measuring its formation or decay. In order to determine the magnitude of the shift as a result of the formation of polarization, it is first necessary to determine the native potential of the underground structure at test locations before cathodic protection is applied. The potential measurement is then repeated after the cathodic protection system is energized and the structure has had sufficient time to polarize. Typically, the on-potential is continuously monitored at one test location directly following energization of the cathodic protection system and an off-potential reading is made when there is no measurable shift in the on-potential reading with time over a period of several minutes. The off-potential is then compared with the native potential; if the difference is greater than 100 mV, then the 100 mV criterion has been satisfied at that location. Off-potential readings are then obtained at the other test locations to determine whether the criterion is met at these locations. The time required for sufficient polarization to develop is highly dependent on the nature of the structure (coating condition, underground environment, types and number of bonds, etc) and the design of the cathodic protection system. From a practical standpoint, it is wise to re-examine the overall structure-CP system if a reasonable amount of polarization does not develop within a few hours of energizing the cathodic protection system.

An alternative method of assessing the formation of cathodic polarization is to measure the on-potential immediately following energization of the cathodic protection system and then to remeasure the on-potential after a few hours to days of operation of the CP system. If the on-potential shifts in the cathodic (negative) direction by more than 100 mV, then it can be conservatively assumed that the criterion has been met. This is because the applied CP current generally decreases with time, decreasing the magnitude of the voltage drop. Thus, the total shift in the on-potential must be a result of the sum of additional cathodic polarization and environmental polarization of the structure; both of which reduce the corrosion rate of the structure and are included in the 100 mV of polarization in the criterion. If this method is used, it should be confirmed that the applied cathodic protection current decreased with time.

Measuring the positive potential shift associated with polarization decay that occurs following de-energizing the cathodic protection system is the most common method of determining the amount of polarization. When a cathodic protection system is de-energized, an instantaneous positive shift in the structure- to-soil potential occurs as a result of the elimination of the voltage drop in the soil. The potential measured at this time is referred to as the off-potential, as previously described, and is used as the starting point for assessing the polarization shift. There may be a spike in the potential reading immediately following interruption of the CP system as a result of inductive effects of the pipeline and CP system. This spike may last a few hundred milliseconds such that the off-potential is typically measured 200 to 500 milliseconds following interruption.

The potential will then exhibit an exponential decay in the positive direction as the capacitor across the structure to electrolyte boundary discharges. This component of the potential shift is the cathodic polarization of the structure as a result of the applied cathodic current. A gradual linear decay in the potential will then occur over minutes to weeks as a result of a return of the environment at the pipe surface to a native condition. This component of the potential shift is the environmental polarization. To obtain the total polarization shift, the final potential after polarization decay is measured and subtracted from the off-potential. If this difference is greater than 100 millivolts, then the criterion has been satisfied.

Application

The 100 mV of Polarization Criterion is most commonly used on poorly-coated or bare structures where it is difficult or costly to achieve either of the -850 mV criteria. In many cases, 100 mV of polarization can be achieved where the off-potential is less negative than -850 mV Cu-$CuSO_4$. The application of the 100 mV of Polarization Criterion has the advantage of minimizing coating degradation and hydrogen embrittlement, both of which can occur as a result of over protection. In piping networks, the 100 mV of Polarization Criterion can be used for the older, poorly-coated pipes while the Polarized Potential of -850 mV Criterion can be used for the newer piping in the network. Because of its fundamental underpinnings, the 100 mV of Polarization Criterion can also be used on metals other than steel where a specific potential required for protection has not been established.

Limitations

There are a number of limitations with this criterion. The time required for full depolarization of a poorly-coated or bare structure can be several days to several weeks, making the method very time consuming and leaving the structure unprotected for an extended period of time. Fortunately, much of the depolarization occurs within a few hours and it frequently is not necessary to wait for the full decay, except where the total polarization is very close to 100 mV. Once the criterion has been met, it is not necessary to continue waiting for further depolarization. At the other extreme, if a depolarization of less than 50 mV is measured within a few hours, it is questionable whether the 100 mV of Polarization Criterion can be achieved. At this point, it may be prudent to assess whether a longer wait for total depolarization is justified.

The 100 mV of Polarization Criterion is frequently used to minimize the costs for upgrading cathodic protection systems, and the associated increase in power costs, in areas with degrading coatings. Because of the complicated nature of the measurements, the cost of conducting surveys for the assessment of the 100 mV of Polarization Criterion is considerably higher than for the -850 mV criteria. Thus, an economical analysis may be required to determine whether there is actually a cost savings associated with application of the 100 mV of Polarization Criterion.

The 100 mV of Polarization Criterion should not be used in areas subject to stray currents because 100 mV of polarization may not be sufficient to mitigate corrosion in these areas. It is generally not possible to interrupt the source of the stray currents in order to accurately measure the depolarization. All DC current sources affecting the structure, including rectifiers, sacrificial anodes, and bonds must be interrupted in order to apply this criterion. In many instances, this is not possible, especially on older structures where the criterion is most likely to be used.

The 100 mV of Polarization Criterion should not be used on structures that contain dissimilar metal couples because 100 mV of polarization may not be adequate to protect the active metal in the couple. This criterion also should not be used in areas where the intergranular form of external stress corrosion cracking, also referred to as high-pH or classical SCC, is suspected. This is because the potential range for cracking lies between the native potential and -850 mV Cu-$CuSO_4$ such that application of the 100 mV of Polarization Criterion may place the structure in the potential range for cracking.

Cathodic Protection Coupons

A cathodic protection coupon is metal sample that is intended to represent a structure at a coating holiday. The coupon has a lead wire attached to it which is normally bonded to the structure through a test station so that it receives cathodic protection current just as the structure does at a coating holiday. Cathodic protection coupons are used to help determine the level of cathodic protection of a buried or submerged metallic structure. Tests that can be made with cathodic protection coupons include:

- measuring the coupon-to-electrolyte potential with the coupon connected to the structure,

- measuring the coupon-to-electrolyte potential after disconnecting the coupon from the structure (coupon instant disconnect potential),

- measuring the current flow between the coupon and the structure.

The coupon-to-electrolyte potential is typically measured with the reference electrode in close proximity to the coupon. This is accomplished by the use of a permanently installed reference electrode near the coupon or by placing a portable reference electrode in a soil access tube.

Measurements made with coupons can help determine if a criterion has been met:

- Since the coupon to electrolyte potential is measured with the reference electrode in close proximity to the coupon, the voltage drop is minimized for a current applied potential.

- Measuring the coupon to electrolyte potential after disconnecting the coupon from the structure is a way of interrupting all sources of cathodic protection current in order to obtain a direct measurement of the polarized potential.

- Measuring the coupon to electrolyte potential after disconnecting the coupon from the structure is a way of interrupting all sources of cathodic protection current in order to obtain an "off" reading to be used in determining the level of polarization.

Situations where using a cathodic protection coupon could be used include:

- Current interruption on multiple rectifiers affecting the structure that cannot be synchronized

- Foreign CP systems that are affecting the structure being tested cannot be interrupted

- The presence of directly connected sacrificial anodes

Net Protective Current Criterion

SP0169-2007 states under paragraph 6.2.2.2.1 (Special Conditions) that: "On bare or ineffectively coated pipelines where long-line corrosion activity is of primary concern, the measurement of a net protective current at predetermined current discharge points from the electrolyte to the pipe surface, as measured by an earth current technique, may be sufficient" for cathodic protection to be achieved.

This statement establishes the fourth criterion for cathodic protection of underground piping, referred to as the Net Protective Current Criterion. This criterion was originally based on the concept that, if the net current at any point on a structure is flowing from the electrolyte to the structure, there cannot be any corrosion current discharging from that point on the structure. The theory of electrochemical kinetics shows that corrosion can occur at a point on a structure that is collecting net cathodic current from the electrolyte as long as the polarized potential is more positive than the equilibrium potential. Nevertheless, the criterion can be effective, from a practical standpoint, because the collection of net cathodic current at any point along the structure produces beneficial cathodic polarization and also promotes beneficial changes in the environment at the structure surface, as described above.

Typically, the criterion is applied by first performing a close-interval structure-to-soil potential survey or a cell-to-cell potential survey with the cathodic protection system de-energized in order to locate the anodic discharge points along the pipeline. For the surveys to be effective, the CP systems must be de-energized for a sufficiently long time such that all polarization has decayed. The CP system is then energized and the structure is allowed to polarize. A side drain method is then used at the anodic discharge points to determine whether the structure is receiving cathodic current at these locations. With the side drain method, the potential difference between an electrode placed directly over the structure and one placed on either side of the structure is measured. If the electrode located over the pipe is negative with respect to the other two electrodes, then current is collecting on the pipe at the location and the criterion is satisfied.

Application

The Net Protective Current Criterion is normally used on poorly-coated or uncoated structures where the primary concern is long-line corrosion activity. The technique also is normally only used in situations where other criterion cannot be easily or economically met. With the exception of these applications, this criterion is not a standard criterion for establishing the effectiveness of a cathodic protection system.

Limitations

There are a number of limitations with this criterion. First and foremost is the fact that the criterion essentially states that any magnitude of net current flow to the structure (and therefore, any amount of cathodic polarization of the structure) is adequate to mitigate corrosion. In general, this is not the case and therefore, the criterion should only be considered for use as a last resort. Application of the criterion should be avoided in areas of stray current activity or in common pipeline corridors because of the possibility of misinterpretation of the potential readings. The criterion also may not be effective in areas with high resistivity soils, for deeply buried pipelines, or where the separation distance of the corrosion cells is small. Finally, the side drain measurements at a given location are only indicative of the direction of current flow at that location and are not necessarily representative of behavior elsewhere on the pipeline. Thus, for the application of this criterion, it is generally necessary to perform side-drain measurements at close intervals (2 to 20 feet) along the pipeline.

Other Criteria For Steel And Cast Iron

The four criteria listed for steel and cast Iron piping are the only acceptable criteria listed in SP0169-2007 for underground or submerged metallic piping. However, other criteria can be used on a piping system where they have been used in the past and it can be demonstrated that their use has resulted in effective cathodic protection. Other criteria also can be used on underground structures such as reinforced concrete pipe, piling, etc. The two most common other criteria that have been used in the past for underground structures are the 300 mV Potential Shift Criterion and the E-Log I Curve Criterion.

300 mV Potential Shift Criterion

The 300 mV Potential Shift Criterion was contained in the original version of RP0169 (the predecessor of SP0169-2007) and stated that adequate protection is achieved with "A negative (cathodic) voltage shift of at least 300 mV as measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte. Determination of this voltage shift is to be made with the protective current applied." This criterion is similar to the 100 mV of Polarization Criterion, where the latter is assessed based on the formation of polarization on a structure. With both criteria, it is first necessary to determine the native potential of the underground structure at test locations before cathodic protection is applied. The potential measurement is then repeated after the cathodic protection system is energized and the structure has had sufficient time to polarize. The difference between the two criteria is that, in the case of the 300 mV Potential Shift Criterion, the on-potential is used for assessment of the criterion while, in the case of the 100 mV of Polarization Criterion, the off-potential is used for assessment. In the 300 mV Potential Shift Criterion, it is stated that "The Corrosion Engineer shall consider voltage (IR) drops other than those across the structure-electrolyte boundary for valid interpretation of the voltage measurements." Thus the relationship between the 300 mV Potential Shift Criterion and the 100 mV of Polarization Criterion is analogous to the relationship between the -850 mV with the Cathodic Protection Applied Criterion and the Polarized Potential of -850 mV Criterion.

The 300 mV Potential Shift Criterion has mainly been used for mitigation of moderate rates of uniform corrosion of bare steel structures. It has been applied for protection of entire structures and also for hot-spot protection. On these structures, native potentials of -200 mV to -500 mV Cu-$CuSO_4$ are commonly observed and it has been found that a 300 mV shift is adequate to mitigate corrosion in some instances. Thus, the development of the criterion was empirical. The 300 mV Potential Shift Criterion is more applicable to impressed current CP systems than to galvanic anode systems because galvanic anodes may not have sufficient driving voltage to meet the criterion where (when) more negative native potentials are encountered.

Probably the most successful application of this criterion has been on steel reinforced concrete structures. These structures typically have noble native potentials (-200 mV to -400 mV Cu-$CuSO_4$), and passive steel surfaces, with the exception of hot spots, such that a potential shift of 300 mV can be readily achieved. Application of this criterion avoids problems associated with over-protection.

Many of the limitations associated with the 100 mV of Polarization Criterion are applicable to the 300 mV Potential Shift Criterion as well. These include the time required for polarization, the possibility of moving the potential into the cracking range for SCC, and difficulties in areas containing stray currents or galvanic couples. In general, the 300 mV Potential Shift Criterion should not be used where high-pH SCC is confirmed or suspected, or where stray currents or galvanic couples are present. In the original version of RP0169 it is stated "This criterion of voltage shifts applies to structures not in contact with dissimilar metals."

Probably the single greatest limitation of the 300 mV Potential Shift Criterion is that situations will exist in the field where the criterion appears to be applicable yet corrosion may not be adequately mitigated. In some situations, the majority of the potential shift will be the result of voltage drops in the soil or across the coating and very little polarization of the structure will occur. This is the reason that this criterion was removed from the primary list of criteria in the 1992 version of RP0169.

E-Log I Curve Criterion

The E-Log I Curve Criterion also is found in the original version of RP0169. The criterion states that adequate protection is achieved with "A voltage at least as negative (cathodic) as that originally established at the beginning of the Tafel segment of the E-Log I curve. This voltage shall be measured between the structure surface and a saturated copper- copper sulfate half cell contacting the electrolyte." The criterion was originally developed based on an incorrect interpretation of an E-Log I curve. It was thought that a break in the cathodic curve exists as the structure is polarized from the native potential and that the "break" has some fundamental significance. This break was thought to occur at the beginning of the "Tafel Region." A review of the theory of cathodic protection indicates that the net cathodic current measured at any applied cathodic potential is equal to the difference between the rate of the reduction reaction and the rate of the oxidation reaction. An Evans diagram (potential versus log current plot) shows that there is a smooth transition from zero current, at the native potential, to the linear Tafel region. The Tafel region starts when the rate of the oxidation (corrosion) reaction is negligibly small in comparison to the rate of the reduction reaction. Depending on the Tafel slopes for the oxidation and reduction reactions, the beginning of the Tafel region can vary between 50 mV and 100 mV cathodic from the native potential.

Presently, the E-Log I Curve Criterion is rarely used for evaluating existing cathodic protection systems. However, the measurement technique, originally developed for applying the E-Log I Curve Criterion, is now most commonly used to determine the minimum current required for protection. The structure-to-soil potential, using a remote reference electrode, is plotted as a function of the current output of a cathodic protection system. Typically, it is necessary to use an interruption technique and off-potentials for making the E-Log I plot in order to accurately establish the curve. The potential required to achieve a desired minimum current value is identified on the curve. This value should be at least as negative as the value at the beginning of the Tafel region of the E-Log I curve. Once the potential and current values have been established, established, future surveys consist of checking the current output of the cathodic protection system and the potential of the structure with respect to the remote reference electrode, placed in the same location as that used in the original E-Log I tests.

Because of the elaborate nature of the technique, its use is generally limited to structures where conventional means of assessment are difficult. Examples include river crossings for pipelines, well casings, and piping networks in concentrated areas such as industrial parks. The technique can give erroneous results in areas of stray currents. The reference electrode must be placed in the same location each time the potential is measured. Furthermore, there is no guarantee that a repeat E-Log I curve will yield the same results as the original curve.

CRITERION FOR ALUMINUM PIPING

In SP0169-2007, there is a single criterion for aluminum piping. Under paragraph 6.2.3.1, "The following criterion shall apply: a minimum of 100 mV of cathodic polarization between the structure and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion." This criterion is identical to the 100 mV of Polarization Criterion used for cast iron and steel.

There are two precautionary notes, under Section 6.2.3.2, that are unique to aluminum piping; one dealing with Excessive Voltages (Paragraph 6.2.3.2.1) and one dealing with alkaline conditions (Paragraph 6.2.3.2.2). Under Paragraph 6.2.3.2. 1, it is stated that:

"Notwithstanding, the minimum criterion in Section 6.2.3.1, if aluminum is cathodically protected at voltages more negative than 1200 mV measured between the pipe surface and a saturated copper/copper sulfate reference electrode contacting the electrolyte and compensation is made for the voltage drops other than those across the pipe-electrolyte boundary, it may suffer corrosion as a result of the buildup of alkali on the metal surface. A polarized potential more negative than 1200 mV should not be used unless previous test results indicate that no appreciable corrosion will occur in the particular environment."

Under Paragraph 6.2.3.2.2, it is stated that: "Aluminum may suffer from corrosion under high-pH conditions and application of cathodic protection tends to increase the pH at the metal surface. Therefore, careful investigation or testing should be made before applying cathodic protection to stop pitting attack on aluminum in environments with a natural pH in excess of 8.0."

The basis for these cautionary notes is the incompatibility of aluminum in high pH environments. The protective passive films on aluminum break down in high pH electrolytes, leading to significant increases in the corrosion rate, even at relatively negative potentials.

In addition to these precautionary notes, several of the limitations for the 100 mV Polarization Criterion for steel and cast iron also apply to aluminum. These include the time consuming nature of the measurement technique, difficulties associated with interrupting all current sources, and limitations in applying the criterion on structures with dissimilar metals and in the presence of stray currents. Because no other criterion is applicable to aluminum, good engineering practice must be used to address these limitations. For example, sources of stray current should be identified and eliminated, if possible. Aluminum piping should be isolated from other metals before cathodic protection is applied (Isolation of aluminum is required for the cathodic protection criterion of dissimilar metals under Section 6.2.5 of SP0169-2007, see below).

CRITERION FOR COPPER PIPING

In SP0169-2007, there is a single criterion for copper piping. Under paragraph 6.2.4.1, "The following criterion shall apply: a minimum of 100 mV of cathodic polarization between the structure and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion."

This criterion is identical to the 100 mV of Polarization Criterion used for cast iron, steel and aluminum. There are no precautionary notes with this criterion but several of the limitations with the 100 mV of Polarization Criterion for steel and cast iron also apply to copper. These include the time consuming nature of the measurement technique, difficulties associated with interrupting all current sources, and limitations in applying the criterion on structures with dissimilar metals and in the presence of stray currents. Sources of stray current should be identified and eliminated, if possible. Since copper is a noble metal, steel, cast iron, or other metals usually will undergo preferential galvanic attack when coupled to copper. Therefore, it is desirable to eliminate such dissimilar metals couples before the application of cathodic protection.

CRITERION FOR DISSIMILAR METAL PIPING

In SP0169-2007, there is a single criterion for dissimilar metal piping. Under paragraph 6.2.5.1, the following criterion is listed: "A negative voltage between all pipe surfaces and a stable reference electrode contacting the electrolyte equal to that required for the protection of the most anodic metal should be maintained." There is one precautionary note, under Paragraph 6.2.5.2:

"Amphoteric materials that could be damaged by high alkalinity created by CP should be electrically isolated and separately protected." Amphoteric metals include aluminum, titanium and zirconium.

In practice, this criterion only applies where carbon steel or cast iron is coupled to a more noble metal such as copper. In this situation, either of the -850 mV criteria would apply (-850 mV with the Cathodic Protection Applied Criterion or Polarized Potential of -850 mV Criterion). Other criteria, such as the 100 mV of Polarization Criterion would not be applicable.

ACKNOWLEDGMENT

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REFERENCES

1. NACE Standard Practice SP0169-2007 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems", NACE International, Houston

Chapter 5 - Static Stray Current Interference Testing

INTRODUCTION

The objective of this chapter is to provide enough information to allow the Corrosion Professional, first to recognize an interference problem based on pipe-to-soil potential data and then determine what steps are required to eliminate or control the problem.

The primary cause of interference currents or stray currents was initially related to operation of direct current traction systems, such as rail systems, mining carts, and the like. Due to the increased use of impressed current cathodic protection systems for pipelines and other underground and submerged metallic structures, these types of cathodic protection systems have also become another major cause of interference problems.

This chapter will discuss how to determine the source of the interference current, determine the point of maximum exposure, and describe methods to mitigate the problem.

Please note that all pipe-to-soil voltages shown in this chapter are with respect to a saturated copper/copper sulfate reference electrode (CSE).

DEFINITIONS

Interference currents, or stray currents, are defined as currents performing work in one grounded plant, which leaks to, and flow through electrolytic paths, and are picked up by nearby grounded plants. Interference currents are normally separated into two main classifications as follows:

1. Static Interference - These stray currents are those which maintain constant amplitude and constant geographical paths. Examples of typical sources are railroad signal batteries and impressed current cathodic protection systems.

2. Dynamic Interference - These stray currents are those, which are continually varying in amplitude and/or continually, changing their electrolytic paths. They can be man-made or caused by natural phenomena. Typical examples of man-made sources are DC welding equipment and DC electrical railway systems. Natural sources such as telluric currents are caused by disturbances in the earth's magnetic fields caused by sun spot activity.

Although the Corrosion Professional needs a good working knowledge of both types of interference currents, we will only focus on static interference for this chapter. Dynamic Interference will be discussed in the Advanced Course.

STATIC INTERFERENCE

During this chapter you will find that all forms of interference correction require considerable field work and testing. It can be time consuming and therefore very expensive. Much of the expense can be saved if careful planning is done in the design stage before a cathodic protection system is installed. This means that all involved know of the potential problem, and are aware of foreign lines, and other underground structures, in the vicinity of the newly proposed system.

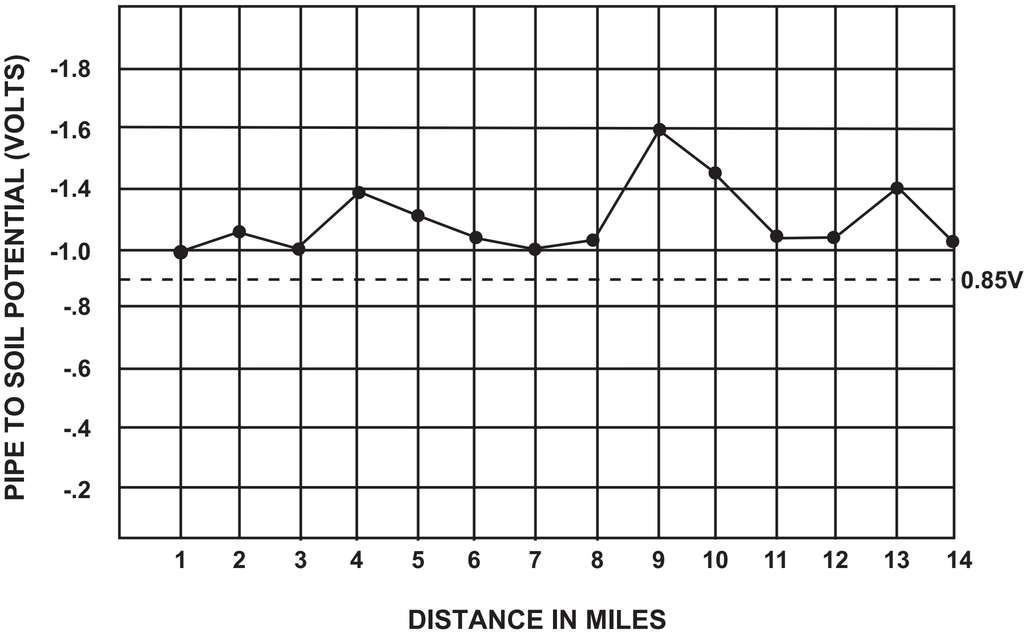
One of the easiest ways of keeping abreast of possible interference problems in an area is through a Corrosion Coordinating Committee. These committees are sometimes known as "electrolysis committees" and are composed of individuals representing companies that operate, maintain, or engineer underground structures, such as pipelines, cables, tanks and their associated cathodic protection systems. By being involved or requesting information from one of these committees, the Corrosion Professional can possibly avoid costly, time-consuming field testing in the design phase of the system.

Most companies conduct periodic corrosion surveys on their underground structures (pipelines). Pipe-to-soil potential measurements are normally taken along the pipeline during the survey and the data plotted on a long strip chart or graph, distance (horizontal axis) vs. potentials (vertical axis). Figure 5-1 shows a typical potential survey plot with no interference problems. The pipe-to-soil potential survey is the best way to ensure proper operation of a company's own cathodic protection system.

This survey is also a means of determining the existence of interference problems. Figure 5-2 and 5-3 show potential plots for coated and bare pipelines respectively, which are experiencing stray current interference. Based on the plotted data, interference may be suspected if:

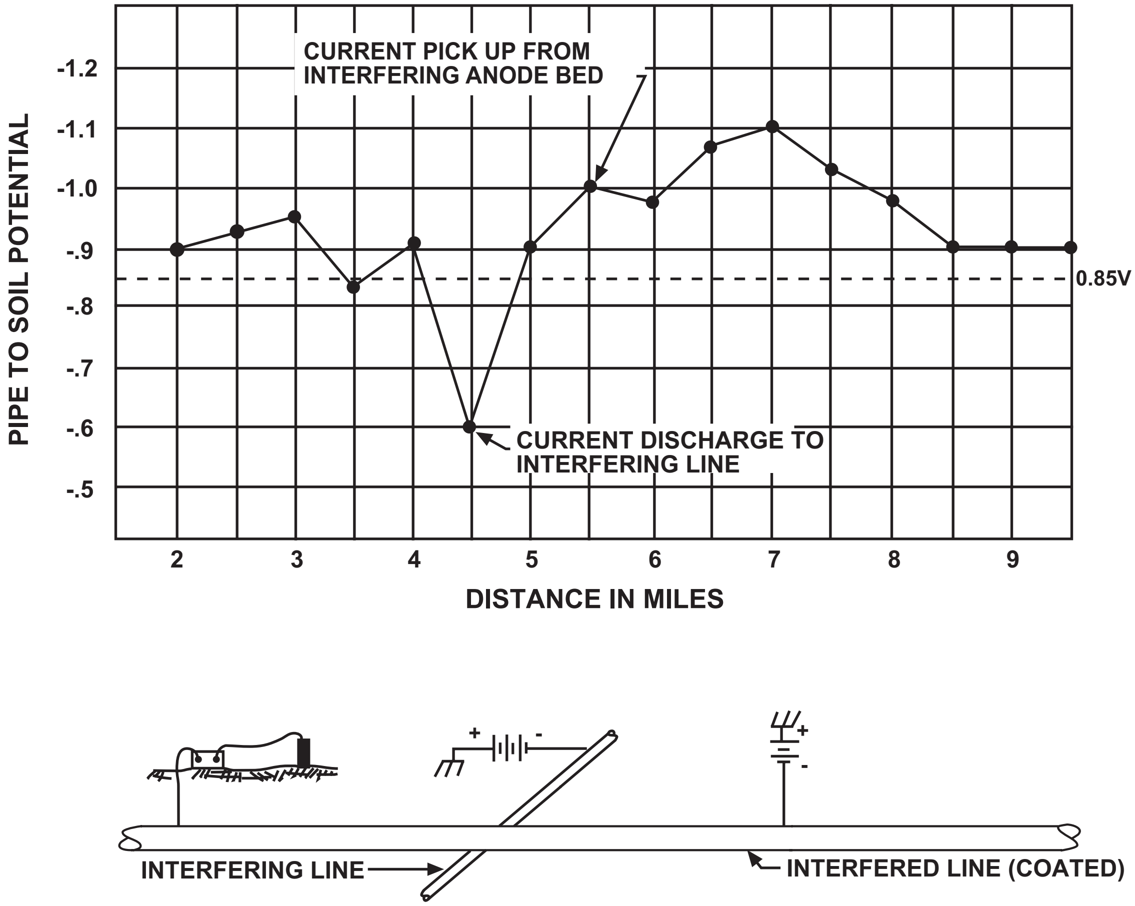
- Voltage curve profile shows abnormal variation from previous survey curves.

- High negative values are noted remote from any cathodic protection system on the surveyed line.



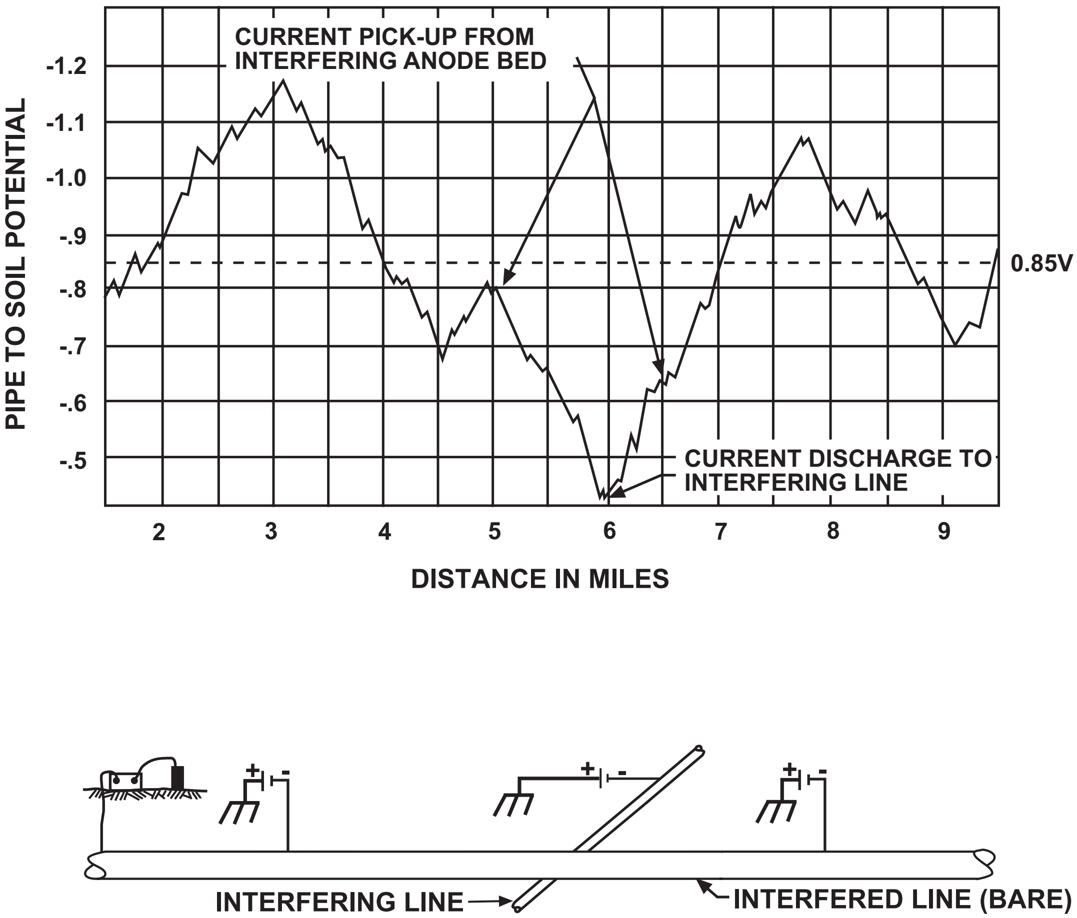
POTENTIAL VS DISTANCE PLOT

FIGURE 5-1



POTENTIAL PLOT WITH INTERFERENCE
COATED PIPELINE

FIGURE 5-2



POTENTIAL PLOT WITH INTERFERENCE
BARE PIPELINE

FIGURE 5-3

- Low negative or positive voltages are present.

Note: Plots of coated lines normally have smoother voltage attenuation curves as opposed to bare lines which often have jagged curves making them more difficult to interpret.

Small variations in potential can normally be ignored provided that adequate levels of cathodic protection are maintained.

Although Figures 5-2 and 5-3 only show one survey or one year’s worth of data, the Corrosion Professional can now utilize computer software which can plot several years of pipe-to-soil data on one graph. This allows for an easy comparison of voltage curves of previous surveys.

INTERPRETATION OF DATA

Interpretation of data can best be illustrated through an example. Let us look at a coated pipeline section being cathodically protected by a conventional impressed current anode bed. There are four foreign pipelines crossing our protected line, as shown in Figure 5-4, and a test station exists at each line crossing us, as shown in Figure 5-5.

All pipe-to-soil potentials should be taken using a high impedance (10 megohms or greater) voltmeter, connected as shown in Figure 5-5, while interrupting the rectifier associated with or influencing the line being tested. When taking potentials at line crossings, the reference electrode should be placed in contact with the soil directly above the pipe crossing. A pipe locator should be utilized to locate this point.

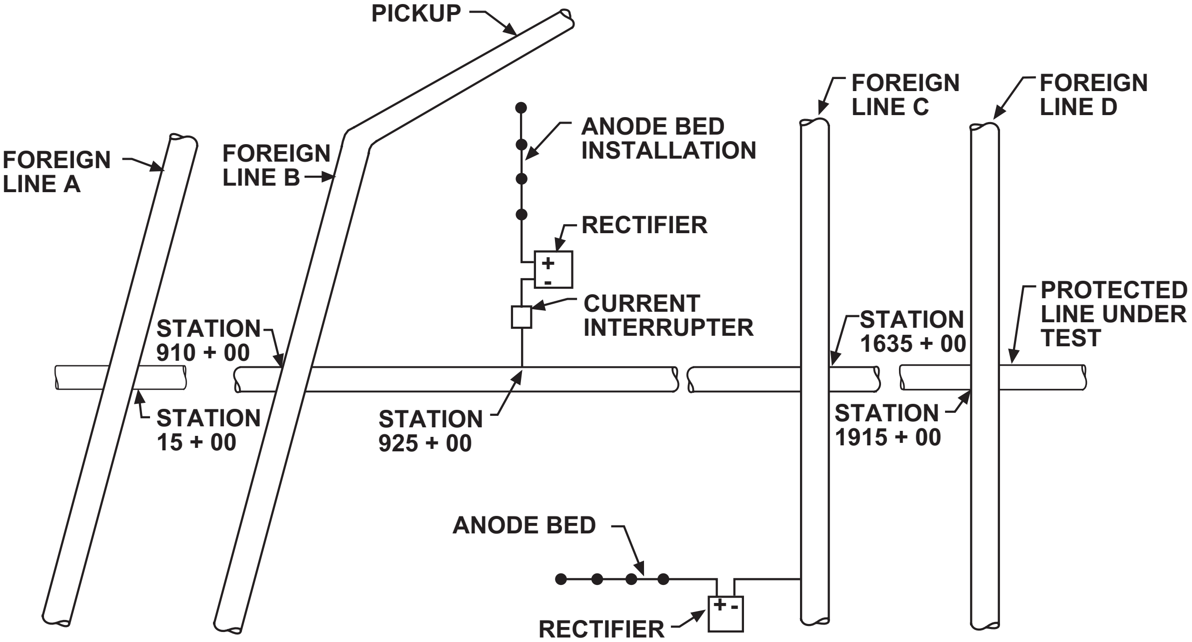
When interpreting data on multiple pipelines, it is best to look at each crossing individually, as shown in the examples.

Crossing A - Figure 5-6

The example shows that with our rectifier "on" the pipe-to-soil potential for our line is -0.89 V. Pipeline A has a pipe-to-soil potential of -0.86 V.

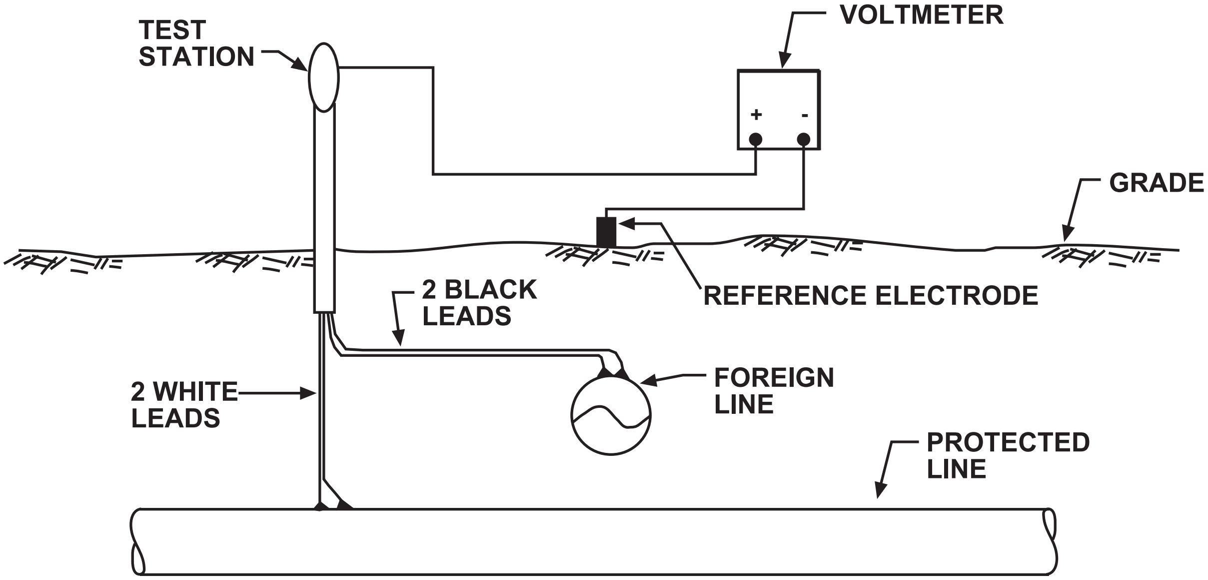
When the rectifier is switched "off" our potential becomes more positive (-0.85 V). Where Pipeline A has become more negative (-0.88 V).

The pipeline under test is considered to be protected, based on the recorded test data.



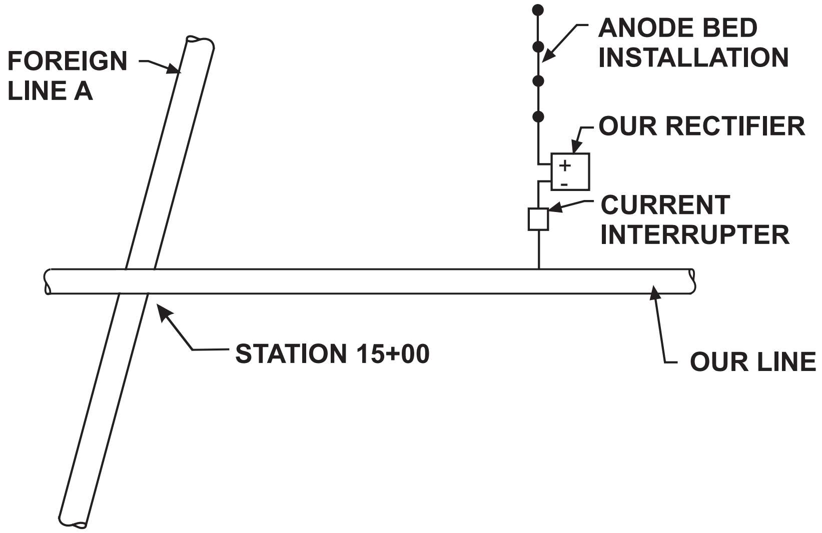
FOREIGN LINE CROSSINGS

FIGURE 5-4



TYPICAL FOREIGN LINE CROSSING TEST POINT

FIGURE 5-5



FOREIGN LINE A	
ON	− 0.86 V
OFF	− 0.88 V
ΔV	+ 0.02 V

OUR LINE	
ON	− 0.89 V
OFF	− 0.85 V
ΔV	− 0.04 V

FOREIGN LINE CROSSING A

FIGURE 5-6

It can be expected however, that a coating holiday exists near the point of crossing. This conclusion is based on the fact that the potential of the foreign line decreased (or became more positive) when our rectifier was switched "on”. This is an indication that there is an appreciable amount of current flowing to our line, thus creating an area of more negative soil locally around the foreign line.

The foreign line at the crossing is cathodically protected. Its potential at the crossing (a local condition) is decreased by energizing our rectifier. However, the reduction is not sufficient to indicate loss of protection. In this particular case no corrective measures would be required.

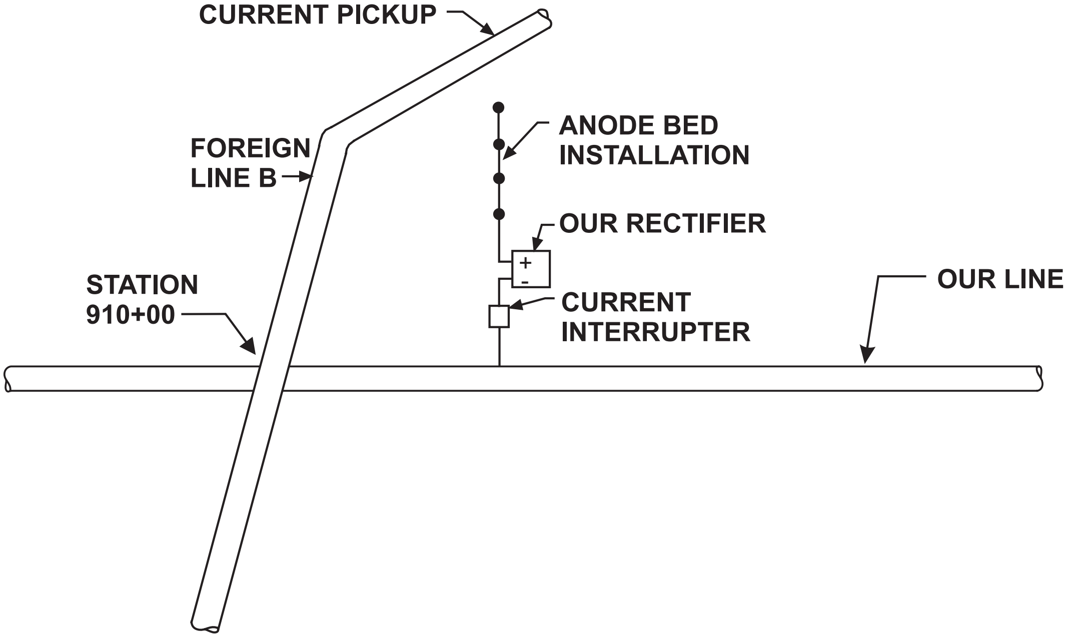
Crossing B - Figure 5-7

The example shows that with our rectifier "on" the pipe-to-soil potential for our line is -1.85 V. Pipeline "B" has a pipe-to-soil potential of -0.48 V. When the rectifier is switched "off" our potential becomes more positive (-1.04 V). Where Pipeline "B" has become more negative (-0.71 V).

The data indicates that our pipeline is cathodically protected. The foreign pipeline at this crossing is not protected because its potential is much less negative than -0.85 V with our rectifier "off”. When the rectifier was energized, the foreign line potential was drastically shifted in the positive direction, indicating that severe damage may be occurring on the foreign line. In this example corrective measures would be deemed necessary.

Due to the close proximity of the foreign pipeline to the anode bed, as shown, the interference can be expected to occur as a result of current picked up by the foreign pipeline where it passes through the gradient field surrounding the anode bed. Two tests should be conducted to verify the influence of the anode bed. First, if the potential of our line is the same or almost the same with respect to a remote electrode as it is to the electrode directly over the point of crossing, this would tend to indicate that no coating damage is present on our line. Second, if the potential of the foreign pipeline, measured with respect to a reference electrode placed directly above it, in areas near the anode bed, swings in the negative direction when the rectifier is switched "on”, current pick-up by the foreign line is indicated.

Where interference is found, it is necessary to determine if the actual crossing is the point of maximum exposure (explained later in this chapter). This is done by moving a reference electrode, in contact with the electrolyte, several feet at a time, first in one



FOREIGN LINE B	
ON	− 0.48 V
OFF	− 0.71 V
ΔV	+ 0.23 V

OUR LINE	
ON	− 1.85 V
OFF	− 1.04 V
ΔV	− 0.81 V

FOREIGN LINE CROSSING B

FIGURE 5-7

direction and then in the other, away from the point of crossing and directly above the foreign line. If an area exists where the positive swing is greater than at the actual crossing, the electrode should then be moved in smaller increments until the maximum point of exposure is located in this area. All information such as location, "on" and "off" potentials, and voltage changes (ΔV) at this point should be recorded.

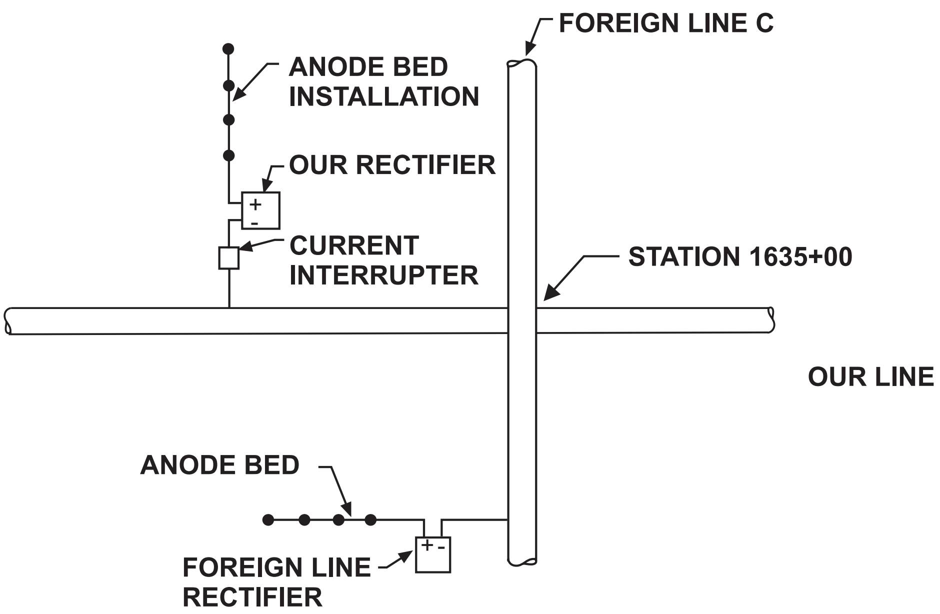
It would rarely be necessary to move the electrode more than 100 feet in either direction from the point of the actual pipeline crossing. The point of maximum exposure may be located in an area other than the point of the actual crossing if the soil resistivity varies considerably in the crossing area or it the coating (if any) on the foreign pipeline varies in quality.

Crossing C - Figure 5-8

This example shows, that with our rectifier "on" the pipe-to-soil potential for our line is -0.71 V. Pipeline "C" potential is -0.75 V. When our rectifier is switched "off" our potential becomes more positive (-0.65 V), where Pipeline "C" potential show no change (-0.75 V).

Based on the data, our line is not receiving adequate levels of cathodic protection in this area. This could be due to interference caused by the cathodic protection system for Pipeline "C". If the potential of our line is measured with respect to a reference electrode located remotely to both the foreign and our line and the potential is found to be representative of normal protective potentials, the less negative potential at the crossing is shown to be a local condition. The foreign pipeline crossing most likely causes this condition. Corrective measures must be taken in this case. Determine the length of the tested line that is less negative than -0.85 V, can be done by taking close pipe-to-soil potential readings directly above the line in both directions from the point of crossing. Measured data should be recorded and then plotted, potential versus distance. If the resulting graph is similar to the one shown in Figure 5-9, then interference from the cathodic protection system on the foreign line is confirmed.

Another test to confirm this interference is to interrupt the rectifier on the foreign line and take pipe-to-soil potentials on our line, with the reference electrode located directly over the crossing. If the potential of the pipe shifts in the positive direction when the rectifier is energized, then the interference is confirmed. The foreign pipeline in this case is not adversely affected.

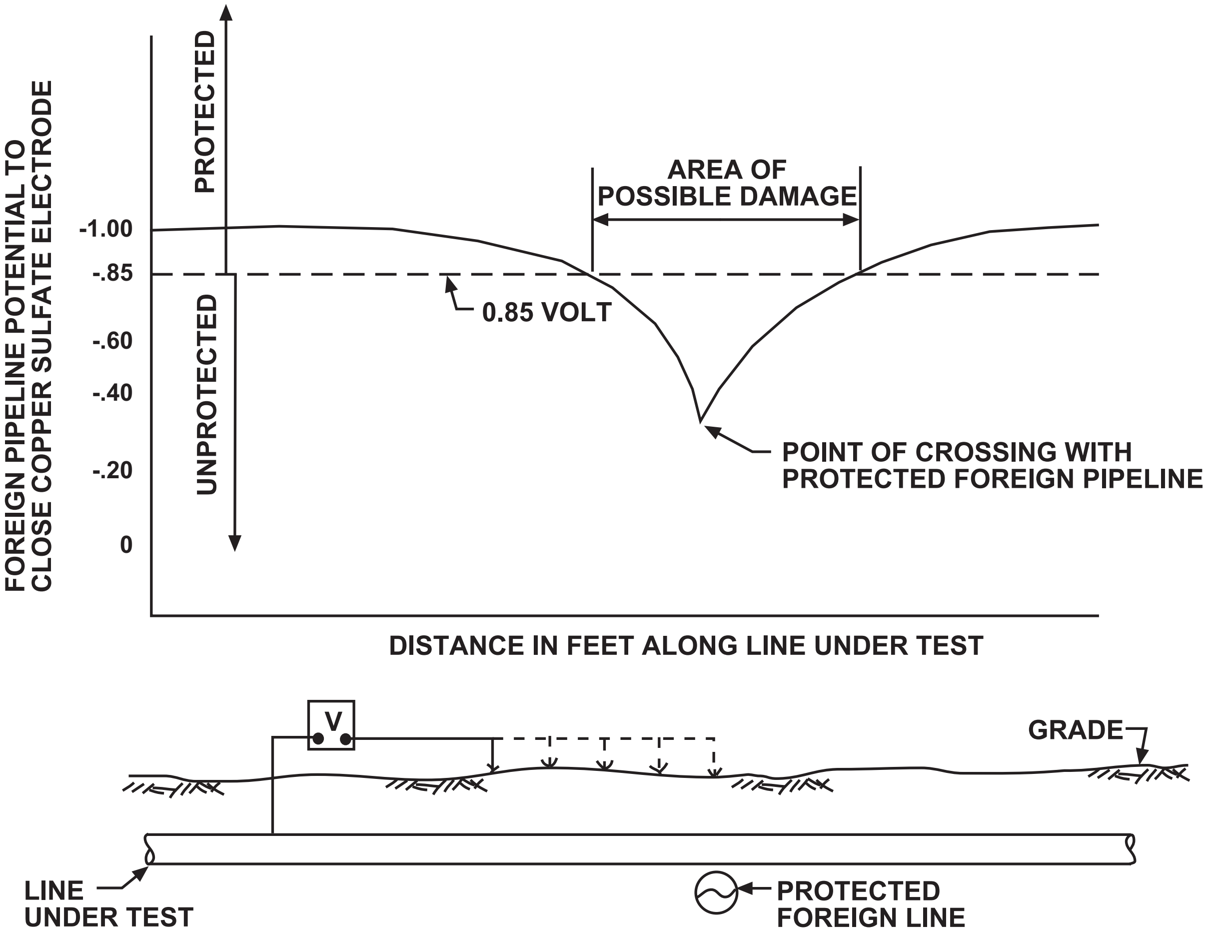


FOREIGN LINE C	
ON	– 0.75 V
OFF	– 0.75 V
∆V	0 V

OUR LINE	
ON	– 0.71 V
OFF	– 0.65 V
∆V	– 0.06 V

FOREIGN LINE CROSSING C

FIGURE 5-8



TYPICAL INTERFERENCE AT CROSSING WITH PROTECTED FOREIGN PIPELINE

FIGURE 5-9

Crossing D

This example is shown in Figure 5-10. This example shows, that with our rectifier "on" the pipe-to-soil potential for our line is -0.97 V. Pipeline "D" potential is -0.65 V. When our rectifier is switched "off" our potential becomes more positive (-0.93 V), where Pipeline "C" potential shows no change (-0.65 V).

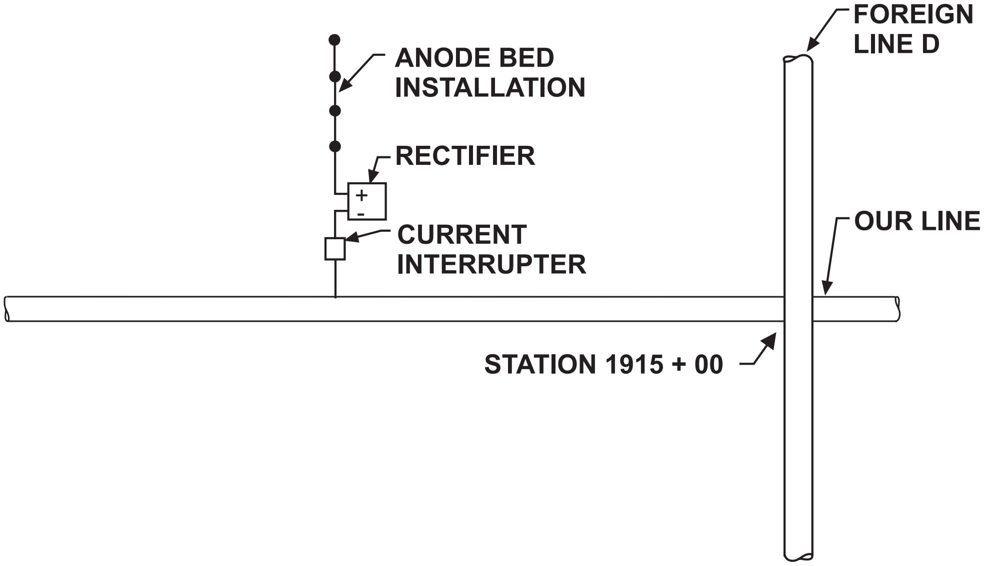
Based on the potentials our line appears to be adequately protected. The potentials measured on Pipeline "C" indicate that this line is not cathodically protected or the level of protection achieved is not satisfactory. The cathodic protection system protecting the line under test has no effect on the foreign line. Therefore, no mitigation is required.

Finding the Source of Static Interference

As discussed in Chapter 2 of the Basic Course, the presence of static stray currents is not readily apparent due to their steady state characteristics. In such cases, the presence of static stray current effects is picked up by detailed potential measurements on a structure, which reveal typically concentrated areas of anodic condition. Structure currents flowing in both directions toward an area of current discharge may also reveal them. As indicated, a detailed potential survey in the vicinity of the protected structure is normally required to locate the source of the interference. Potential measurements are normally taken with respect to a copper-copper sulfate reference electrode. If low negative or positive pipe-to-soil potentials are noted, this is a good indication that a foreign structure may exist nearby, whose protective current is affecting the surveyed structure. That foreign structure should be considered as the prime suspect for containing a current source which is creating interference problems and should be investigated.

The first step is to locate the structure and identify it. The next step is to search for a current generating device or another structure in the vicinity of the known structure, which may contain a current source. The following steps should be followed in the search:

1. Inquire of its Owners.
2. Follow the foreign pipeline geographically.
3. Examine its route maps.



FOREIGN LINE D		OUR LINE	
ON	– 0.65 V	ON	– 0.97 V
OFF	– 0.65 V	OFF	– 0.93 V
∆V	0 V	∆V	– 0.04 V

FOREIGN LINE CROSSING D

FIGURE 5-10

In the case where no foreign structure is evident in the vicinity of the low negative or positive pipe-to-soil potential measurements, it will be necessary to conduct an investigation through local utility companies, local citizens, or as previously mentioned through information available from Corrosion Coordinating Committees in the area. Corrosion Professionals can use other tests, such as earth current readings, to track the path of the current back to the source. The easiest way to trace the current is with the use of two identical reference electrodes and a high impedance voltmeter. By measuring the potential between the two electrodes spaced approximately 25 feet apart, the direction of current flow can be determined and its path traced.

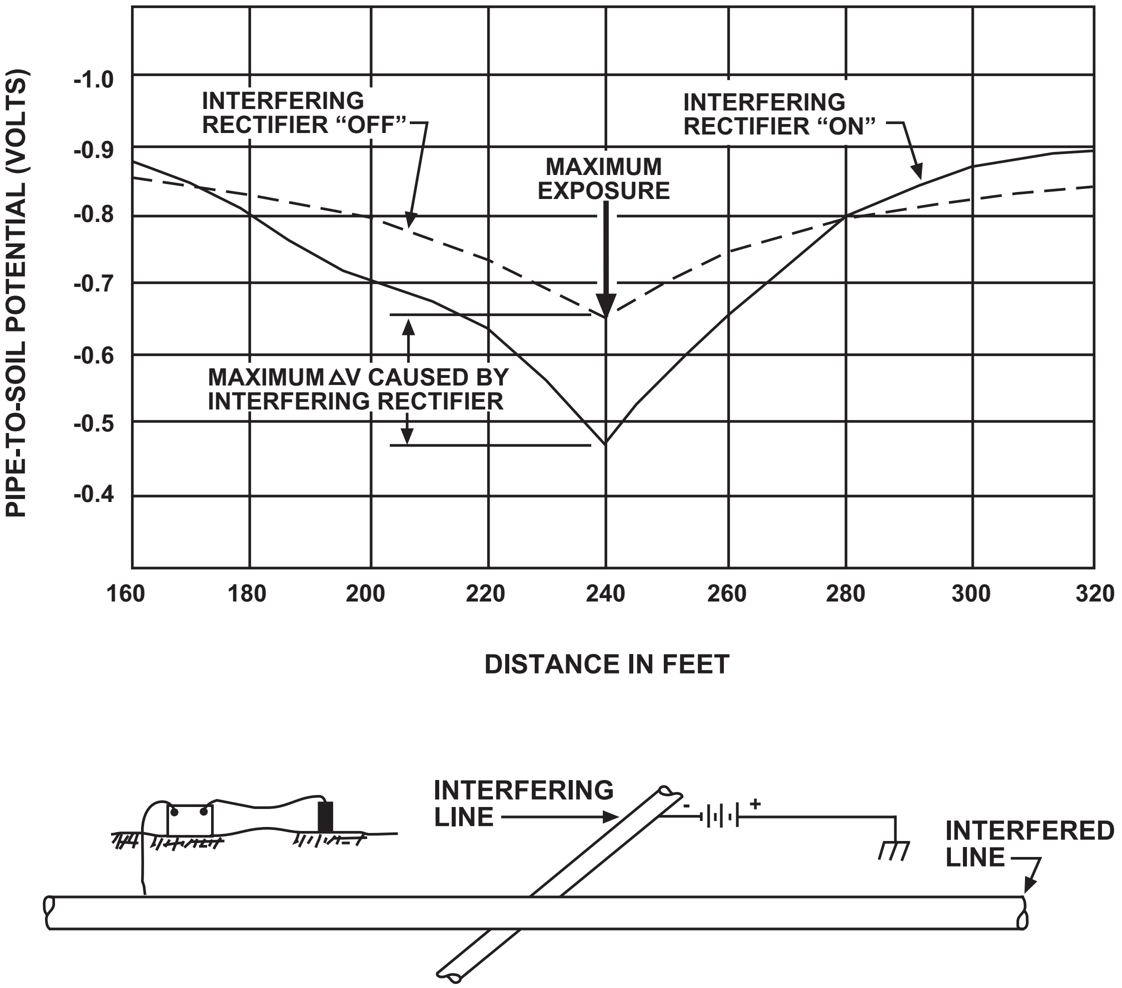
When the suspected source is found, testing as shown on previous examples must be performed to confirm that this is indeed the cause of the abnormal pipe-to-soil potentials. Because these tests require interrupting the current source, you must receive the Owner's permission, prior to conducting any testing. If the suspected source is not the cause of the abnormal potentials the search must go on until the actual current source is located.

Determining the Point of Maximum Exposure

The point of maximum exposure is defined as the geographical location at which the most adverse electrolytic effect exists. This point coincides with the location where the bulk of the stray currents are flowing from the metallic structure/pipeline into the electrolyte. It is important to understand that at this point electrolytic corrosion will occur on the affected structure unless the interference current is mitigated.

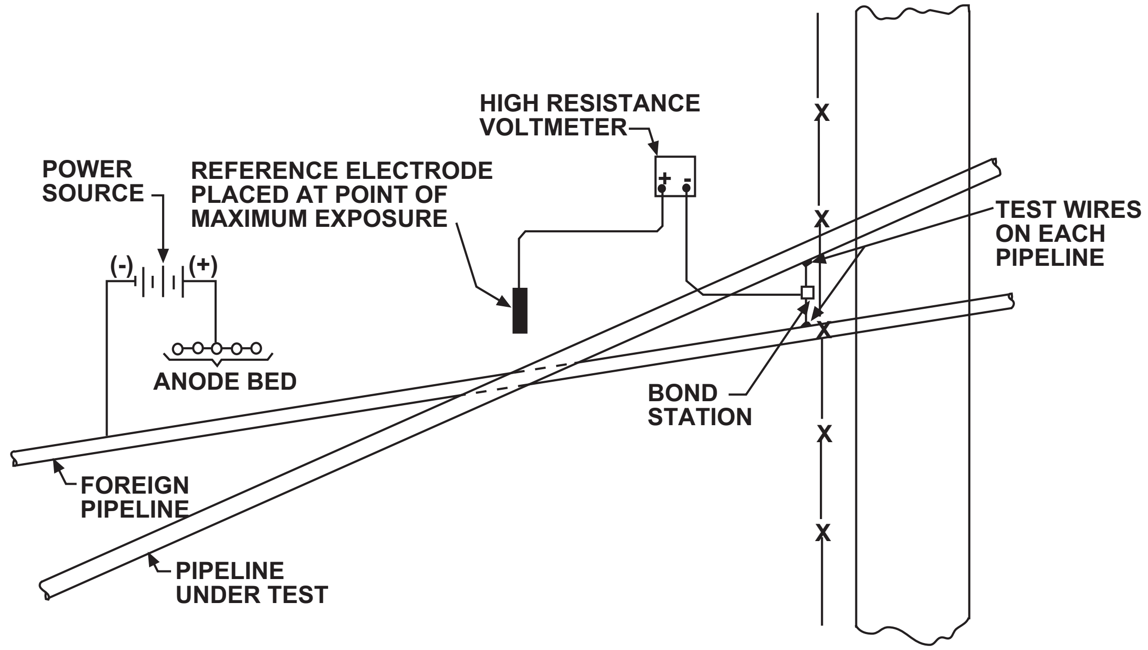
The point of maximum exposure can be located by measuring the pipe-to-soil potentials in the suspected drainage area while interrupting the interfering current source. The location where the maximum positive voltage change is measured when the current source is energized indicates the point of maximum exposure as shown in Figure 5-11.

The interference at the point of maximum exposure must be cleared. This may not always be the most convenient place to establish a current drainage bond to the interfering structure. If the drainage bond is installed elsewhere, the interference at the point of maximum exposure must still be cleared. Figure 5-12 shows a bond installed between the two pipelines at the fence. This bond, however, has to clear the interference at the point of maximum exposure, to mitigate the problem.



POTENTIAL PROFILE
INTERFERING SOURCE INTERRUPTED

FIGURE 5-11



MEASURING STRUCTURE TO SOIL POTENTIAL
AT POINT OF MAXIMUM EXPOSURE WITH
INTERFERENCE BOND AT ANOTHER LOCATION

FIGURE 5-12

MITIGATION OF STATIC INTERFERENCE

Mitigation by Bonds

After it has been established that an interference problem exists and the point of maximum exposure has been located, a bond can be installed between the two structures. A bond is a means of draining the stray currents

off the affected structure by a non-electrolytic condition. This is due to the fact that electrolytic corrosion occurs at the point of maximum exposure or where current enters the soil (electrolyte). To mitigate the electrolytic corrosion process, a low resistance current discharge path must be provided between the two structures. A metallic conductor can be used to provide this path if the polarity is correct and the potential difference between the two pipes is large enough to draw sufficient current through the conductor.

At the point of connection or bond, the potential of the interfering structure must be more negative than the structure effected. If this is not the case, current will not flow in the proper direction. If the current flows in the wrong direction, from the interfering structure to the effected structure, the results would be increased interference. This condition of reversed current flow is known as negative resistance.

An ideal point to connect the bond would be the negative terminal of the DC source of interference. In the case where the DC source is a cathodic protection rectifier, the effected pipe/structure could be bonded to the structure through the negative side of the rectifier. The interfering structure is actually an extension of the rectifier's negative terminal.

Bond or drain conductors are normally installed between structures at the point of crossing. This keeps bond conductor lengths short, thus keeping the resistance low and maximizing current flow. Bond conductor size is a resistance factor and therefore, must be taken into account. Cable sizes for bonds typically range from AWG No. 6 to AWG No. 10 but in some rare cases these sizes may not be large enough. It is also important to install the proper "shunt" size or rating. If the current to be drained is 1 A, the shunt must be rated for 1 A or slightly larger. If the shunt is rated lower than the 1 A the bond connection could be lost.

Note: The Owner or operator of the pipeline/structure causing the interference must be in agreement with the remedial measures prior to installation or connection to their pipeline/structure. You must obtain their permission prior to making any connections.

It is also recommended to receive permission from all effected parties prior to removal of any established bond or remedial measures.

The bonding method is used extensively and when installed correctly, provides some benefit to the effected pipeline/structure, but at the same time always results in some loss of protection on the interfering structure. Various factors such as the distance between the anode bed and the affected or foreign structure, the rectifier current output, and the coating resistance of both structures are some of the items which determine the degree of benefit and detriment.

The following is an example of mutual effects which could occur when bonding interfering pipelines/structures. It is only a guideline; each location must be tested properly and evaluated on an individual basis (see Figure 5-13).

1. A coated cathodically protected line bonded to a bare unprotected line has a detrimental effect on the coated line and a negligible effect on the bare line.

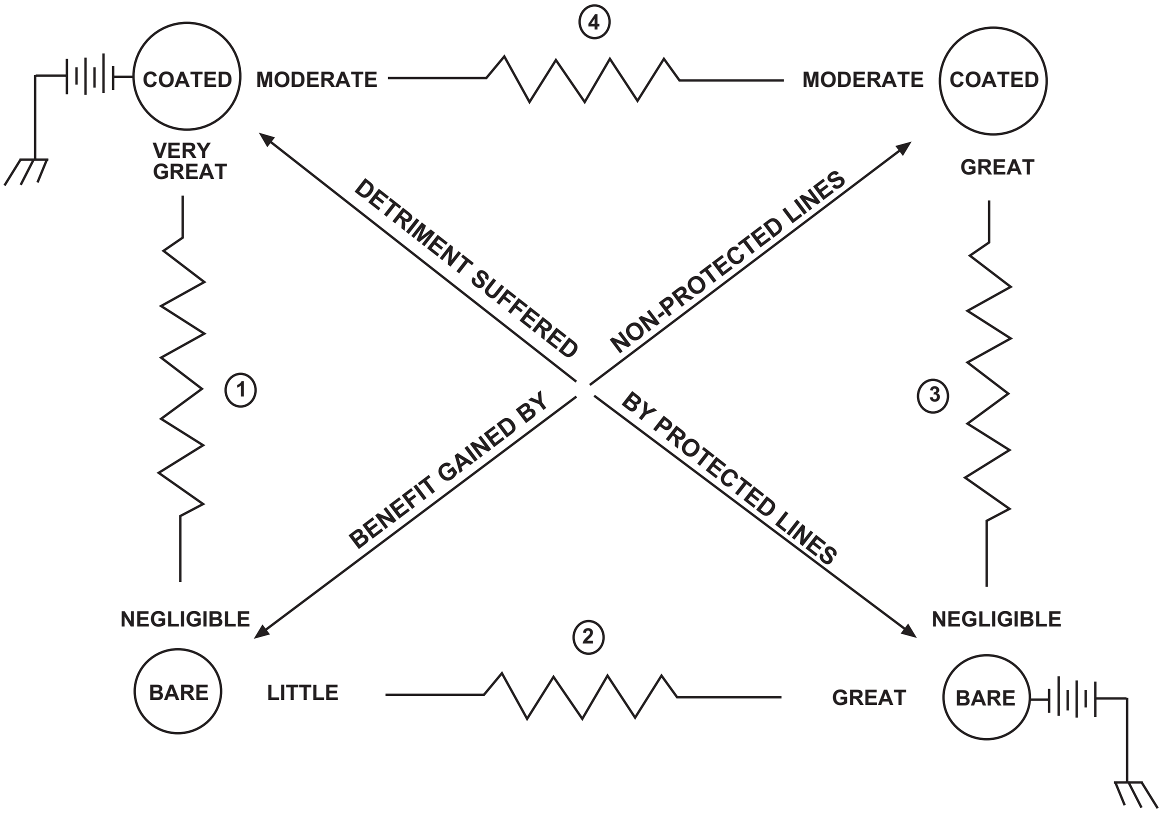
2. A bare cathodically protected line bonded to a bare unprotected line has a detrimental effect on the bare line and little effect on the unprotected line.

3. A bare cathodically protected line bonded to a coated unprotected line has a negligible effect on the bare line but has a great effect on the coated line.

4. A well-coated cathodically protected line bonded to a well-coated unprotected line has moderate effect on both lines.

Mitigation by Addition of Cathodic Protection

A cathodic protection system utilizing galvanic anodes or an impressed current system may be regarded as a device which "draws" current off the protected structure through a metallic path and "pumps" some of that current back to the structure through an electrolytic or solution path giving it protection. The galvanic anode(s) or the drain rectifier, whichever is used, provides the driving potential for the drained current. A galvanic anode or impressed current system of sufficient strength will cause the flow of current back to the interfered structure in a greater magnitude than was draining off, causing a protective current flow. All drain current then uses the metallic lead, which connects to either the galvanic anode or the negative terminal of the drain rectifier. If the pipe-to-soil potential of the draining pipeline/structure is maintained at a potential more negative than -0.85 both at the point of maximum exposure, there will no longer



BONDING EFFECTS EXPECTED WITH DIFFERENT PIPE COMBINATIONS

FIGURE 5-13

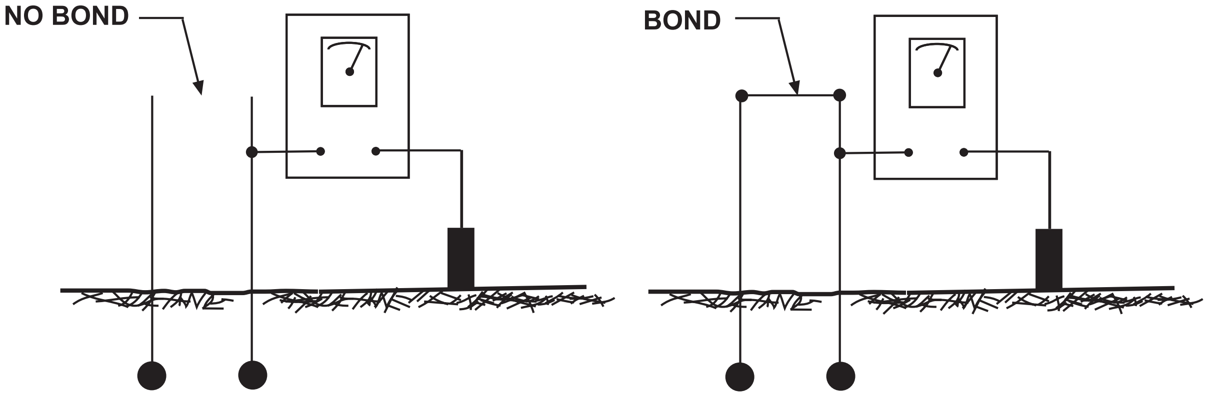
be a detrimental flow of current. The most attractive aspect of using a galvanic or rectifier anode bed drain as opposed to a bond, is that there is no detrimental effect placed upon the interfering protection system Rarely is a rectifier and anode bed installed for the sole purpose of mitigating stray currents. However in areas where pipelines/structures of several companies are adequately protected and tests show that at crossings no structure is less negative than -0.85 volt, then anode beds are effectively acting as mitigation
drains.

Galvanic anode drains are commonly used in lieu of bonds where small amounts of drain currents flow. In areas of large current drains, the use of galvanic anode drains would be impractical due to the high consumption rate of the anode, which would result in frequent anode replacement. The amount of drain current can be determined experimentally by installing temporary galvanic drainage to clear the interference and measuring the current through the drain wire to the anode(s) using an ammeter. The measured current can be correlated with consumption rates of the anode material to determine the theoretical life of the galvanic anode. The consumption rate can be obtained from the manufacturer of the anode. One test anode can be used to obtain data required to extrapolate the requirements for adequate interference clearance.

Natural Potential Criterion

The natural potential criterion is often used to determine if the clearance of interference currents through remedial measures such as bonds, galvanic or impressed current anode bed drains, has been achieved. The basis of this criterion is that the effected structure has its pipe-to-soil potential restored to its original or natural potential which existed at the point of maximum exposure before the interfering current shifted it in the positive direction. The installation of a galvanic anode usually increases the pipe-to-soil voltage of the structure to a more negative level than the natural potential. If requested or required a variable resistor in the galvanic anode drain lead could be used to limit the drain current to a level where the natural potential is restored. This will also lower the consumption rate and increase the life of the galvanic anode.

The natural potential is the most commonly used criterion in the setting of interference mitigation measures, because in most instances it is the simplest and most economical approach. It is also considered, by most, to be an equitable solution to the interference problem as the foreign line is returned to its original potential. Figure 5-14 shows a simple example of the natural potential criterion.



INTERFERING RECTIFIER OFF

INTERFERING RECTIFIER ON -
METER READING IS IDENTICAL
TO THAT AT LEFT

NATURAL POTENTIAL MITIGATION “IN A NUTSHELL”

FIGURE 5-14

The following are step-by-step procedures which should be used to set a resistance bond based on the natural potential criterion.

Step 1: Observe and record the natural potential of the interfered structure before energizing the rectifier and before making any connections between the two structures.

Step 2: Connect a current interrupter in series with the positive output terminal of the rectifier. Set interrupter at a convenient cycle, such as 10 seconds "on" and 5 seconds "off".

Step 3: Place portable copper-copper sulfate reference electrode in contact with the electrolyte at the point of maximum exposure and observe and record the shift in pipe-to-soil potentials.

Step 4: Install a variable resistor between the effected and interfering structures. With the rectifier "on", vary the resistance value until the pipe-to-soil potential on the effected structure reaches the same value as the natural potential recorded during Step 1.

Step 5: Measure the final resistance of the test bond between the two structures and record it.

Step 6: Reinstall resistance of a proper type for permanent installation or fabricate a wire resistor with the same resistance. Make sure the size of the wire used is adequate for the maximum current drain.

Step 7: Retest if deemed necessary.

Mitigation of the interference current is complete when the final bond is installed and the pipe-to-soil potential of the interfered structure has been restored to its original or natural potential.

TYPICAL EXAMPLES OF STATIC INTERFERENCE

As stated before, every interference problem is a special case because there are too many variables involved and therefore, it is doubtful that there will be two exactly the same. Interference cases however, can be put into groups or classifications. If the Corrosion Professional can learn to recognize into which classification(s) an interference problem falls, he can use the basic concepts shown in the following examples to mitigate the interference.

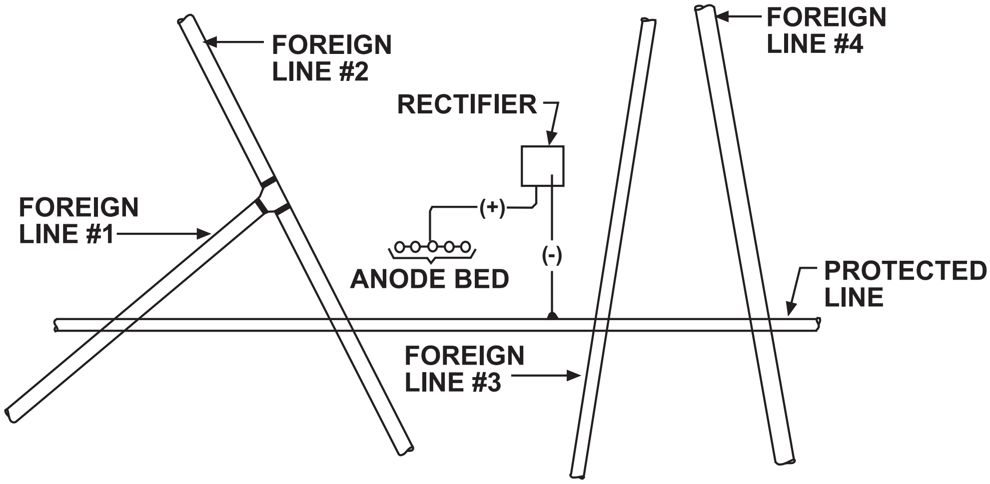
Case #1

This is a situation where a protected pipeline is crossed by several unprotected foreign lines (see Figure 5-15). It is always good practice to begin testing at the crossing closest to the impressed current anode bed and then work progressively away from the anode bed along the interfering structure. After all bonds have been made to the structures, which are adversely affected, each bond should be reexamined and, if necessary, readjusted as required. It is usually found that subsequent bonding will normally reduce all preceding bond currents. Adjustment of any given bond may necessitate the adjustment or readjustment of other bonds so that all bonds should be examined and reexamined in a "round robin" fashion until no appreciable readjustment is necessary.

Figure 5-15 shows four foreign lines crossing the protected line, which is protected by an impressed current system using one rectifier. The four lines cross the protected line in the area of influence of its anode bed. Foreign Line #1 and #2 appear to be connected to each other and should be electrically continuous. Since only one current source is involved, the "natural potential" criterion testing procedure should be used at each crossing. As stated above, start with Foreign Line #2 because it is closest to the anode bed. The natural pipe-to-soil potential of Foreign Line #2 should be measured and recorded. A bond should not be installed however, until the natural potential of Foreign Line #1 is measured and recorded because it appears to be electrically continuous with Foreign Line #2. When the natural potentials are measured on both lines, a bond should be installed between the interfering line and Foreign Line #2. The resistance should be adjusted to clear the interference from Foreign Line #2. Conduct tests at Foreign Line #1 crossing to determine if the bond installed on Foreign Line #2 has cleared Foreign Line #1 or whether a tolerable increase of Foreign Line #2 bond current will clear Foreign Line #1.

If adjusting the bond at Foreign Line #2 cannot attain Foreign Line #1 clearance, it will then be necessary to treat Foreign Line #1 as a separate structure and clear the interference with a separate bond to the interfering line.

Next, using the same criterion, clear Foreign Line #3 and Foreign Line #4. At this point all necessary bonds will have been established, but they must be retested to determine if the bond current at any pipeline crossing is now excessive. This would be due to the weakened influence of the impressed current anode bed at all crossings. Retesting at



ONE PROTECTED PIPELINE CROSSED
BY SEVERAL NON-PROTECTED LINES

FIGURE 5-15

crossings and readjustments of bond resistances (if necessary), should be conducted in the same order as the original tests. If substantial adjustments are made during the second round of tests, a third round of testing should be conducted.

Case #2

In this case we have a cathodically protected line, with two or more impressed current anode bed systems, crossing an unprotected foreign line (see Figure 5-16).

When more than one interference source such as many closely spaced rectifiers on a given pipeline/structure are causing interference on a foreign line, the sum of the interference from all
the current sources must be cleared at the point of maximum exposure.

The natural potential of the foreign line can be measured by de-energizing both/all rectifiers or current sources on the protected line. Rectifiers may then be re-energized and a current drain bond installed from the foreign line to the protected line, restoring the foreign line to its natural potential.

In a situation where there are many rectifiers protecting one pipeline and influencing a foreign pipeline, testing may be simplified by interrupting rectifiers separately. As each rectifier is de-energized, the effect at the crossing should be measured and recorded. All recorded changes should then be added and the sum effect cleared by a bond at the crossing.

Let's consider the following example:

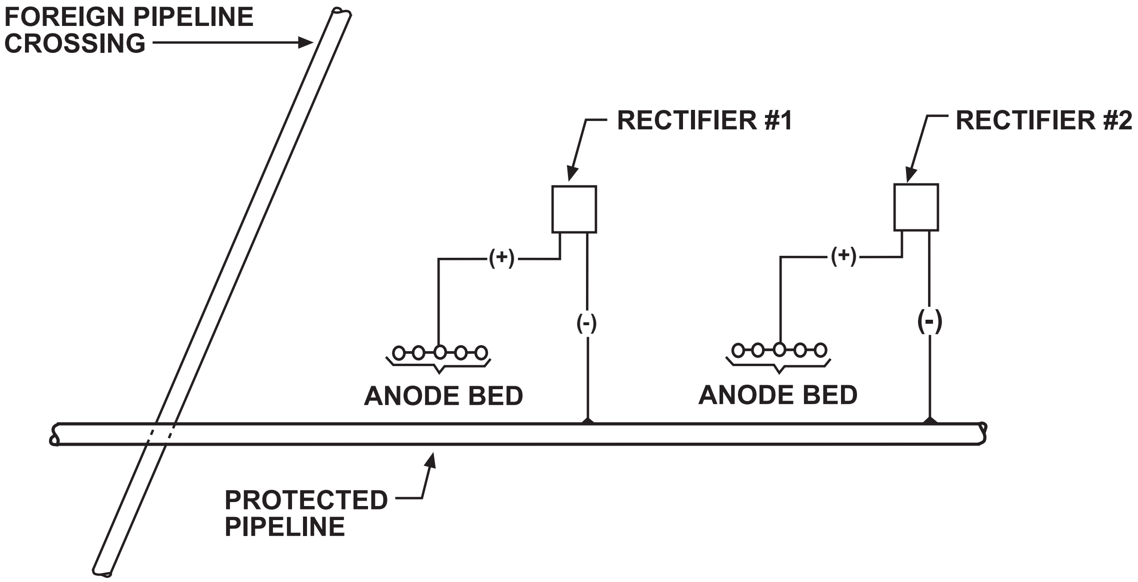
1. Assume that the measured foreign pipe-to soil potential at the point of crossing with both rectifiers energized is -0.30 V.

2. When Rectifier #1 is de-energized the foreign pipe-to-soil potential shifts from -0.30 V to -0.60 V, a voltage change of +0.30 V.

3. When Rectifier #2 alone is de-energized the foreign pipe-to-soil potential shifts from -0.30 V to -0.40 V, a voltage change of +0.10 V.

4. Add both voltage changes, 0.30 + 0.10 = 0.40 V.

5. Install a resistance bond between the two pipelines so that with both rectifiers



TWO OR MORE RECTIFIERS ON ONE PIPELINE
AND NONE ON THE OTHER LINE

FIGURE 5-16

operating the 0.40 V positive shift on the foreign line is cancelled. This condition will be reached when the foreign pipe-to-soil potential reads -0.70 V (which is the natural potential) with both rectifiers operating.

The Corrosion Professional can simplify this procedure by utilizing synchronized current interrupters. This allows us to interrupt several rectifiers simultaneously. Mitigation of interference caused by several sources can be done at the same time.

Case #3

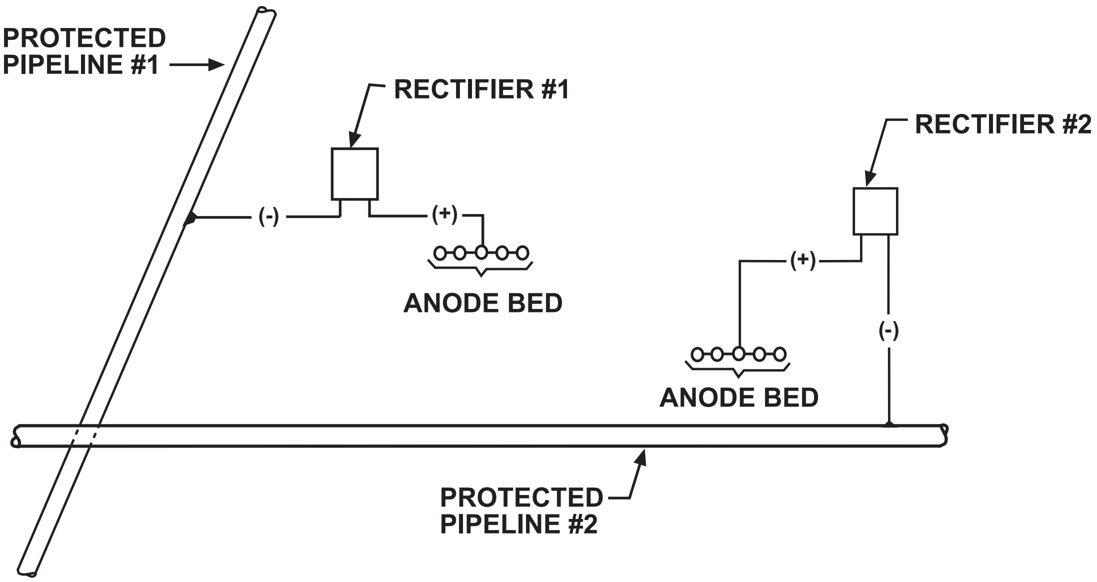
In this situation we have two pipelines which are both protected by their individual impressed current anode bed systems. A mutual interference exists between the lines but effects are tolerable to both structures.

If all underground structures are adequately protected there will be no need for mitigation. Cases such as this frequently exist where balanced conditions are present and both pipeline Owners are satisfied that the interference from the other is tolerable.

Figure 5-17 shows a somewhat balanced situation where near-equal mutual influence between structures exists. With Rectifier #2 energized and Rectifier #1 interrupted an interference survey is conducted on Pipeline #2. When Rectifier #1 cycles "on", the potential readings on Pipeline #2 at points away from the crossing shift in the negative direction. At the point of crossing, potentials are shifted in the positive direction. Based on this test we can see that current from Rectifier #1 is being picked up by Pipeline #2 from the soil at points remote from the crossing, while current is being discharged to the soil at the point of the crossing.

Now determine the effects of Rectifier #2 in this area, while assuming that it is providing adequate levels of cathodic protection on Pipeline #2. Because it is maintaining adequate levels of protection, a substantial amount of current is flowing from the soil to the pipe throughout the area influenced by Rectifier #1. As a result, Rectifier #1 current output is additive with that of Rectifier #2 at pick-up areas remote from the crossing, while cancelling out a portion of Rectifier #2 current pick-up at the point of crossing.

Provided that the cancellation of Rectifier #2 current is not excessive to the point where pipe-to-soil potentials become more positive than -0.85 V at the point of maximum exposure, there is no cause for alarm. It should be noted that although interference still exists, its detrimental effect is cancelled by the interfered structures own cathodic



MUTUAL INTERFERENCE INVOLVING TWO PIPELINES
THE EFFECTS OF WHICH ARE TOLERABLE
TO THE OPPOSITE STRUCTURE

FIGURE 5-17

protection current thereby rendering the interference harmless.

Referring back to Figure 5-17, imagine that an impressed current system was installed on the interfered pipeline in the vicinity of the crossing. Operated at a typical output, the anode bed system could shift the entire curve more negative, which would raise the graph to a condition where the lowest point on the curve was more negative than -0.85 V. That being the case, the foreign line's interference would be rendered harmless.

Note: The interference is not eliminated but merely rendered harmless or considered tolerable. That is why the term "mitigation" is often used when dealing with stray current interference. It is defined as the act of rendering or making interference milder or harmless.

In cases such as this example, Corrosion Professionals representing each Owner's pipeline/structure should desire adequate levels of cathodic protection at crossings and should endeavor to attain them by:

1. Cooperatively adjusting both rectifier outputs.

2. The installation of additional cathodic protection devices installed as required at crossings. Galvanic anodes can be strategically located at the crossings.

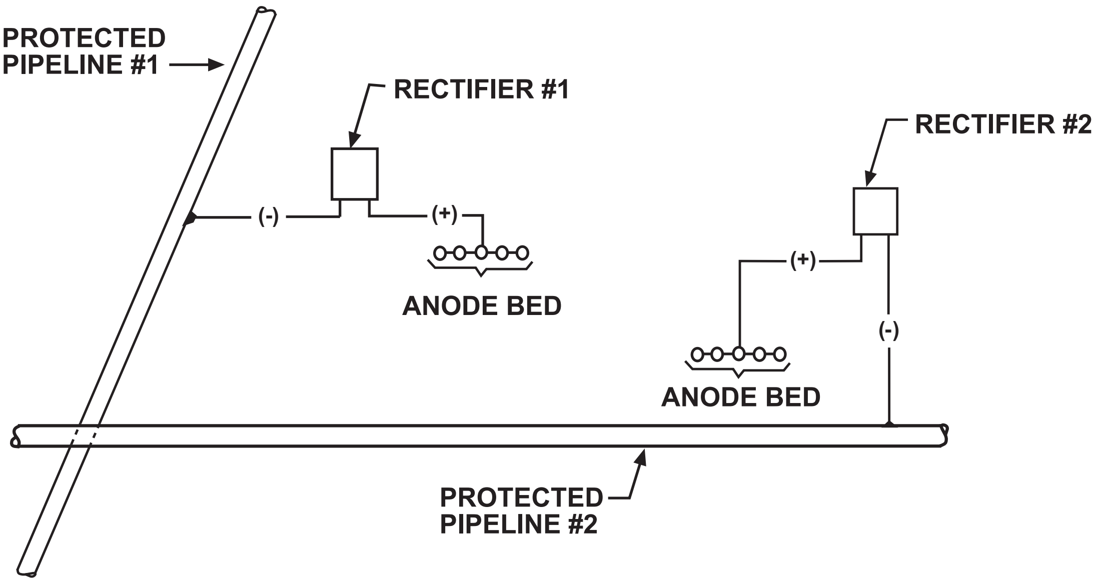
3. The least preferable approach in this case would be installing a mitigation bond between the two structures.

The installation of a bond is normally required only if one party is exerting an overwhelming influence upon the other structure, as is the case in the next example.

Case #4

Figure 5-18 illustrates an example where two structures, which are protected by individual impressed current cathodic protection systems, are experiencing mutual interference but one structure is exerting an overwhelming influence.
As shown, Pipeline #1 crosses Pipeline #2 and each line has an anode bed which is influencing the other line, but due to its close proximity, the anode bed of Rectifier #1 has an overwhelming effect on Pipeline #2, as can be seen by the following measurements.

1. With Rectifier #2 "on" and Rectifier #1 interrupted, Pipeline #2 potential at the



MUTUAL INTERFERENCE INVOLVING TWO PIPELINES WHERE ONE IS EXERTING OVERWHELMING INFLUENCE ON THE OTHER

FIGURE 5-18

crossing shifts from -0.50 V (on) to -0.80 V (off); voltage change equals +0.30 V.

2. With Rectifier #1 "on" and Rectifier #2 interrupted, Pipeline #1 potential at crossing shifts from -1.10 V (on) to -1.20 V (off), voltage change equals +0.10 V.

The above data indicates that Rectifier #1 is the most influential of the two units and is shifting the potential of Pipeline #2 in the positive direction by 0.30 V. Rectifier #2 does not provide adequate levels of protection at the crossing, so the Owner of Pipeline #2 is justifiably concerned by the positive shift. If the Owner of Pipeline #2 requested the installation of a drain bond to change his pipe potential from -0.50 V to -0.80 V, it would be an unfair demand due to the fact that his rectifier system current has caused the -0.80 V potential, while causing a small, but positive potential shift on Pipeline #1 of 0.10 V.

A fair solution in this case may be to subtract the smaller voltage change (0.10 V) from the larger one (0.30 V). This way, the bond should be set so that the current flow between the structures will raise the potential of Pipeline #2 by the voltage difference (0.20 V). The installation of the bond will stabilize Pipeline #2 at -0.70 V with some resultant decrease in Pipeline #1 pipe-to-soil potential.

In a case such as this, Pipeline #1 will often have sufficient current available to allow excess bond current to flow so that Pipeline #2 may obtain adequate current to raise its voltage above the desired cathodic protection criterion. This help may be afforded to Pipeline #2 in lieu of Pipeline #2 installing an additional cathodic protection device nearby which would complicate matters.

Or, if the Owner of Pipeline #2 decides to install an additional impressed current system anode bed nearby, the Owner of Pipeline #1 might offer temporary help in the form of excessive bond current.

Case #5

It should be mentioned that the most extreme unbalanced condition encountered would be if Pipeline #2 passes through the anode bed of Pipeline #1. Pipeline #2 would pick up current near the anodes. The interference current must somehow return to Pipeline #1. If the current on Pipe #2 flows away from the crossing, it will discharge at a remote location. This situation is described as "end-wise interference", a term often used by Corrosion Engineering personnel. The following measurements are an example of end-wise interference:

1. As is shown in Figure 5-19, with Rectifier #1 interrupted, the current flow on Pipeline #2 shifts from +3.52 A (on) to +0.44 A (off), a current change of +3.08 A. With the polarity shown, the 3.08 A of current is flowing away from the crossing and the anode bed for Rectifier #1. In order to mitigate this interference, a bond must be installed so that the current flow is reversed (or made equal to 0) when Rectifier #1 is interrupted. Mitigation of this condition is shown in Figure 5-20.

2. After the bond has been installed and adjusted so that the end-wise current flow has been mitigated, Pipeline #2 should be tested at the crossing with Pipeline #1 to determine if an interference condition exists at that location. If interference still exists at the crossing with the bond in place, the bond resistance must be lowered to increase the bond current drain so that the pipe-to-soil voltage on Pipeline #2 is restored to its natural potential or -0.85 V.

Summary of Examples

Corrosion Control personnel usually get alarmed when they see any positive pipe-to-soil potential shifts as a result of interrupted foreign current sources affecting their plant. The reason for their alarm is usually due to their limited knowledge of the subject and inability to adopt generally accepted test procedures that were set up for the "ideal interference problem".

The following important conclusions should be derived from the above examples:

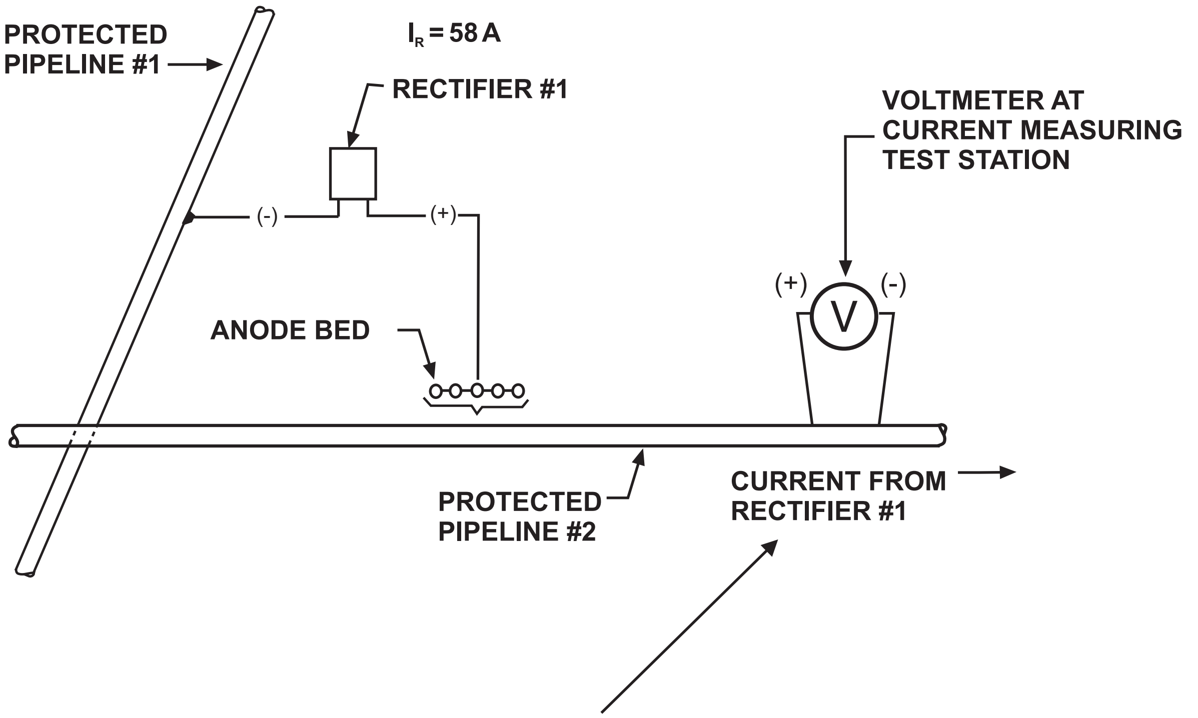
1. A positive potential shift at the point of maximum exposure is not always harmful and may well be tolerable. If the pipeline is cathodically protected at the point of maximum exposure, there is no need to install mitigation.

2. In a small percentage of situations, the point of maximum exposure is not at the crossing but at a remote site, know as current draining "end-wise" from the crossing.

Things to Watch Out For

The following are some items which the Corrosion Professional needs to take into account when testing for and implementing mitigative measures.

1. Extreme care must be taken when installing resistance bonds to drain current from lines which are not electrically continuous. Pipelines using compression couplings or bell and spigot joints are normally not electrically continuous. Segmented lines such

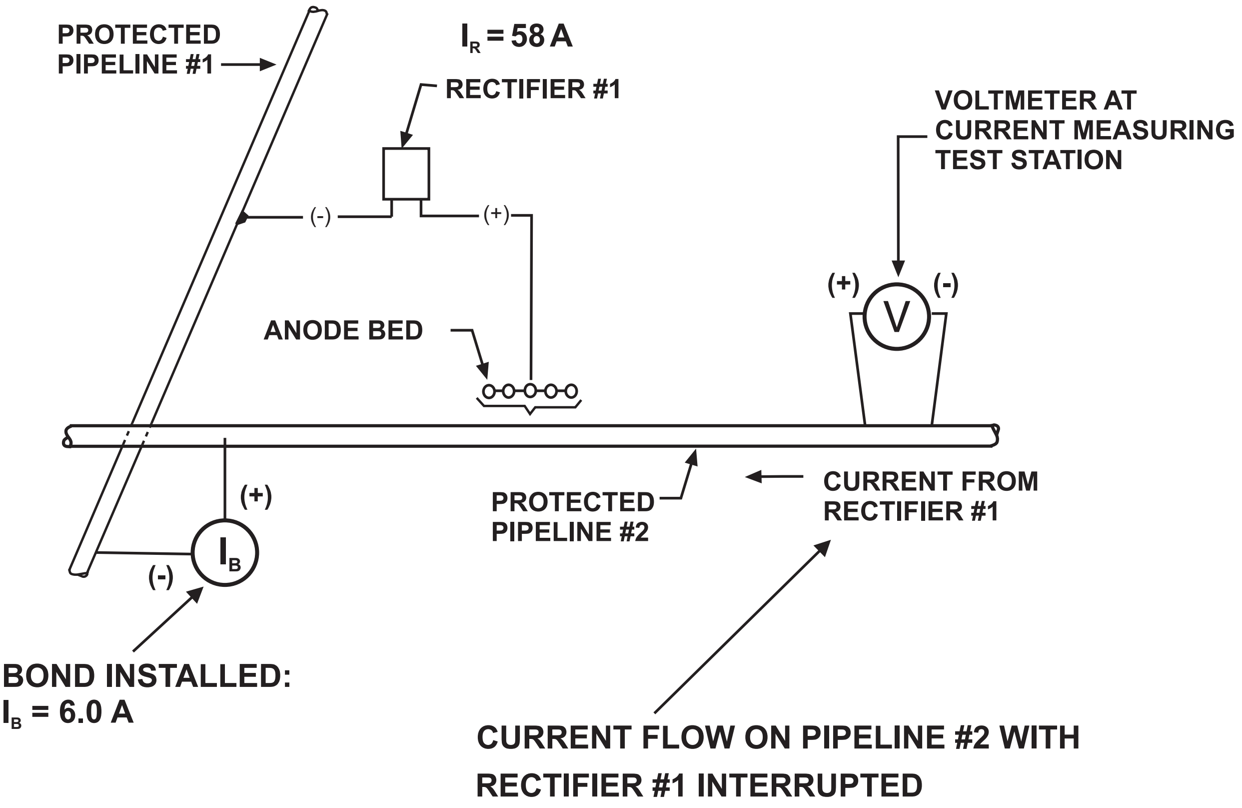


CURRENT FLOW ON PIPELINE #2 WITH RECTIFIER #1 INTERRUPTED

ON	+ 3.52 A
OFF	+ 0.44 A
ΔI	+ 3.08 A

END-WISE INTERFERENCE

FIGURE 5-19



ON	+ 0.24 A
OFF	+ 0.44 A
ΔI	− 0.20 A

END-WISE INTERFERENCE MITIGATED

FIGURE 5-20

as these could be prone to increased corrosion. The joint or pipe section which is bonded would not be adversely affected, but the adjacent sections would be because they would tend to discharge to the bonded section. The installation of galvanic anodes on the draining ends of the joints at the exposure area would normally provide sufficient current output to mitigate interference. An alternative approach would be to install jumper cables across joints to make the line electrically continuous.

2. The mitigation of interference through the use of a bond is not possible if the pipe-to-soil potentials of the interfered line are more negative than the potentials of the protected line. As previously stated this is known as negative resistance condition whereby the current will drain or flow opposite to the desired direction.

Chapter 6 - Corrosion Control for Pipelines

INTRODUCTION

Corrosion control measures are taken into account during the initial design of a pipeline system and should be taken into account during the construction/installation of the piping system. This chapter will discuss design and installation practices which should be implemented to assure that the piping system meets its designed service life.

PREFACE

Mr. A.W. Peabody stated in the NACE Publication "Control of Pipeline Corrosion" the following:

First attempts to control pipeline corrosion relied on the use of coating materials with the reasoning that if the pipeline metal could be isolated from contact with the surrounding earth, no corrosion could occur. This concept is entirely reasonable and logical. Furthermore, a coating will be completely effective as a means of stopping corrosion if:

1. The coating material is an effective electrical insulator,

2. It is applied with no breaks (holidays) whatsoever and will remain so during the backfilling process, and

3. It constitutes an initially perfect film, which will remain so with time.

In the past, this was asking more than can be expected from presently available coatings which were in a price range making them economical for pipeline use. Today, the cost of high performance coatings has come down and they are economically viable. Although coatings, by themselves, may not be the one perfect answer to corrosion control, they are an extremely effective weapon when properly used. A properly selected and applied coating will provide all the protection necessary on most of the pipeline surface to which it is applied. On a typical well-coated pipeline this should be better than 99 percent.

The engineer who is well informed on pipeline coating and then advises his company on the best technical and economical coating to use will find that this probably is the most important single area where his talents can benefit his company. Other facets of pipeline corrosion engineering are important also but a mistake in the selection of a coating material can mean many lost dollars during the useful life of the pipeline. On the other hand, the right coating material properly used will make all other aspects of corrosion control relatively easy.

Good practice in modern pipeline corrosion control work comprises the use of good coatings in combination with cathodic protection as the main lines of defense. Supplementary tactics, such as the use of electrical isolation, local environmental control, etc. may be used to reinforce these basic control methods.

In selecting a coating system for a given pipeline project, the most important characteristic to design for is stability. By this we mean a coating combination, which will:

1. Have a high electrical resistance after the pipeline has been installed and the backfill stabilized and will;

2. Have the least reduction in electrical resistance with time.

The four fundamental elements of a successful coating system involve:

1. Material Selection
2. Specification
3. Application
4. Inspection

The desirable characteristics of a coating system, along with the selection, specification, application, inspection procedures, and field test methods will be discussed. Internal and atmospheric coatings, while important, will not be covered in much detail.

COATINGS

The first line of defense against corrosion is the use of coatings.

History of the Use of Coating Systems

Pipelines were laid bare (uncoated) in the early 20th century and as a result, deterioration of the uncoated system was rapid. This sparked the research for practical corrosion control methods, which resulted in the development of coating systems.

By the late 1920's, forerunners of today's hot enamel coatings were well established, and by the 1940's, technological advances had resulted in vast improvements on these enamel type coating materials. The implementation of cathodic protection systems for the mitigation of corrosion on underground piping systems was also introduced. Testing and experience soon indicated that corrosion mitigation could be done more effectively and economically by using a combination of coatings and cathodic protection.

The selection, application and performance of available coating materials should be considered for each specific corrosion control situation.

General

The best method of protecting a structure, whether it is made of steel, concrete, wood or other construction material, is by the use of protective paints and coatings.

Paints and protective coatings provide protection in one of three ways:

1. Providing a barrier between the substrate and the environment.

2. By inhibitive action changing the environment to a less aggressive one.

3. Providing cathodic protection by sacrificing themselves to protect the more noble structure.

Coatings are used in four areas in pipeline work:

1. Atmospheric Coatings

2. Transition Area Coatings – Air/Soil Interface

3. Linings and Internal Coatings

4. Underground Coatings

Atmospheric Coatings are used to protect surfaces exposed to the atmosphere. Various types of coatings are specified depending on service requirements – industrial, marine, urban, high temperature, etc.

Transition Area Coatings are coatings used to transition an underground coating to above ground service. These coatings normally cover up the underground coating to protect it from ultraviolet light, abrasion, ground movement, etc. and transition from 6 inches above ground to 12 inches below ground.

Linings and Internal Coatings can be broken down into linings used for internal corrosion control and product quality inside tanks and vessels and internal pipeline coatings used for corrosion control or improved flow in pipelines.

Underground Coatings are used to provide a barrier coating between the pipeline and the electrolyte. Without the application of a protective coating (or cathodic protection) to the metallic surfaces, the surfaces will corrode if they are in contact with a conductive electrolyte such as soil or water. Corrosion will occur due to the formation of galvanic cells on the surface of the metal, which will have anodic and cathodic areas, as shown in Figure 6-1.

If the metallic surfaces are coated with an isolating type coating, it will not be in contact with the electrolyte and thus no corrosion will take place as shown in Figure 6-2.

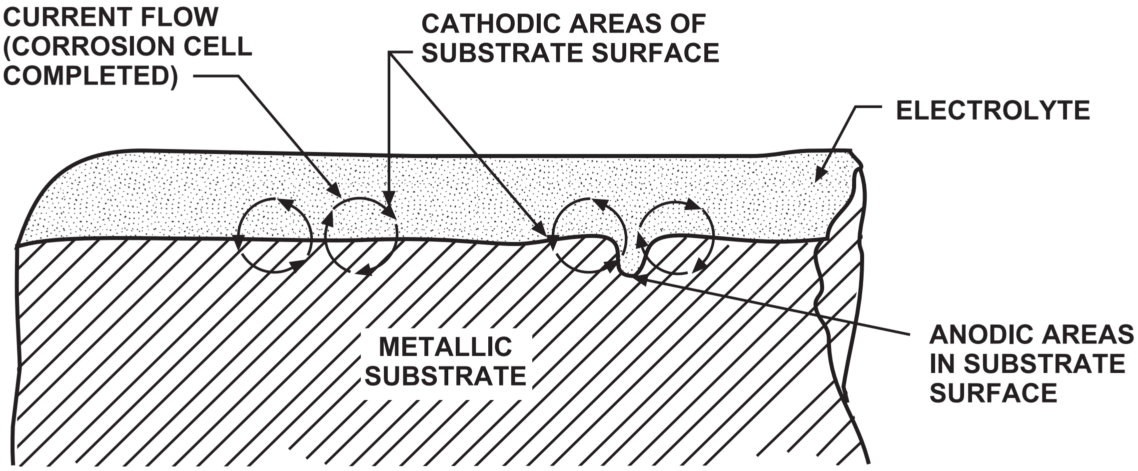
If a conductive type coating is used that contains a metallic pigmentation anodic to the substrate, it will provide cathodic protection to the substrate where the coating pigmentation is damaged all the way to the metallic surface, thus preventing corrosion of the substrate, as shown in Figure 6-3.

To obtain the best of both systems, a conductive inhibitive primer can be used which is in turn top coated with an isolation type coating, as is shown in Figure 6-4.

In general, each generic class of coating, such as epoxy, urethane, chlorinated rubber, vinyl, etc., provides particular performance characteristics that should be considered during the coating selection process.

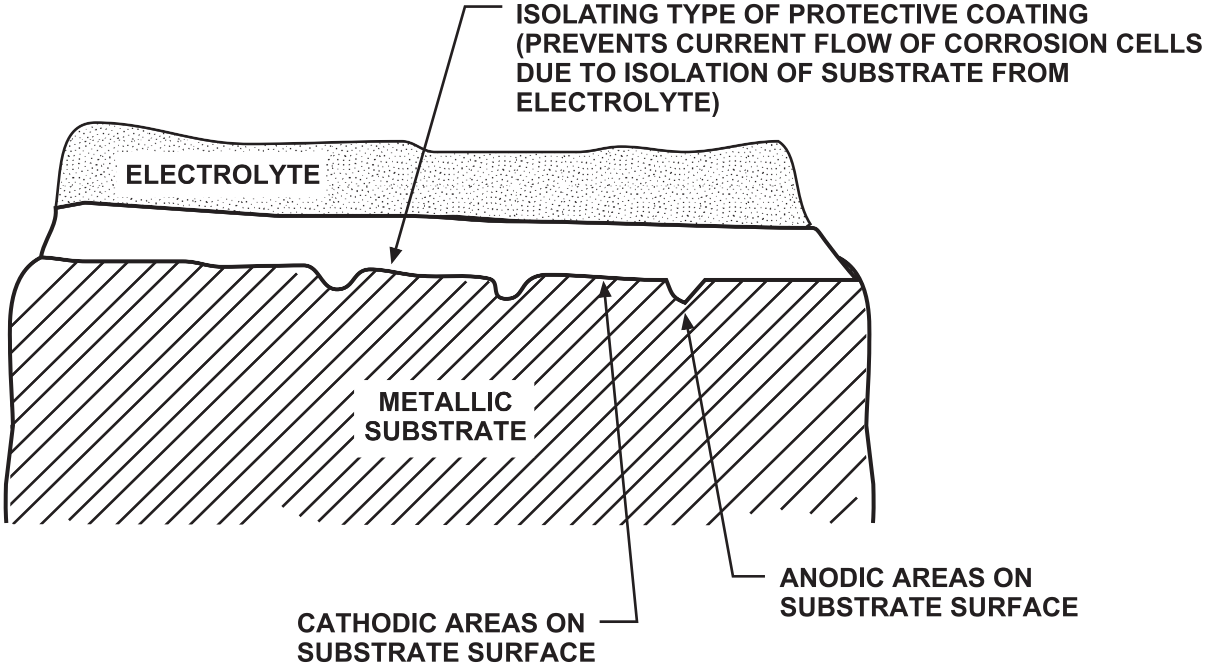
Types of Underground Coatings

Since the start of large scale piping installation there has been, and will continue to be, many developments in coating materials and protective coating systems. Manufacturers are striving to find materials or combinations of materials, which have the best possible electrical and mechanical strength, ease of application and stability in long term performance - all at a cost compatible with economical pipeline construction. Some materials now available will be described briefly. Detailed information on each type of coating may be obtained from manufacturers.



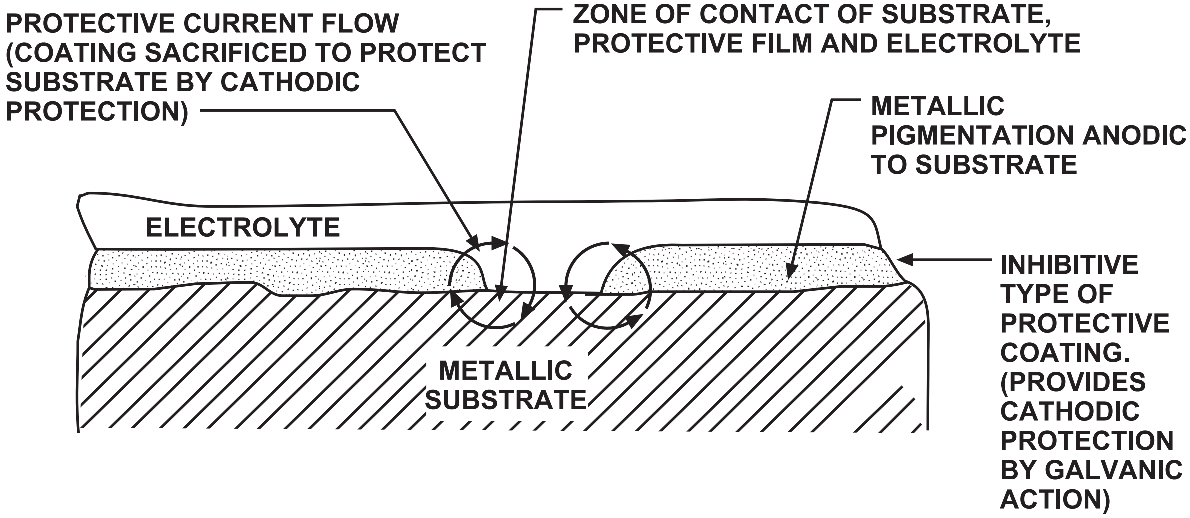
TYPICAL CORROSION CELL WITHOUT PROTECTIVE COATING

FIGURE 6-1



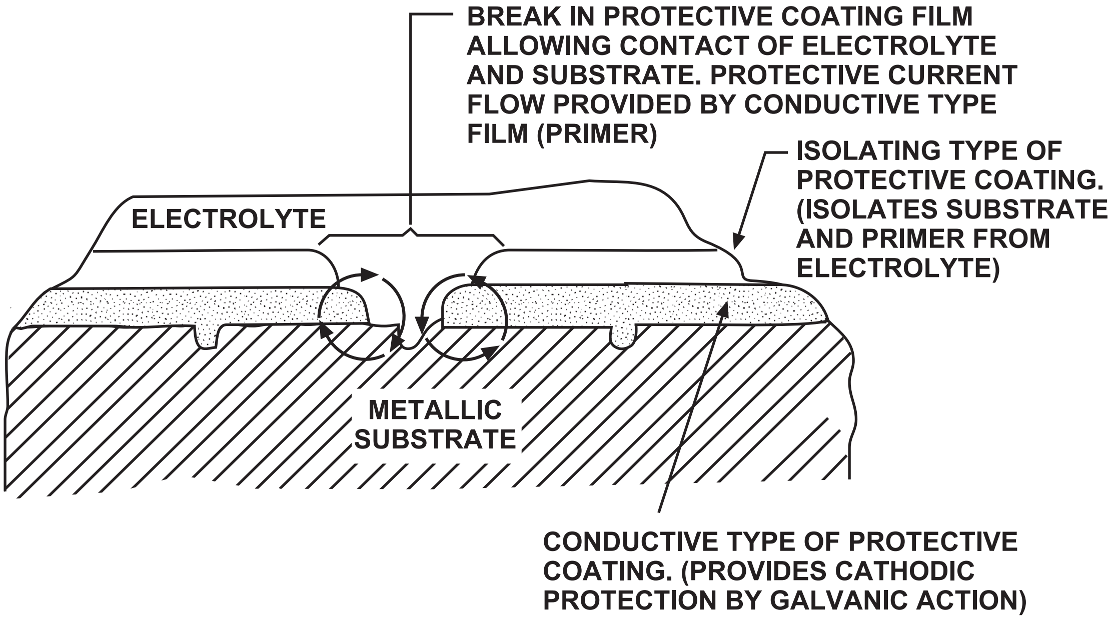
TYPICAL CORROSION CELL WITH ISOLATING TYPE OF PROTECTIVE COATING

FIGURE 6-2



TYPICAL CORROSION CELL WITH INHIBITIVE TYPE OF PROTECTIVE COATING

FIGURE 6-3



TYPICAL COMBINATION OF ISOLATING AND CONDUCTIVE TYPES OF PROTECTIVE COATING OVER CORROSION CELL

FIGURE 6-4

Enamels

This term is usually applied to hot-applied coatings of coal tar or asphalt, both of which have been used for many years. Only Coal Tar Enamel is available today. These coatings are formulated from coal tar pitches or petroleum asphalts by combining the processed base materials with inert mineral fillers, for improved mechanical strength and impact and deformation resistance. The operating temperature requirements for this type of coating are achieved by modifying the combined materials with various plasticizers. Application of this coating system requires the use of heating equipment. Hot enamels are applied over basic tar cutback or synthetic primers to an overall thickness of 3/32" (94 mils) to 5/32" (156 mils) by mill, yard, or over-the-ditch application methods. Over the ditch application commonly known as the "granny rag" method is only used for tie in welds and repairs due to the hot coating and the toxic fumes that are generated. Bond strength is largely dependent on the degree of surface preparation, primer application and application temperature.

The quality of the materials used in producing enamels has a direct bearing on the long-term stability of the system.

The following are some of the advantages and disadvantages of enamel coating systems:

Advantages

- Over 90 years of experience
- Minimum holiday susceptibility
- Low current requirements for cathodic protection
- Good resistance to cathodic disbondment
- Good adhesion to steel

- Disadvantages

- Reduced availability
- Air quality problems during application
- Subject to hydrocarbon attack
- Not recommended for above ground use
- Cracking problems at low temperatures
- Not recommended for high temperatures

Fusion Bonded Epoxy - FBE

Commonly referred to as fusion bonded epoxy, FBE or thin film coatings. The first formulations were introduced in 1959 and became commercially available in 1961. Of all the pipe coating systems, fusion bonded epoxy systems are the most resistant to hydrocarbons, acids and alkalis. One advantage of the coating is that it does not cover up pipe surface defects due to the thinness of the film, thus permitting excellent inspection of the pipe after coating.

For proper application, fusion bonded epoxy requires special care and attention to detail. Items of concern are: surface cleanliness, removal of non-visible surface contaminants, proper heating, humidity control, uniform application of coating material, adequate cure and effective holiday detection.

The application process consists of uniformly heating the pipe to the recommended temperature (450º - 475º F). Each product has its own individual application requirements and tolerances that must be strictly adhered to. Powdered resin is applied by electrostatic deposition to a 12-16 mil thickness.

The following are some of the advantages and disadvantages of fusion bonded epoxy powder coating systems:

Advantages

- Over 40 years of experience
- Good resistance to cathodic disbondment
- Wide operating temperature: -40º to 180º F
- Excellent adhesion to steel
- Excellent resistance to hydrocarbons
- Permits excellent steel inspection

Disadvantages

- High application temperature of pipe (450º F)
- Difficult to apply consistently
- Surface preparation is critical
- Surface temperature of pipe is critical

Electrical inspection should be performed as required by NACE Recommended Practice

RP0274 "High-Voltage Electrical Inspection of Pipeline Coatings Prior to Installation". Pipe requiring limited repair, perhaps one holiday per ten square feet, due to surface defects or coating imperfections and other minor defects is repaired by a two part epoxy patching compound or a 100 percent solids, liquid epoxy material.

For more details on FBE see NACE Recommended Practice RP0394 “Application, Performance, and Quality Control of Plant-Applied, Fusion-Bonded Epoxy External Pipe Coating”.

Extruded Plastic Coatings

This system usually consists of high density polyethylene or polypropylene extruded over the surface of the pipe. Normal coating thickness ranges from 30 to 50 mils and the coating is applied over approximately 10 mils of hot applied thermoplastic modified rubber adhesive by a specialized yard coating process.

Coating repairs in the field are normally made using plastic tapes or heat shrinkable sleeves made of the same basic materials.

The following are some of the advantages and disadvantages of extruded plastic coating systems:

Advantages

- Minimum holiday susceptibility i.e. the ability to resist development of holidays with time
- Wide operating temperature range
- Self-healing adhesive
- Non-polluting, low energy required for application
- Ease of application
- Excellent handling properties - high impact strength

Disadvantages

- Difficult to remove coating
- Higher initial cost
- Weld joint coatings can be problematic

Hot Applied Mastics

Mastics are commonly referred to as materials which are formulated with selected sands and other inert materials bound with an insulating compound, which is usually asphalt. These materials are normally applied hot over basic tar cutback primers by a continuous pressure extrusion process at stationary coating yards and are normally thicker than other coatings in common use. Typical thickness applied ranges from ½" (500 mils) to ⅝" (625 mils).

Hot mastics are used because of good coating integrity and performance resulting primarily from their greater than normal thickness.

Protective wrappers or dielectric wrappers (for increased electrical resistance) are not needed under normal pipelining conditions because of their thickness and hardness. Grades with various melting points are available to provide compatibility with pipeline operating temperatures.

The following are some of the advantages and disadvantages of hot applied mastic coating systems:

Advantages

- 70 years of experience
- Thickest corrosion coating
- Reduces concrete weight requirements
- Minimum holiday susceptibility
- Excellent resistance to cathodic disbondment
- Operating temperature range: 40º to 125º F

Disadvantages

- Higher initial cost
- Higher freight costs because of its weight
- Subject to hydrocarbon attack
- Not recommended for above ground use
- Requires torch for patching
- Reduced flexibility in below freezing temperature
- Poor bonding to steel substrate

Cold Liquid Coatings

Coatings in this category include materials which are applied in a cold liquid form and solidify either by solvent or chemical cure. Evaporative setting coatings include solvent cutbacks of tar and asphalt. In the asphaltic category, in addition to the petroleum-derived asphalts, are what are known as natural asphalts. These natural asphalts, which are mined in the form of gilsonite stock, are used to make coatings which generally have higher electrical strength than coatings using petroleum-based asphalts.

These coatings may be applied with or without primers and fiberglass reinforcement. Normal application thickness ranges from 40 to 60 mils.

The following are some of the advantages and disadvantages of solvent cured cold liquid coatings:

Advantages

- 70 years of experience

Disadvantages

- Long cure time - 24 hours or more
- Subject to hydrocarbon attack
- Not recommended for above ground use
- Reduced flexibility in below freezing temperature
- Poor bonding to steel substrate

Chemically cured coatings include materials such as combinations of epoxy resins and coal tar or other chemical compounds of similar nature. Such materials are normally received as two components, one of which is a chemical hardener. Once the two materials are combined, they will harden chemically within a specific period of time. The length of time available for application varies with the type of material and the ambient temperature during application. Normal application thickness may be up to 20 mils, depending on the material used.

The following are some of advantages and disadvantages of chemically cured cold liquid coatings:

Advantages

- Over 50 years of experience
- Good resistance to cathodic disbondment
- Wide operating temperature: -40º to 180º F
- Excellent adhesion to steel
- Excellent resistance to hydrocarbons
- Permits excellent steel inspection

Disadvantages

- Difficult to apply consistently unless sprayed
- Surface preparation is critical
- Surface temperature of pipe is critical

Backfilling time must be considered when using all of the above systems because of their respective curing time.

Two Part Epoxy Coatings

Coatings in this category include materials which are applied in a hot or cold liquid form and solidify either by solvent or chemical cure. Evaporative setting coatings include solvent cutbacks of coal tar. These coal tar epoxies are used to make coatings which generally have higher electrical strength than coatings using non epoxy based coal tars.

These coatings may be applied with or without primers and fiberglass reinforcement. Normal application thickness ranges from 20 to 40 mils.

The following are some of the advantages and disadvantages of solvent cured cold liquid coatings:

Advantages

- Over 70 years of experience

Disadvantages

- Long cure time - 24 hours or more for the coal tar epoxies
- Not recommended for above ground use

- Reduced flexibility in below freezing temperatures

Chemically cured coatings include materials such as combinations of epoxy resins or other chemical compounds of similar nature. Such materials are normally received as two components, one of which is a chemical hardener. Once the two materials are combined, they will harden chemically within a specific period of time. The length of time available for application varies with the type of material and the ambient temperature during application. Normal application thickness may be from 20 to 40 mils, depending on the material used.

These materials have a quick cure time and harden to a very tough impact and abrasion resistance.

The following are some of the advantages and disadvantages of chemically cured cold liquid coatings:

Advantages

- Over 60 years of experience
- Excellent resistance to cathodic disbondment
- Wide operating temperature: -40º to 180º F
- Excellent adhesion to steel
- Excellent resistance to hydrocarbons
- Excellent abrasion and impact resistance

Disadvantages

- Difficult to apply consistently unless sprayed
- Surface preparation is critical
- Surface temperature of pipe is critical
- Atmospheric conditions - humidity, dew point, etc. are critical

Backfilling time must be considered when using all of the above systems because of their respective curing times.

Hot Applied Waxes

Hot applied petroleum or microcrystalline wax is a refined and blended long-chain solid hydrocarbon mixture centrifuged from heavy oil stocks. Coating can be used with or without primer. However, when specified, primer must be compatible with the coating system. Coating application minimum average thickness should be no less than 20 mils. When wax coating systems are applied at a coating mill, an outer wrap is normally applied to provide additional protection during storage, shipping and installation. This outer wrap usually consists of snug fitting a uniform layer of Kraft paper, rag felt or a plastic film over the coating.

The operating temperature limitations are somewhat lower for this system than for enamel coatings.

The following are some of the advantages and disadvantages of hot applied wax coatings:

Advantages

- Over 90 years of experience
- Minimum holiday susceptibility
- Low current requirements for cathodic protection
- Good resistance to cathodic disbondment
- Good adhesion to steel

Disadvantages

- Subject to hydrocarbon attack
- Not recommended for above ground use
- Not good at high temperatures

Cold Applied Wax

Cold applied wax coatings are grease type materials formulated by blending petroleum wax with plasticizers and inhibitors. These systems are hand-applied to the pipe surface without primer and over wrapped with a component wrapper, similar to that used for the hot applied microcrystalline wax system. Coating application thickness is normally a minimum of 20 mils.

The following are some of advantages and disadvantages of cold applied wax coatings:

Advantages

- Over 90 years of experience
- Minimum holiday susceptibility
- Low current requirements for cathodic protection
- Good resistance to cathodic disbondment
- Good adhesion to steel

Disadvantages

- Subject to hydrocarbon attack
- Not good at high temperatures

Prefabricated Films and Tapes

Tape materials are being used frequently as a full coating system. Tapes normally used are plastic films of polyvinyl chloride (PVC) or polyethylene with a self-adhesive backing applied to primed pipe surfaces, or plastic films with butyl rubber backings and plastic films with various bituminous backings or combinations of bituminous material and chemical resins.

The following are some of advantages and disadvantages of prefabricated films and tapes:

Advantages

- Over 60 years of experience
- Minimum holiday susceptibility
- Low current requirements for cathodic protection
- Good resistance to cathodic disbondment
- Good adhesion to steel

Disadvantages

- Subject to hydrocarbon attack
- Not good at high temperatures

Tapes are usually thin film coatings. Best protective results are obtained with applications ranging from 15 to 35 mils, with a ¾" to 1" overlap, maintaining a tension approximately 5 pounds per inch of tape during the application.

Heat Shrink Sleeves and Tapes

Heat shrinkable polyethylene sleeves and tapes for field application became popular in the mid-1980's, particularly the type with an irradiated cross linked polyethylene backing. They do not generally require a primer and have an exceptionally high dielectric strength (greater than 500 volts per mil) and adhesion characteristics at immersed temperatures up to 150º F. The sleeves are used for weld joints and repairing defect areas. Surface preparation consists of proper cleaning as outlined in Surface Preparation Standards.

The following are some of the advantages and disadvantages of heat shrink sleeves and tapes:

Advantages

- Over 30 years of experience
- Minimum holiday susceptibility
- Low current requirements for cathodic protection
- Good resistance to cathodic disbondment
- Good adhesion to steel

Disadvantages

- Subject to hydrocarbon attack
- Not good at high temperatures

Directional Drilled Crossings

Many pipelines today are installed via horizontal directional drilling (HDD), thrust boring or slick boring. Corrosion control considerations for drilled crossings include the use of a corrosion coating and the use of an Abrasion Resistant Overlay (ARO) or sacrificial coating over the corrosion coating.

The overlay coating or sacrificial coating must bond to the corrosion coating and provide protection for the corrosion coating during the pipe installation process. The most common types of overlay coatings are FBE over FBE, 2 part epoxy over FBE or 2 part epoxy over 2 part epoxy. Other materials or combinations are available based upon the corrosion coating's properties.

Desired Coating System Qualities

As previously indicated, one of the ways in which a protective coating system provides protection to the coated structure is by providing a barrier between the substrate and the environment. In order to provide a permanent barrier, the coating system must possess the following qualities:

1. Electrical Resistance

An underground coating system should have good dielectric strength to assure high electrical resistance per square foot of coated area. For the coating system to be effective, this resistance value should not change appreciably with time.

The resistance of the coating is somewhat related to the electrical insulating property of the coating. Therefore, since the corrosion of the pipe is an electrochemical process resulting from current flowing from the pipe, the insulating properties of the coating will lessen the probability of corrosion occurring.

Another reason why a coating with high dielectric properties is desirable is based on the fact that the higher its electrical resistance, the lower the amount of current required to cathodically protect the piping system. Thus, the coating system which provides the highest resistance for the operating life of the facility is the most desirable for the application of cathodic protection.

2. Moisture Absorption

The moisture absorption of the coating is related to its permanent high dielectric strength. The presence of a water solution is required to initiate and support the electrochemical attack on buried metallic structures in conjunction with the corrosive elements in the soil. Therefore, if the structure could be effectively isolated from the surrounding soil moisture, the corrosion process can be controlled or eliminated. Low moisture absorption properties of the coating would therefore limit the influence of the electrolyte on the buried structure.

3. Water Vapor Transmission

Another desirable coating property is resistance to water vapor transmission. All coating materials, regardless of generic type, have a characteristic water vapor transmission rate. When selecting a coating the higher the degree of impermeability, the better the protective coating material.

4. Impact and Abrasion Resistance

From the time that the pipe is coated to the point when it is installed, the pipe will have been subjected to considerable handling. For this reason it is desirable to have a coating system that has the ability to withstand physical damage. Its ability to withstand physical damage depends largely on its impact, abrasion, and ductile properties.

The greater the coating system's resistance to impact and abuse, the less the chance of coating damage resulting during backfilling. Any damage or holidays on the coated surface would tend to concentrate corrosion activity at those locations and also increase the amount of cathodic protection current required to protect the pipeline.

The coating system should have good ductile properties to insure against damage, which may otherwise be caused during the installation of the pipeline due to associated flexing and bending.

5. Deformation Resistance

Soil surrounding the coated pipeline can impose stresses on the coating as the earth expands and contracts, and as it absorbs and dissipates moisture. Some soils may exhibit sufficient gripping action (soil stress) to actually pull the coating from the pipe surface. A satisfactory coating must be able to withstand such stresses without serious damage.

The operating temperature of the pipeline affects the deformation resistance. If the pipe is operating at a temperature near, or at, the softening point of the coating, it will be more susceptible to deformation by soil movement. Therefore, when selecting a coating system, the operating temperature of the piping system must be taken into account.

6. Bond Strength

In order for a pipe coating to perform satisfactorily it must possess strong and permanent adhesion properties. Poor bonding or adhesion to the pipe surface may allow moisture to accumulate between the pipe and coating thus possibly creating a corrosive environment.

Voids or gaps created between the coating and pipe surface due to poor bonding may adversely affect the performance of the coating and the effectiveness of associated cathodic protection systems.

Bonding strength must be sufficient to prevent the flexing and handling of the pipe during installation without the loss of adhesion.

It is essential that field joints and coating repairs also have excellent adhesion to the pipe and be compatible with the initial coating system used on the structure.

7. Compatibility with Cathodic Protection

Coating systems used in conjunction with cathodic protection systems must possess some resistance to electrical potentials to prevent disbonding of the coating due to hydrogen evolution between the structure and the coating.

Coatings must also be compatible with the alkaline environment, which is usually present with the use of cathodic protection systems.

8. Environmental Contaminants

When selecting a coating system for use in a given environment, the presence of chemicals which may be aggressive toward the coating must be determined and taken into account. Some materials are better suited to, and have a better resistance to, a particular environment than others do. Environments which are considered acidic, alkaline, or where hydrocarbons are present, are frequently encountered along a piping system.

9. Bacterial Organisms

Organisms such as fungi and bacteria are commonly found in soils. The severity of coating deterioration and resulting corrosion damage attributed to bacterial activity is a controversial issue.

Bacterial activity can be arrested by the application of cathodic protection, which increases the pH level of the soil around the pipe creating an environment in which bacteria cannot exist.

10. Weather Resistance

Coating systems must have some resistance to ultraviolet rays and extreme temperature changes. These conditions may be encountered by the coated pipe section during storage or shipping and therefore must be considered.

11. Ease of Application

A good coating system must be easy to apply. A system, which has all the properties previously discussed but is difficult to apply or requires highly specialized equipment to apply, may not be considered a good coating system from an economic standpoint. The application of the coating system must be as holiday free as possible.

The desired qualities discussed above, when all accomplished, would establish a so-called "perfect" coating material system. However, such a coating does not exist. Therefore, the individual responsible for specifying a coating system for a given piping system should, taking the above qualities into account, determine which type of coating will be compatible with the environment, the piping material, and the operating temperature of the system.

Surface Preparation

Buildings, bridges and structures of all types are no better than their foundations. The architect of a corrosion resistant protection coating system faces an analogous situation. The "foundation" for a protective coating system is the surface preparation. To obtain planned and predictable results, one must start with a controlled, uniform and known foundation. Surface preparation is the most critical part of the performance for all coated surfaces.

There are different types of surface preparation methods such as:

1. Dry abrasive blasting with sand or mineral abrasives

2. Grit blasting

3. Shot blasting

4. Abrasive blasting with shot/grit mixtures

5. Acid pickling

6. Wet abrasive blasting

7. Weathering off the mill scale

8. High pressure water blasting with water containing chemical neutralizers or rust converter additives

9. Solvent cleaning

10. Power tool cleaning, such as needle guns, buffers, etc.

11. Hand tool cleaning, such as scrapers, wire-brushes, etc.

12 High Pressure Water Jetting

The degrees of cleanliness that can be achieved are:

1. SSPC-SP5/NACE No. 1 - White Metal Blast Cleaning

2. SSPC-SP10/NACE No. 2 - Near-White Metal Blast Cleaning

3. SSPC-SP6/NACE No. 3 - Commercial Blast Cleaning

4. SSPC-SP8 - Pickling

5. SSPC-SP 7/NACE No. 4 – Brush-Off Blast Cleaning

6. High pressure water blast to remove all loose material

7. Solvent clean to remove oil and grease, and hand tool and power tool cleaning to remove all loose particles, SSPC SP1, SP 2 and SP3

8. Water wash with additives if needed, to remove or neutralize any chemical contaminants

9. SSPC-SP 14/NACE No. 8 – Industrial Blast Cleaning

Coating Specification

Corrosion control personnel should develop appropriate specifications to deal with the aspects of a particular project, whether new or rehabilitative. The purpose of this section is to provide guidance on the more important points to consider when formulating the document. The specifications should state what will or will not be acceptable and what the vendor or coating contractor is expected to do when conditions are found to be unacceptable. The important points for consideration are shown below:

1. Condition of the Bare Pipe
   a. Pipe Material
   b. Size
   c. Surface condition
   d. Age

2. Handling and Storage - mill, transit, field
   a. Pipe handling - bare and coated
   b. Handling equipment - acceptable types
   c. Protection from weathering and UV
   d. Coating material - maximum storage temperatures and shelf life
   e. Stacking

3. Atmospheric Conditions - mill or field during surface preparation, application
   a. Temperature ranges - ambient, surface
   b. Relative humidity
   c. Dew point

4. Surface Preparation
   a. Methods and standards
   b. Pre-cleaning and pre-heating

    c. Abrasives, tools, equipment
    d. Cleanliness of surface and profile
    e. Accessibility and Inspection
    f. Remedial work - repair surface imperfections
    g. Personnel qualification
    h. Lighting minimum
    i. Compressed air quality

5. Application
    a. Methods and standards, manufacturer's instructions
    b. Materials, solvents, cleaners
    c. Tools and equipment
    d. Material temperature -minimum/maximum
    e. Surface temperature minimum/maximum
    f. Thickness of coating system - minimum/maximum
    g. Drying time, cure time, cool time
    h. Accessibility and Inspection
    i. Remedial work - cutback trim
    j. Personnel qualification
    k. Lighting minimum
    l. Compressed air quality

6. Inspection
    a. Methods and standards
    b. Personnel qualification
    c. Lighting minimum
    d. Work access

   e. Instrumentation
   f. Forms and reports
   g. Acceptance of conforming work
   h. Handling non-conforming work
   i. Acceptance of remedial work
   j. Settling disputes
   k. Hold points

7. Post Installation Evaluation
   a. Coating efficiency resistance testing
   b. Reports
   c. Remedial measures

The key to any good coating job is, of course, the design and specification of the system.

There are many causes for coating failures, and the service life of a coating system is dependent on selection of the coating system, surface preparation, coating application, inspection, and maintenance (where feasible). To obtain a good coating system, several requirements must be met: a tight specification; selection of the proper coating system, material supplier, and application contractor; and implementation of adequate inspection. The specification stage is a point at which a coating job can go wrong before it even begins. A good, tight specification is essential if the requirements for a successful job are to be met.

A good specification spells out what is to be coated, how it is to be done, and what the characteristics (thickness, freedom from discontinuities, etc.) of the coating film should be. It should be kept simple and to the point. Selection of a coating system is, of course, very important. If the wrong type of coating is chosen for the job, the results achieved are certainly not going to be satisfactory. The coating industry is continually making advances in developing new products to do a better job and in learning more about the performance of older products.

In selecting a primer, the degree of attainable surface cleanliness is of great importance. A surface which has been abrasive blasted is easily wetted by most primers. Hand cleaned or power tool cleaned surfaces are not wetted or penetrated by some of the quick, dry primers. Therefore, slower drying primers are required.

The biggest mistake is to select a coating based on cost/mil-ft^2. Buying coatings on the sole criteria of cost/mil-ft^2 has led to many poor performances. Once the corrosion engineer has selected the generic type of coating suitable for the intended service, the actual cost differential between one specific coating and another is usually insignificant when the total cost of the coating work is considered.

Laboratory panel testing is a method often used for determining the quality of coating systems. However, the same system can be given ratings of poor, good, and outstanding when tested by three different laboratories in supposedly the same type of salt fog cabinets. The only true evaluation is field performance. Ask suppliers for their recommendations and case histories of coating systems, then check with the maintenance people where those systems have been used.

HANDLING COATED STEEL PIPE

Transportation and Handling of Coated Pipe

Pipe sections should be handled carefully during loading for delivery by truck or rail so that damage will be kept to a minimum. Pipes should be padded and adequately secured in order to avoid coating damage during normal shipping conditions.

When pipe sections are transported by rail, the pipes should be transferred directly to stringing trucks if possible to avoid excessive handling. If not, they should be placed in a field storage location and then loaded onto stringing trucks. Again, efforts should be made to handle sections as carefully as possible.

When stringing trucks arrive at the job site, facilities must be available for placing the coated pipe sections on the ground. Sections should not be dumped directly from the truck. Coated pipe sections should not be placed directly on the ground unless the area is free of materials, which may damage the coating. Preferably, sections should be placed with skids or supports under the bare pipe ends where the coating has been cut back.

This is seldom possible however, because of the varying lengths of pipes. The best alternate is to place the sections on padded skids. The coating manufacturer should be consulted as to the recommended padding material as well as the number of pipe layers permissible in the pipe pile.

Coated pipe sections should be moved about using belt slings or end hooks. The use of chains or cable wrapped around the pipe should not be permitted, as they can cause serious damage to the coating. Belt slings must be wide enough so that they can bear the full weight of the section without distorting the pipe coating. End hooks, one connected to each end of the section using a cable sling and spreader, should be designed so that their use will not distort the pipe ends. If a pipe section is handled with a single belt sling, swing must be restricted using ropes or other suitable means to avoid accidental swinging into equipment, which could cause coating damage. When the coated pipe section is taken from the ground after stringing, for lining up and welding the section into the pipeline, it should be laid on padded skids under the coated portions to free the ends for welding. Suitable padded skids should be used to avoid damage to the coating.

Pipe Coating Over or In the Ditch

Coating pipe sections in the field should be done in strict accordance with coating specifications. Coating materials must be handled carefully in the field. They must be kept clean of dirt and other foreign matter. Wrapping material must be kept dry. Excessive moisture in a wrapping felt or mat generates steam when it strikes hot enamel and adversely affects the quality of the coating system. Similarly, enamel applied over a moist or wet pipe section will create the same deficiency. The application of coating in weather below freezing may result in a substandard coating system if a frozen film of moisture forms on the pipe. This frozen film of moisture can be so thin that the pipe may appear dry.

When performing recoating or coating repair in the ditch, the same constraints for weather, environmental conditions, pipe temperature, etc. are applied. Pipe will be coated to the same or better quality than original and inspected and tested to ensure the quality.

Handling of field coated sections must be done with care, as described in the previous section.

The manufacturer of the coating materials should be consulted if questions or problems arise concerning the application of its product. The manufacturer will be more than happy to be of assistance because it is very concerned in having its material perform well.

Holiday Detection and Repair

Holidays or flaws in the coating system may be detected by visual inspection or through the use of a holiday detector.

On new pipeline construction, a best practice is to holiday test the pipe upon receipt, during the unloading from the trucks, after the field joints have been coated and during the lowering in. This will ensure you have the best practical coating job prior to backfill.

A holiday detector is a device which impresses an electrical voltage across the coating. An electrode is passed over the entire coating surface. As the electrode passes over a coating defect, there is an electrical discharge between the electrode and the pipe. This discharge or spark actuates a signaling device which alerts the operator that a holiday (coating flaw or discontinuity) is detected. The operator then marks the defect for the repair crew and continues. Upon completion of inspection of the coating system all areas so designated should be repaired. Personnel making such repairs must be trained to repair defects properly and apply the repair materials in such a fashion that the repaired area will be as strong, electrically and mechanically, as the original coating.

Preparation of the coated area requiring repair includes the removal of broken and disbonded material and, for best performance when working with enamel or other thick coatings, feathering the edges of the holiday with a drawknife or equivalent tool. This assures a better bond between the repair materials and the original coating. If an outer wrap such as Kraft paper is present, it must be removed from around the holiday area to obtain good bonding of repair materials at the overlap. The repair materials themselves must be handled carefully and in accordance with good coating practice.

Hot enamels used for repairs must be hot enough to give a good bond to properly primed surfaces. If repriming is required before coating repair, a fast drying synthetic primer should be considered. When holidays are repaired close to a big temperature controlled enamel kettle, buckets of heated enamel may be used. When such kettles are not available, enamel can be heated in buckets with kerosene or propane flame guns or over fires. Caution must be taken so as not to heat the enamel too rapidly or use excessive heat which may "coke" the material, driving off much of the volatile material, thus giving the enamel undesirable coating characteristics.

When holiday repairs consist only of daubing on hot enamel and laying on a patch of felt wrap without prior surface preparation of the damaged area, poor long term performance of the pipeline coating can be expected. Poorly applied patches are apt to disbond in time resulting in lower effective coating resistance and increased cathodic protection current requirements.

When repairing holidays with two part epoxy materials, surface preparation is critical as well as the air and pipe temperature. Retest the repair after the coating has cured.

When repairing holidays with cold or hot applied tape, shrinkable sleeves or patches, again surface preparation is critical. Primer should be used and a coating overlap per the manufacturers requirements achieved. Retest the repair after the coating has cooled.

Inspection

Once the materials and applicator are selected, an important element is inspection. Inspection begins from the time pipe is received at the coating mill and continues right up to the time of backfill in the ditch. Inspectors must be knowledgeable in the areas of quality control methods, coating systems, plant facilities, handling, shipping, joint coating, field conditions, electrical inspection techniques, and repair methods.

Experience and sound engineering judgment in the interpretation of specifications and analysis of test results will contribute to obtaining the best possible coating results.

To assure that we get what we paid for, it is important to provide proper inspection during coating application and pipeline installation.

The purpose of inspection is to make sure that the specifications, which have been prepared so carefully, are being met.

One of the key factors in achieving successful coatings performance is the quality of the coating system application. The "best" coating system will fail prematurely if the application procedures, conditions or workmanship are unsatisfactory. The majority of coatings failures result from poor application techniques.

As we stated above, the specification would describe the material to be used, surface preparation, film thickness, etc. It should also include several limitations that the inspector should insure that the coating applicator adheres to:

1. The coating systems and their dry film thickness must be as specified.

2. No thinners or additives be added to the coating except as allowed by the coating

manufacturer's written instructions.

3. Coatings must be applied in accordance with Steel Structures Painting Council SSPC-PA1 Shop, Field and Maintenance Painting and the specification. The coating manufacturer's instructions regarding the materials, equipment and application methods must be followed unless they are in conflict with the specification.

4. No coating work shall be performed if conditions are outside the ranges allowed by the coating manufacturer for items such as air and/or surface temperature, relative humidity, etc. Coatings shall be applied only if the temperature is above 50ºF (10ºC) and at a relative humidity of 80% or less.

5. Surfaces must receive the specified coating in a thorough and workmanlike manner in accordance with standard practices.

6. Coating material that has been readied for use must be used within the time specified by the manufacturer. Coating must be mixed immediately before use in accordance with standard practices.

7. Coating materials must be dispensed on a "first-in," "first-out" basis in order to prevent the shelf life from expiring.

8. Well-maintained application equipment must be employed.

Procedures for Laying Coated Pipe

Before laying the pipe in the trench, the bottom of the trench must be cleared of any large stones or foreign material which may damage the pipe coating.

Piping should be lowered into the trench by means of belt slings or similar means, which would enable the pipe to be lowered slowly and carefully into the trench, to avoid coating damage. After pipe is placed in the trench, the pipeline should again be inspected for coating damage. Damaged coating must be repaired in accordance with the previous section of this chapter relating to repairs.

HOLIDAY DETECTION AFTER BACKFILLING

There are various techniques that can be used to detect coating defects after backfilling. These include the Pearson Survey, the Direct Current Voltage Gradient (DCVG) survey and the Alternating Current Voltage Gradient (ACVG) survey.

The Pearson Survey was pioneered by J. M. Pearson in the 1930's. The survey consists of measuring the leakage of an audio signal from the pipeline at coating holidays.

A Direct Current Voltage Gradient (DCVG) survey is performed by interrupting the CP system or another DC source and measuring DC voltage gradients over the pipe. DC voltage gradients will be present at coating holidays.

An Alternating Current Voltage Gradient (ACVG) survey is performed by inducing AC on the pipeline and measuring AC voltage gradients over the pipe. AC voltage gradients will be present at coating holidays.

These methods are discussed more fully in the Advanced Course text.

SYSTEM MAINTENANCE

During normal operations there frequently are occasions when the line is excavated for maintenance work which may result in coating damage. Coating repairs should be made with material of equal or better quality than the original coating and should be carried out by qualified personnel.

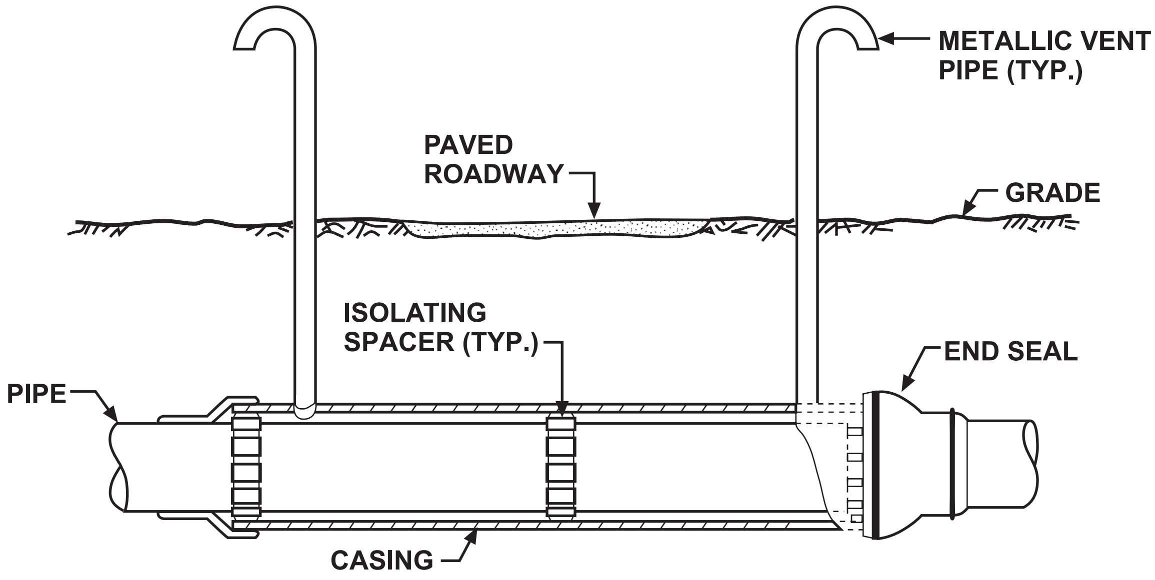
Record keeping of actual coating performance encountered during the life of the line will permit corrosion personnel to evaluate the condition of the coating. Vital information can be obtained by training maintenance crews to identify and report the condition of a coating whenever a section is excavated and examined.

Measuring the effective coating resistance periodically will aid in the assessment of deterioration, damage caused by third parties, or other conditions. If testing reveals a rapid rate of deterioration, an investigation should be initiated to determine the cause. Pearson Surveys, DCVG surveys and ACVG surveys are suitable for this.

CASED CROSSINGS

What is a Cased Crossing?

A cased crossing is a point where a pipeline is routed through another pipe, usually steel, as shown in Figure 6-5A. The casing is used to provide mechanical protection to the pipeline. Casings are sometimes installed where pipelines cross under roadways and



TYPICAL ISOLATED CASING DETAIL

FIGURE 6-5A

railways.

Component Parts of a Cased Crossing

Figure 6-5A shows the components of a typical cased crossing. These components consist of the casing, vents (if specified), isolating spacers, and the end seals.

The casing is usually a steel pipe, although cast iron and concrete pipe have been used. The size of the casing should be a minimum of two sizes larger than the pipeline being protected.

The isolating spacers are installed on the pipe being protected and are used to electrically isolate the pipe from the casing. Spacers are available in various designs ranging from all plastic types to models having isolating blocks secured to steel bands (which may be rubber or plastic lined).

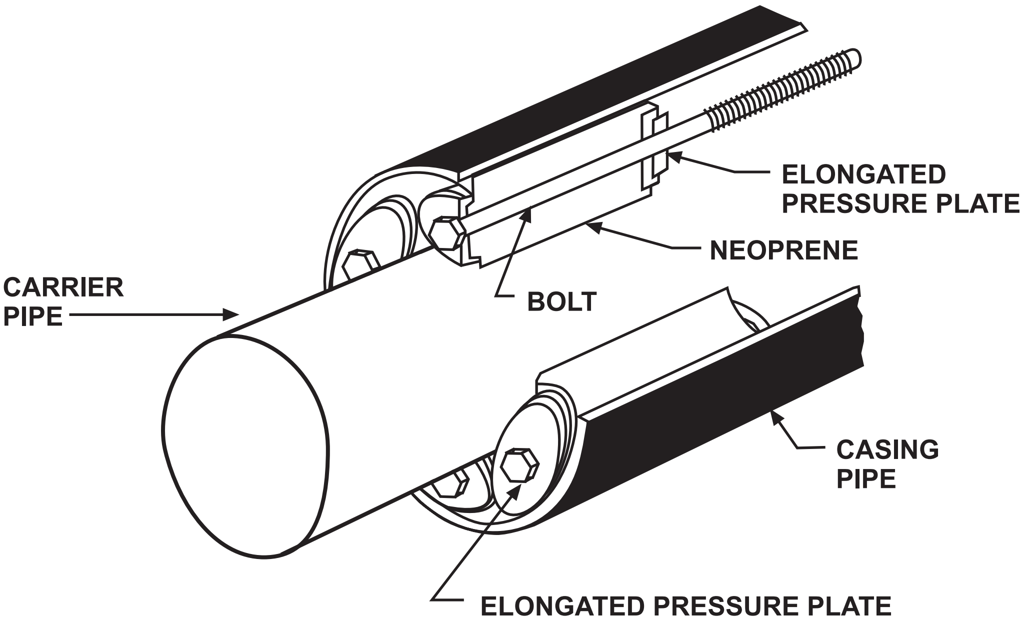
End seals are installed at each end of the casing. They are designed to provide protection against the entry of water, soil or other backfill material which may short the pipe to the casing or cause corrosion in the annular space between the pipe and casing. End seals are available in various designs. One type of design is shown in Figure 6-5A. This is a synthetic rubber sleeve, which is sized to fit both the pipe and casing and are secured to them by means of metallic straps. Another type of end seal commonly used is constructed of solid synthetic rubber as shown in Figure 6-5B. The end seal is placed in the annular space between the casing and the pipe, at the end of the casing. As the bolts are tightened, the elongated pressure plates compress the rubber, which in turn expands to form a continuous seal.

NACE Standard Practice SP0200 "Steel-Cased Pipeline Practices" is a good reference for the design, installation and maintenance of casings.

Proper Methods for Installing Cased Crossings

The first step is to install the casing at the required location. The casing should then be inspected. It should be determined that the casing is straight and round to prevent binding of the pipe during installation. All debris should be removed from within the casing prior to pipe installation.

If the casing is to be provided with vent pipes, as shown in Figure 6-5A, it is recommended that they be installed prior to the installation of the pipe. If vent holes are



MODULAR WALL & CASING SEAL

FIGURE 6-5B

cut in the casing with the pipe in place, damage to the pipe coating may occur due to the heat of the torch, or the resulting coupon may fall into the casing; the coupon could cause an electrical short between the pipe and the casing.

Spacers must be installed on the pipe prior to its installation in the casing. They should be designed to protect the carrier pipe and its coating during insertion and to adequately support and electrically isolate the carrier pipe from the casing when full of product. The number of spacers used and the spacing at which they are installed depend on the type of spacer used and the weight of the pipe. Before installing isolating spacers, the manufacturer should be consulted concerning the number and size of the isolating spacers required. The location of the spacers on the pipe should be planned so that when the pipe is pulled into the casing the end isolating spacers will be close to the ends of the casing. An inspector should make sure that the spacers are not crushed while the tie-in foreman is trying to get that last fraction of an inch that may be required to set up the line-clamps for the welder.

The final step is the installation of the end seals. As previously mentioned, the installation of the end seals between the pipe and casing reduce the ingress of water and debris.

To insure proper installation, the manufacturer of the seal should be consulted concerning the size and type required for the particular installation and for recommended installation procedures.

Although the use of cased crossings is widely accepted, it should be pointed out that their use is presently under scrutiny due to the corrosion problems which tend to develop with their use. Alternate means of providing mechanical protection to the pipe at crossings are being explored.

Testing Cased Crossings for Electrical Isolation

After the carrier pipe has been installed in the casing, it should be tested to determine its electrical condition (clear or shorted). It should be tested before and after it has been tied-in as well as before and after it has been backfilled.

If the carrier pipe is found to be shorted to the casing, this condition must be corrected.

One method of testing the isolation of the pipeline from the casing is by measuring the resistance between the two structures. This resistance can be measured by using an ammeter, a voltmeter, and an external DC power supply connected as shown in Figure 6-6. Another way to measure the resistance is by using a soil resistivity meter connected between the casing and pipe as shown in Figure 6-7. A resistance measurement, which is very high or infinite, would indicate that the two structures are electrically isolated.

An alternate method of testing the isolation is by measuring the pipe-to-soil and casing-to-soil potentials with respect to a portable reference electrode contacting the soil above the pipeline. A current should be impressed on one of the two structures using an interruptible DC source. Figure 6-8 shows a typical test set-up indicating this type of test.

If available, an existing impressed current cathodic protection system on the pipeline can be used for this test, as shown in Figure 6-9, interrupting the rectifier during the test. The potential readings on both structures should be taken using a high resistance voltmeter while interrupting the current source.

Regardless of which current source is used, if the potentials of both structures increase in the same direction, as the current source turns on, the two structures may be shorted. If the potential of the structure connected to the power source increases in the negative direction as the power is turned on, and there is little or no increase in the other structure's potential, then the structures can be considered as being isolated from one another.

Casings should be periodically checked using test stations normally installed at cased crossings. Casings may be properly isolated just after installation, but in time may become shorted due to one or more of the following conditions:

1. Too much strain on pipe when final tie-in was made.

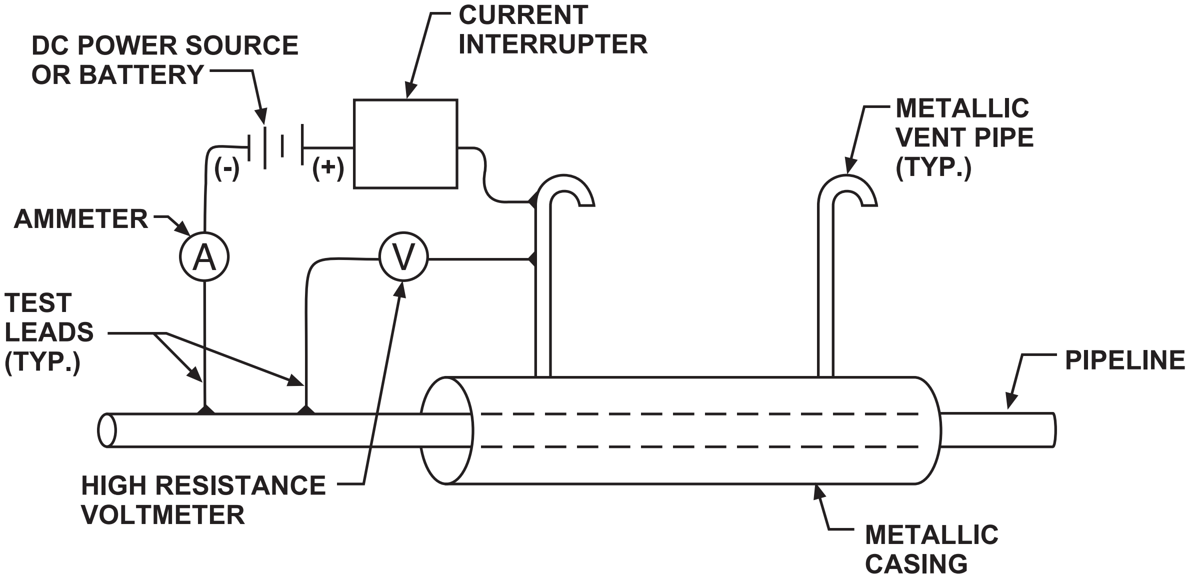
2. Earth movement or settlement.

3. Movement of the casing for whatever reason.

4. Movement of the pipeline due to expansion, contraction, or internal pressure stresses.

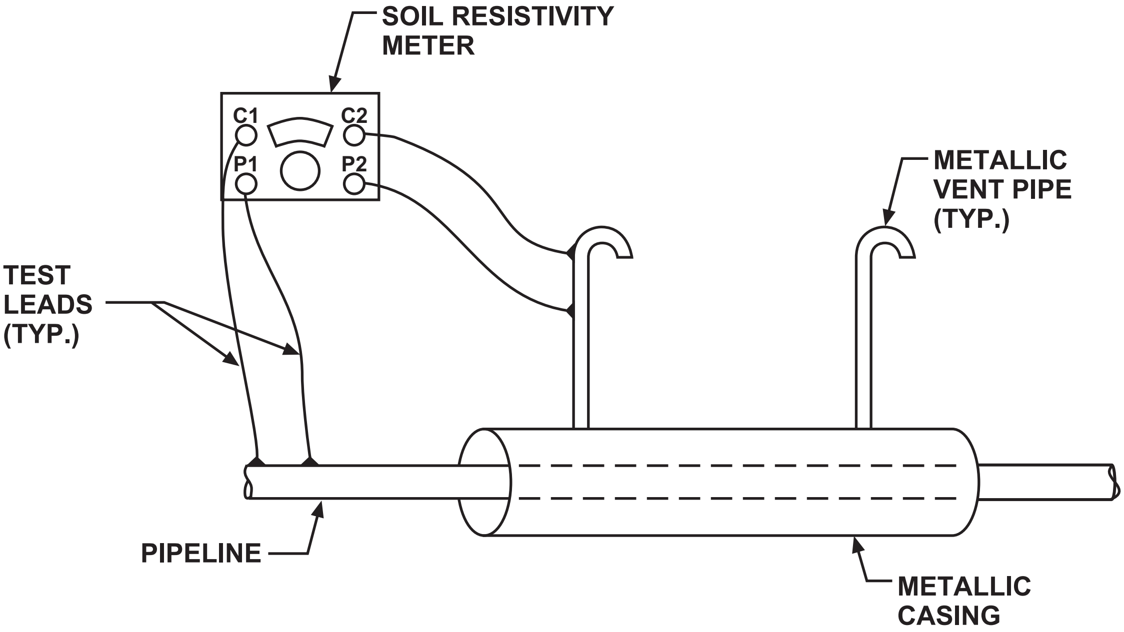
5. Casing isolators being placed too far apart or made of inferior materials.

In the event that a casing is found to be shorted to the pipeline after construction



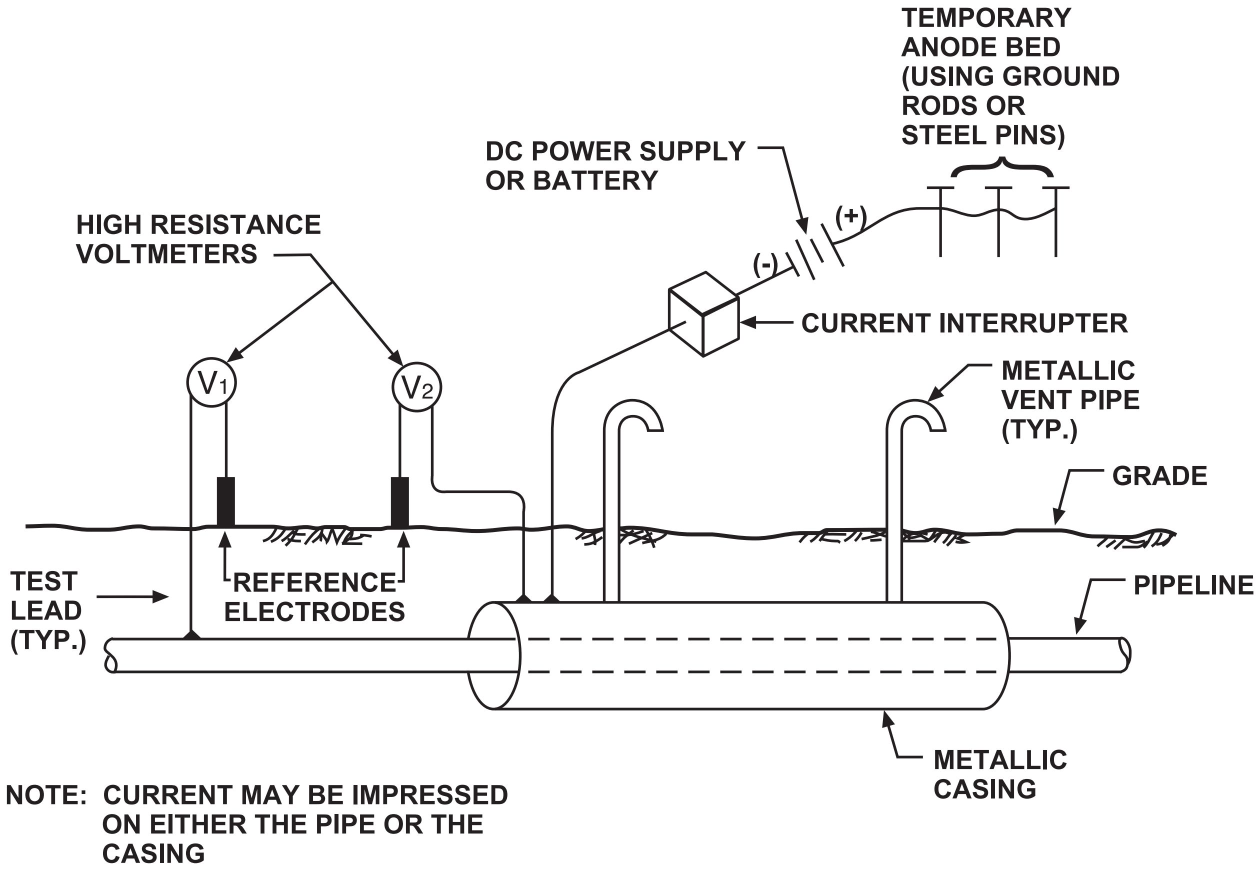
CASING-TO-PIPE RESISTANCE MEASUREMENT USING AMMETER, VOLTMETER AND EXTERNAL DC POWER SOURCE

FIGURE 6-6



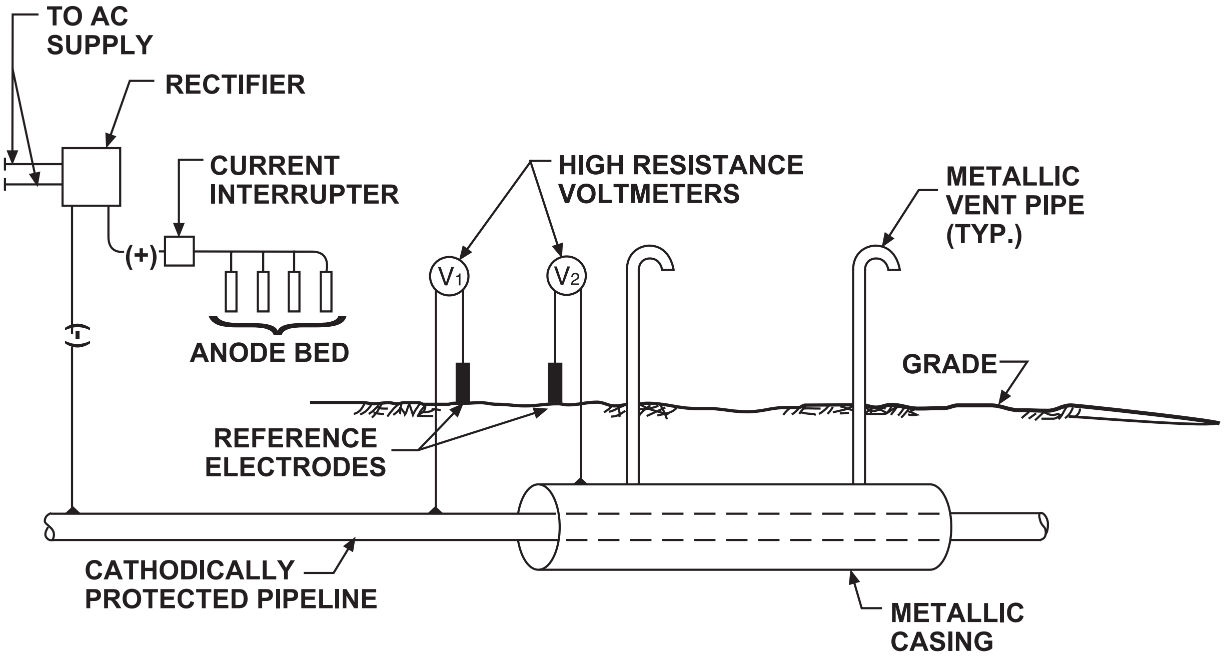
CASING-TO-PIPE RESISTANCE MEASUREMENT
USING SOIL RESISTIVITY METER

FIGURE 6-7



ISOLATION TESTING BY
IMPRESSING CURRENT ON CASING

FIGURE 6-8



ISOLATION TESTING USING EXISTING CATHODIC PROTECTION SYSTEM

FIGURE 6-9

activity in the area has been completed, there are only two acceptable alternatives which can be considered:

1. Excavate the cased crossing, locate the point of contact and clear it.

2. Pump a petrolatum or wax type product into the entire annular space through the vent pipes in order to inhibit corrosion.

Another approach that has been used in the past is to allow the short to remain and to increase the level of cathodic protection at the pipe/casing interface area. This approach does not preclude the possibility of corrosion of the pipe within the casing if water has gotten inside the annular space.

Casing isolation is one of the most important items in a well-designed pipeline system. Therefore, great effort should be expended to determine the most effective and economical method of properly installing the spacers and seals to avoid the possibility of future electrical shorts due to improper installation.

ISOLATING JOINTS

What Does an Isolating Joint Do?

Isolating joints such as isolating flanges, unions, monolithic joints and couplings are used to electrically isolate various components of a pipeline system.

They are often used to isolate a pipeline into sections for cathodic protection purposes.

Applications of Isolating Joints

Isolating joints have numerous applications in transmission and distribution piping systems. The following is a list of some of the applications of isolating joints:

1. Isolating old pipe from new pipe.

2. Isolating coated pipe from bare pipe.

3. Isolating copper or cast iron pipe from carbon steel pipe.

4. Connecting two pipelines of different ownership.

5. Isolating distribution lines from transmission lines.

6. Isolating compressor, regulator, and distribution piping from the main line.

7. Isolating river crossing sections of pipelines.

8. Isolating sections of piping to reduce the magnitude and effects of stray currents.

9. Facilitating the location of contacts in congested areas.

10. Protecting metering devices by isolating the section of pipe on which the meter is installed from the meter itself.

11. Isolating protected pipes from unprotected pipes.

Isolating Flanges

The most commonly used isolating joint is the isolating flange. Isolating flanges are available in various sizes and configurations and are constructed from a large variety of materials designed for specific temperature, product and pressure applications. Figure 6-10A shows an illustration of a typical isolating flange installation. An isolating flange has three (3) isolating components. They are the gasket, the sleeves, and the washers.

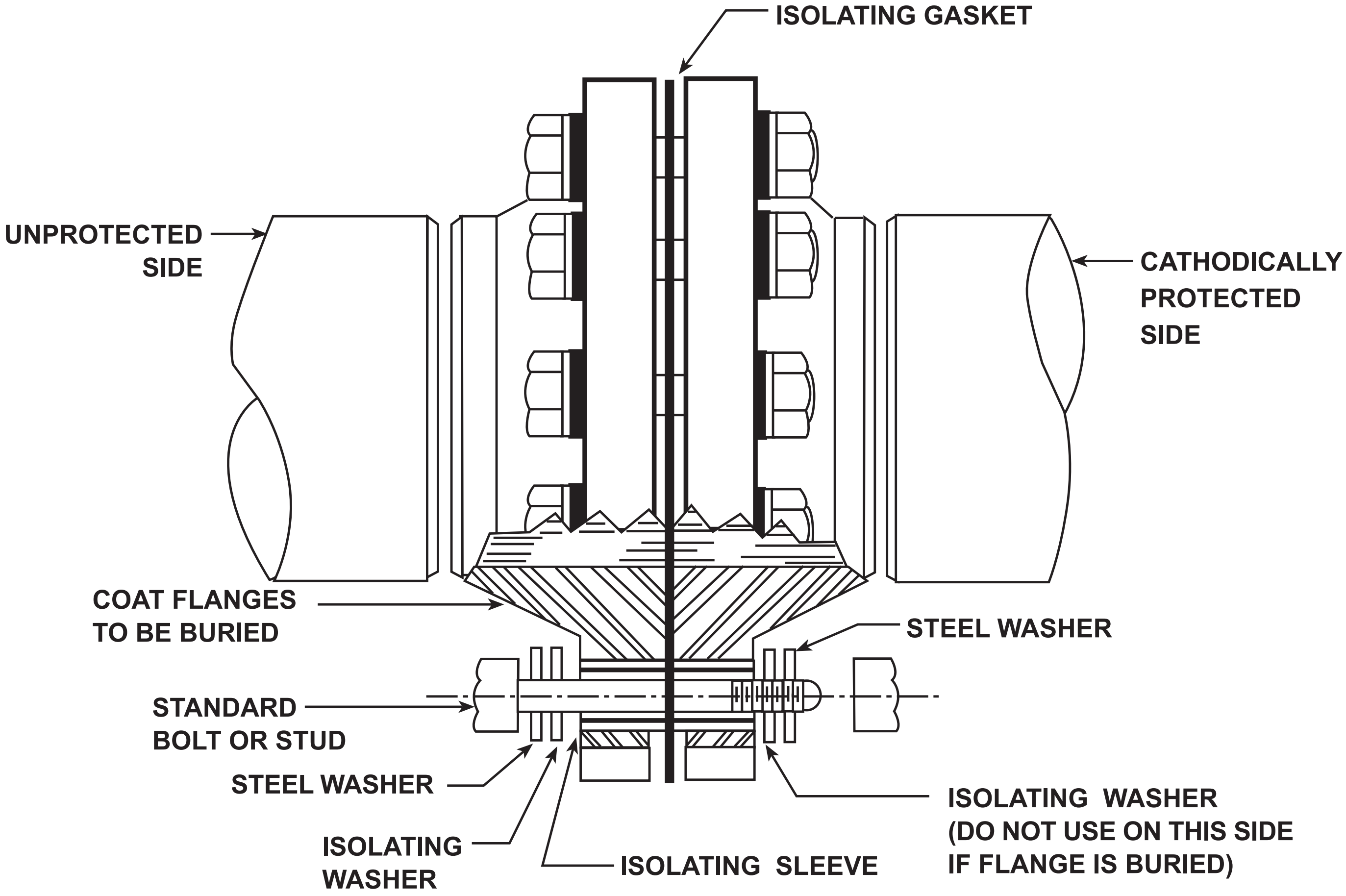
A. Gaskets

Isolating gaskets are either conventional flat gaskets manufactured of nonconductive materials or gaskets consisting of nonconductive retainer materials such as phenolic or epoxy glass with special grooves to accommodate O-ring or quad-ring seal elements. They are usually ⅛" thick. Factors to consider when selecting gaskets are the material compatibility with the piping product and external environment, temperature limitations and sealing capabilities.

The following is a list of types of gaskets commonly used to isolate flanges, along with a brief description of their material composition, configuration, and operating characteristics:

1. Full Face Gaskets (Type E)

Full face gaskets completely cover the flange face from the flange base to the outside



TYPICAL ISOLATING FLANGE ASSEMBLY

FIGURE 6-10A

diameter. Full face gaskets are used on flat faced flanges, however, they can be used with a raised face flange to eliminate debris build up in raised areas that could cause a short.

2. Ring Gasket (Type F)

   Ring gaskets are designed to seat inside the bolt circle and are commonly used with raised face flanges.

3. Ring Type Joint (Type D)

   The Ring Type Joint (RTJ) is an oval glass epoxy or phenolic gasket designed to work specifically with RTJ grooved flanges. RTJ gaskets are sized by R numbers.

   A filler gasket is sometimes used on the ID of the RTJ gasket. This is to eliminate debris bridging across and causing a short.

4. Type D - BX

   BX gaskets are an octagonal shaped phenolic or glass epoxy gasket designed to work specifically with a BX grooved flange. BX gaskets are machined from phenolic tubing or glass epoxy materials.

As previously stated, gasket materials should be selected based on operating requirements of the pipe. Some of the gasket base materials available are:

Paper (phenolic) with a seal element
Glass Epoxy with a seal element
Canvas Cotton Fabric (phenolic)
Neoprene Faced Phenolic
Silicon Glass with a seal element

B. Sleeves

Isolating sleeve materials are designed to fit over standard bolts and within standard bolt holes in flange faces. They are normally 1/32" thick and commonly available in Mylar®, glass epoxy, phenolic and polyethylene. When feasible, they should be full length, extending half way into the steel back-up washers on both sides of the flange. Factors to consider when selecting sleeve materials include: dielectric strength, product compatibility, temperature limits and physical strength with particular attention to their resistance to cut-through from the bolt threads. Mylar® and glass epoxy sleeves typically provide good service in most environments.

C. Washers

Isolating washers should fit under the steel back-up washers and be sized to fit over the isolating sleeve material within the flange "spot" face. They should have the same ID and OD as the back-up steel washers. Factors to consider when selecting isolating washer materials include: dielectric strength, compressive strength, sheer strength, temperature limits and compatibility to environment. Glass clad phenolic or epoxy typically provide good service.

Isolating gasket kits can also utilize a molded one-piece sleeve and washer. The one-piece sleeve and washer reduces possible error in washer-sleeve arrangement sequence and allows the inspector to determine if the flange has been properly isolated in one glance.

Installation of Isolating Flanges

Isolating flange kits can only be installed on out-of-service pipes because the installation requires the opening of pipeline flanges. Isolating gaskets, bolt sleeves, and isolating washers should be installed as per the manufacturer's instructions and the following recommendations:

1. Gasket inner diameter should be the same or slightly smaller than the inner diameter of flange.

2. For buried flanges, isolating washers should be installed only on the unprotected side of the flange, allowing cathodic protection to be provided to studs or bolts.

3. Alignment pins are recommended when possible and should be a minimum of 3/32" (2.381 mm) larger than bolt size.

4. It is important that after the isolating flange is installed, the void area where the two flange faces meet be taped with two layers of plastic tape or equal. Alternatively, an inhibited grease can be used to fill the void area. This could avoid the accumulation of debris, which may lead to electrical shorting of the flange.

5. Replace any broken or cracked sleeves or washers, as they will eventually result in an electrical short and possibly product leakage.

Upon completion of the isolating flange installation, the flange should be tested for effectiveness. Periodic maintenance/testing should be conducted on accessible flanges (aboveground and underground with test points) and whenever a buried flange is excavated.

Isolating Unions

Isolating unions are generally installed aboveground to provide electrical isolation for regulator stations, processing plants, gauge lines, fuel supply lines, water lines, and other pipeline applications.

Isolating unions are available for high and low pressure applications.

They are comprised of two flanged bodies which are screwed onto the end of the pipes to be joined. One flanged end of each body is externally threaded enabling the two sections to be joined using a nut. The nut is isolated from one of the flanged ends through the use of a dielectric material. An O-ring or gasket may be located between the two mating surfaces.

Various dielectric materials are used in the construction of isolating unions, but the most preferred material is nylon. These dielectric materials are machined and/or molded in such a fashion so that they will not be damaged when the union is tightened. Figure 6-10B shows a typical isolating union.

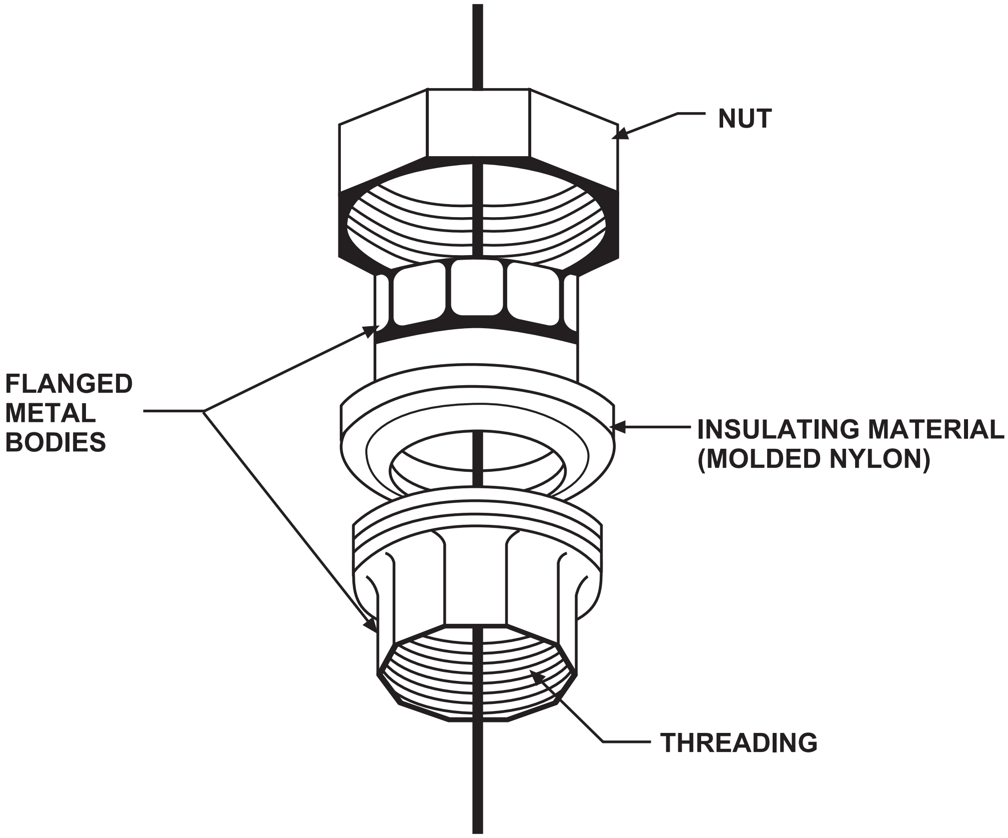
Isolating unions should be tested for effectiveness upon completion of their installation.

Monolithic Isolation Joint

The monolithic isolation joint is a complete factory assembled and factory tested isolation fitting. Only two (2) welds are required for installation. A monolithic isolation joint may be installed either above grade or buried below grade. Figure 6-10C shows a typical monolithic isolation joint.

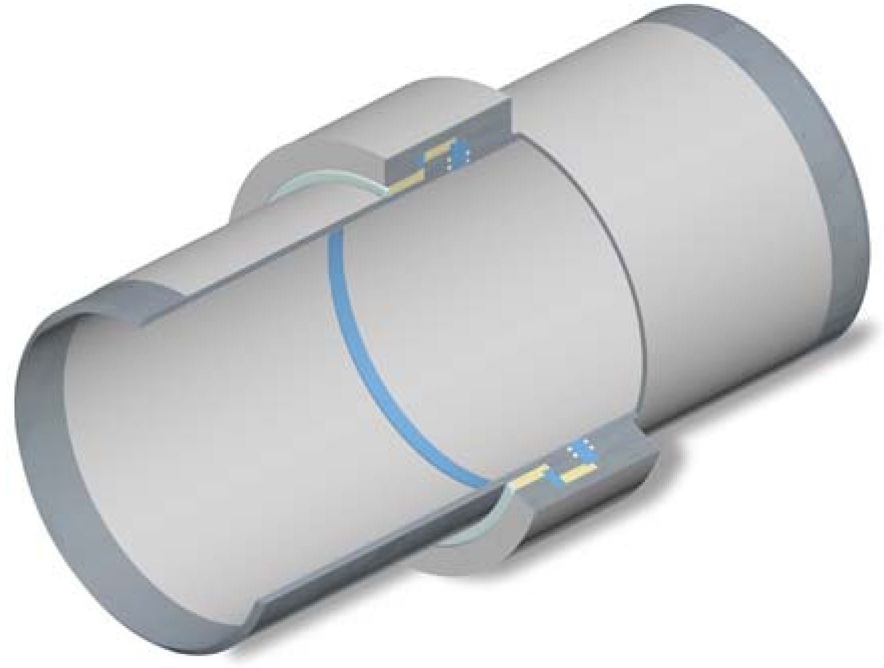
Isolating Couplings

The isolation of small low pressure piping (sizes up to 2") is normally accomplished using



TYPICAL ISOLATING UNION DETAIL

FIGURE 6-10B



TYPICAL MONOLITHIC ISOLATION JOINT

FIGURE 6-10C

fittings with non-conductive interiors. These fittings are normally constructed of cloth-based phenolic, nylon, or Delrin® interior of a quality which permits the machining of the couplings or bushings.

Larger lines can be effectively isolated by the use of compression - type couplings, with nylon and/or rubber gaskets used to prevent electrical contact between the two sections.

A short section of plastic pipe may also be used as an isolator.

All installations should be tested prior to backfill or upon completion of installation.

Testing Isolating Joints

Testing the effectiveness of the installed isolating joint can be done using one or more of the following methods:

Method No .1 - Interrupting Cathodic Protection Source

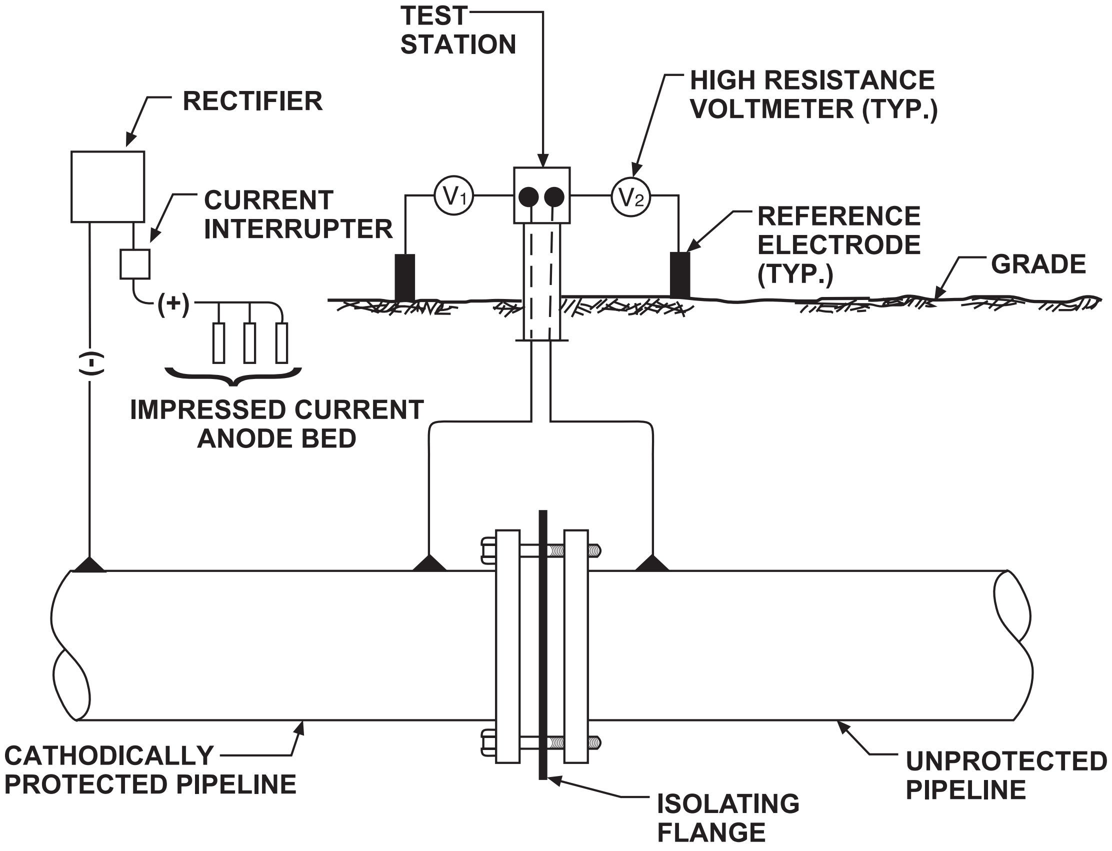
This method consists of setting up a temporary impressed current anode bed or utilizing an existing impressed current cathodic protection system anode bed.

Using the test set-up shown in Figure 6-11, measure the pipe-to-soil potential on each side of the isolating joint while interrupting the current output of the source. Potential readings should be taken on both sides of the joint using a high resistance voltmeter with respect to a close copper-copper sulfate reference electrode.

If the isolating joint is effective, the potential on the side of the joint which is connected to the impressed current system will change as the source is interrupted, while the potential of the opposite will remain constant or shift in the opposite direction. This method can be used for underground as well as aboveground isolating joints.

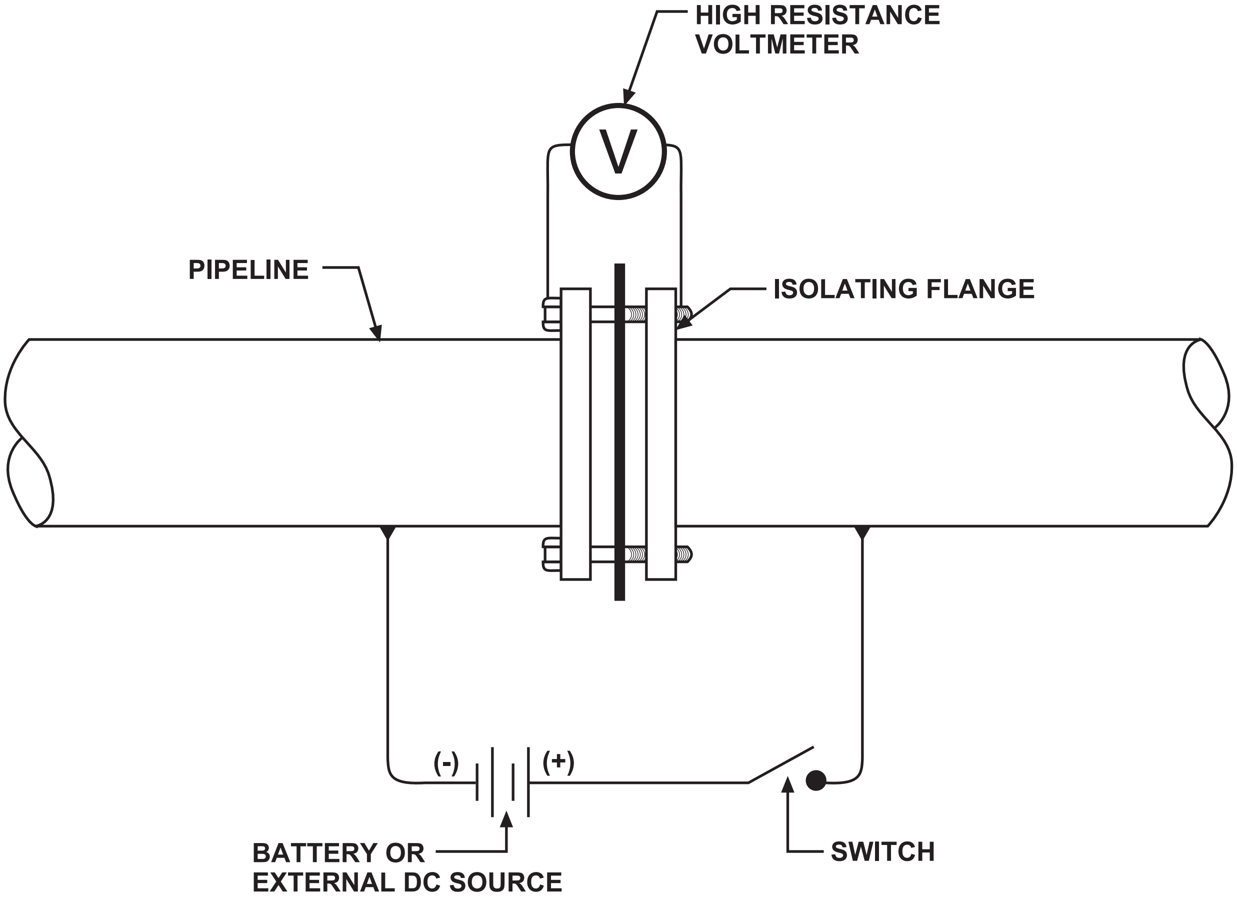
Method No. 2 - Testing for Shorted Bolts on Isolating Flanges Using a High Resistance Voltmeter

Referring to Figure 6-12, a battery or other external DC source is connected across the isolating joint. Moving from bolt to bolt, measure the potential between the two ends of each bolt while momentarily closing the switch. If a potential swing is noted when the switch is closed, this indicates that the bolt is shorted. Satisfactory isolated bolts will



METHOD #1 – TESTING UNDERGROUND ISOLATING JOINT

FIGURE 6-11



METHOD #2 – TESTING ABOVEGROUND OR FULLY EXCAVATED ISOLATING JOINT USING A HIGH RESISTANCE VOLTMETER

FIGURE 6-12

show no potential swing. This method can be used on aboveground joints or fully excavated underground joints.

Method No. 3 - Testing for Shorted Bolts on Isolating Flanges using a Magnetic Compass

As opposed to using a voltmeter, as described in Method No. 2 above, a magnetic compass can be used to locate shorted bolts. While interrupting the DC source, the compass is placed across the flange and moved from bolt to bolt. The compass needle will be deflected markedly at a shorted bolt because of the magnetic field surrounding the bolt through which current is flowing. If there is no deflection of the compass needle as it is placed directly above a bolt, this is a good indication that the bolt is isolated. See Figure 6-13 for a typical test set-up. This method can be used on fully exposed joints.

In order to determine that the desired test results can be achieved with the test set-up, and that the current capacity of the DC power supply is sufficient, the flanges can be temporarily shorted with a screwdriver. If the test set-up is valid, a deflection of the compass should be noted as it is placed directly above the screwdriver and the test current is applied.

Method No. 4 - Using Isolation Checker Instrument

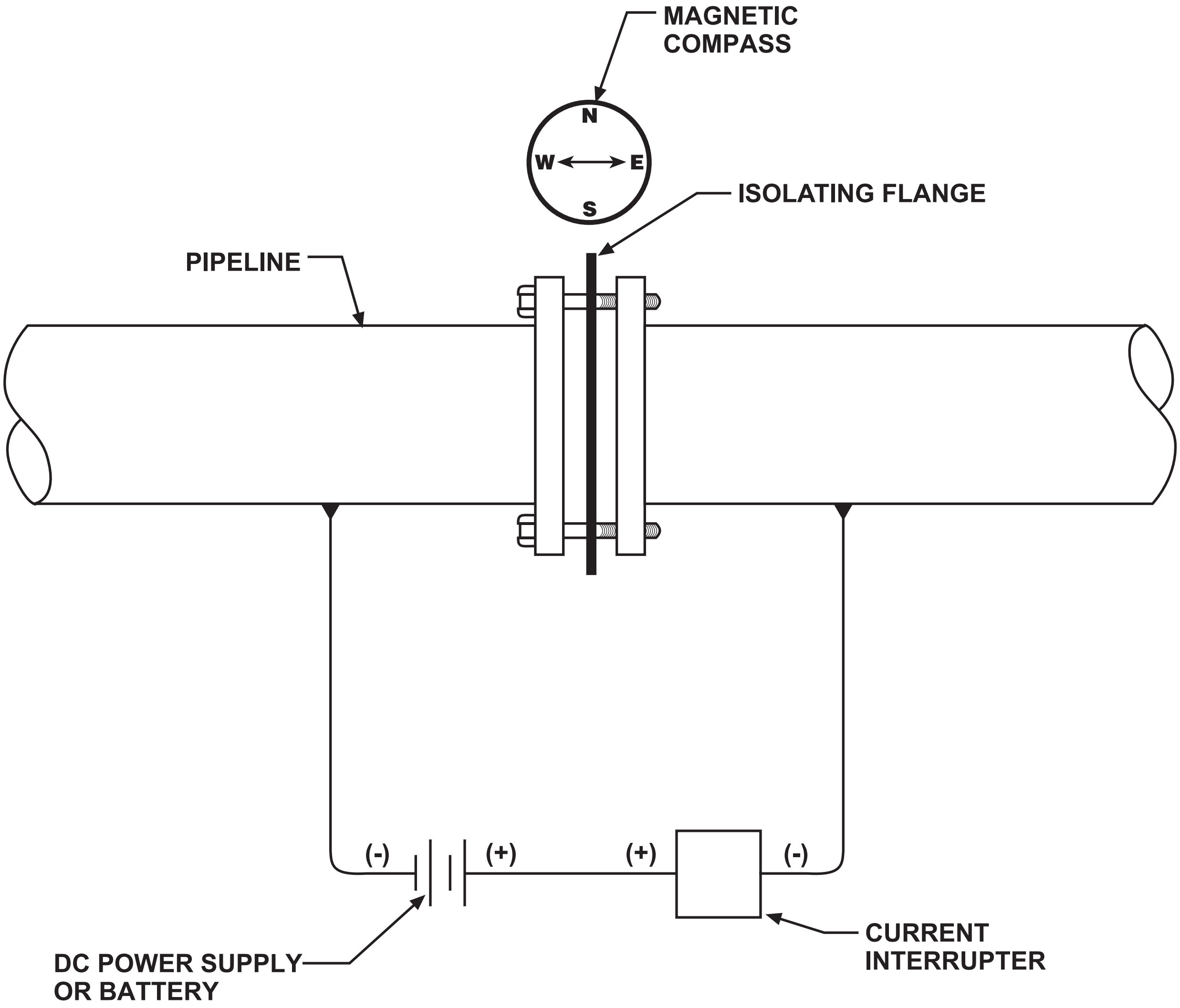
This method utilizes a test instrument known as an isolation checker. The isolation checker, as shown in Figure 6-14, has two test probes on the outside of its casing. These two probes are placed across the isolating joint and the meter read. A full-scale deflection (high reading) on the calibrated meter indicates that the joint is effectively isolating. If, however, the joint is shorted, the meter pointer will be deflected to or near zero on the scale. This method can be used in exposed joints.

Repair of Shorted Isolating Flange

If an isolating joint is found to be shorted/ defective it may be possible to repair it without taking the line out of service. This is possible if the short is due to an isolating bolt sleeve which has broken down or was improperly installed. If this is the case, the shorted bolt can be removed and the isolation replaced or properly reinstalled.

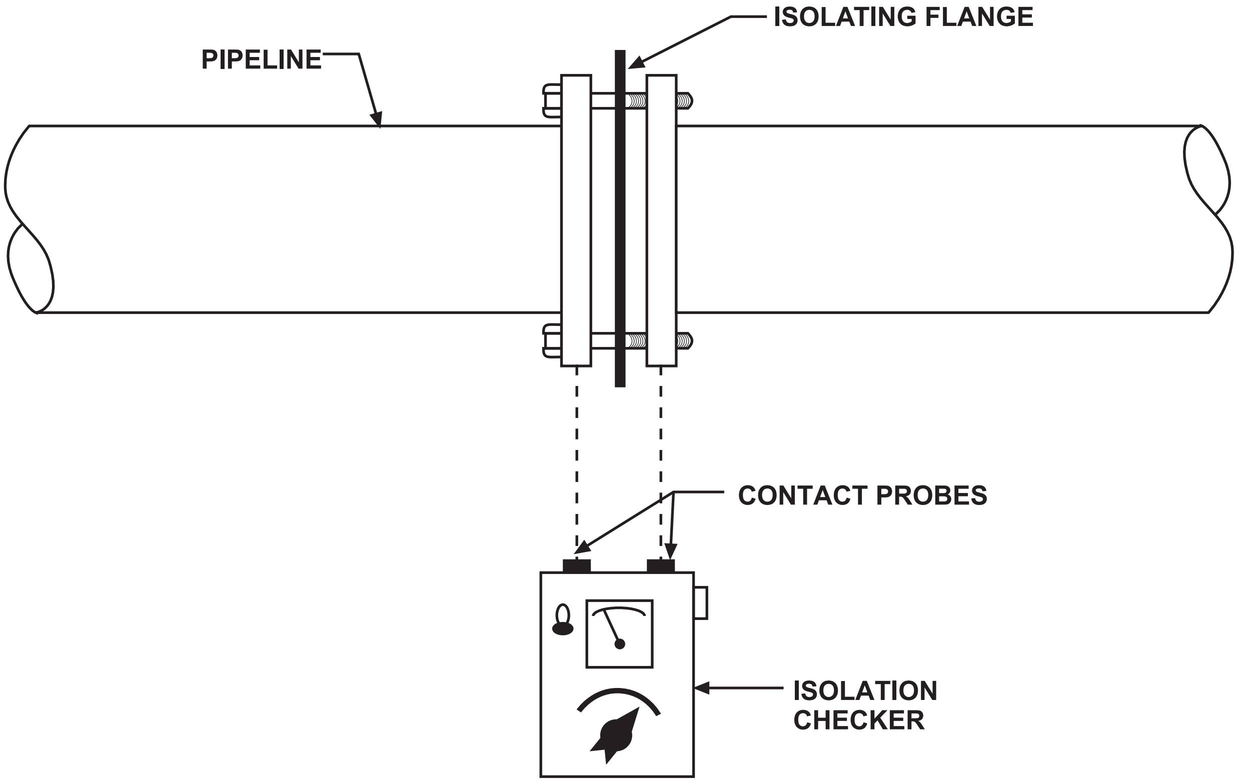
If an isolating flange is found to be shorted, and the above test methods indicate a faulty gasket, the line must be taken out of service and the gasket replaced.

Before disassembling the joint for the replacement of the gasket, a thorough visual



METHOD #3 – TESTING ABOVEGROUND OR FULLY EXCAVATED ISOLATING JOINT USING A MAGNETIC COMPASS

FIGURE 6-13



METHOD #4 – TESTING ABOVEGROUND OR FULLY EXCAVATED ISOLATING JOINT USING AN ISOLATION CHECKER

FIGURE 6-14

inspection of the joint should be conducted. This inspection may lead to the discovery of foreign material between the flange faces or the existence of a metallic conductor across the flanges, which may be shorting the joints.

TEST POINTS

The Purpose of Test Points

Test points are used to electrically contact a buried pipeline to facilitate the monitoring of cathodic protection levels and conducting tests associated with corrosion control.

Ideally, test points should be conveniently located and well-constructed to provide years of reliable service.

Types of Test Points

Each test point/station has a number of wires connected to the pipeline(s) on which tests are being performed. Usually, each wire is color coded by some scheme developed internally by the operating company. The color-coding is used to identify the pipe (or pipes) the wires are connected to and also to indicate the position of each wire with respect to other wires on the same pipe. Each company also develops names for standard types of test stations. Thus, a "Type 1" test station for company "A" may be a "Type B" test station for company "C.” Whichever way each type of test station is designated, knowledge of the type of test station and the wire identification code is essential.

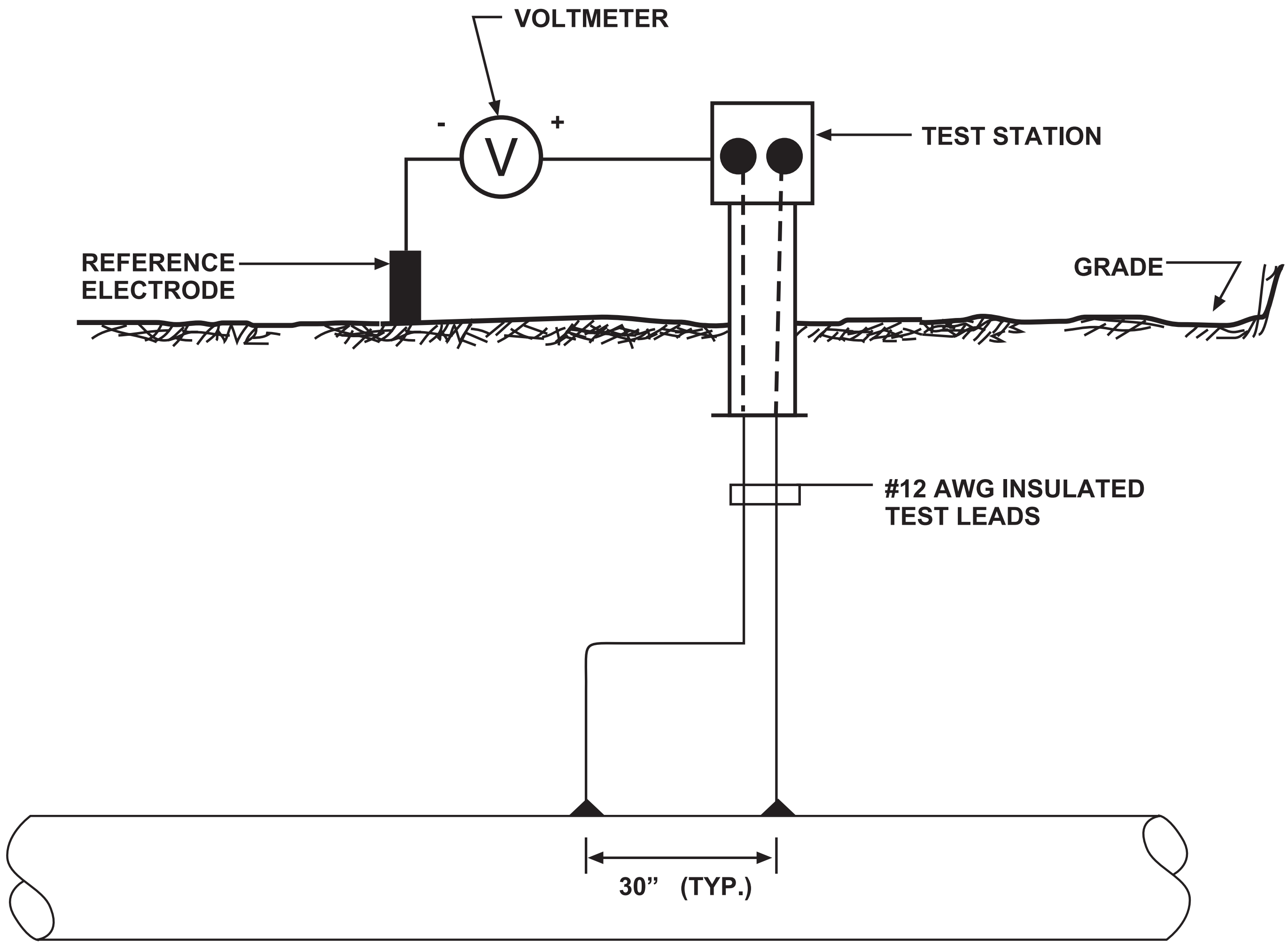
The following paragraphs contain a brief description of the types of tests that can be conducted at the different types of test stations.

1. Two-Wire Test Station

   The two-wire test station is basically a structure contacting test station. (See Figure 6-15).

   TESTS PERFORMED:

   P/S - The Pipe-to-Soil Potential measurement is the primary test made at a test station of this type. The procedure is as follows:



TYPICAL TWO WIRE TEST STATION

FIGURE 6-15

P/S - Pipe-to-Soil, close - One terminal of the voltmeter is connected to one of the test wires. The reference electrode is placed directly over the pipe and connected to the other terminal of the voltmeter.

P/S_R - Pipe-to-Soil, remote - One terminal of the voltmeter is connected to one of the test wires. The reference electrode is placed via a long wire at remote earth. The distance to remote earth varies with the quality of the pipe coating. It is a location outside of the cathodic soil gradient caused by cathodic protection or stray current entering the pipe.

2. IR Drop or Current Measuring Test Station

This four-wire test station is used for measuring line current flow along a pipeline (See Figure 6-16). The wires are color coded or otherwise identified so that their position on the pipe with respect to some reference such as product flow is known. When the 100 ft. (typical) span between the inner wires is a calibrated span (See Figure 6-17) the calibration factor, K, can be applied to the E_{mv} (actual) reading and the magnitude of the line current flow in amperes determined. The direction of line current flow is also determined by observing the polarity of the reading. In cathodic protection testing convention, current flows from (+) to (-). For the polarities indicated on the sketch, a $+E_{mv}$ reading would indicate a line current flow in the direction opposite to pipeline product flow.

To calibrate an IR drop span, carry out the following procedure:

a. Connect the circuit elements as shown on diagram.

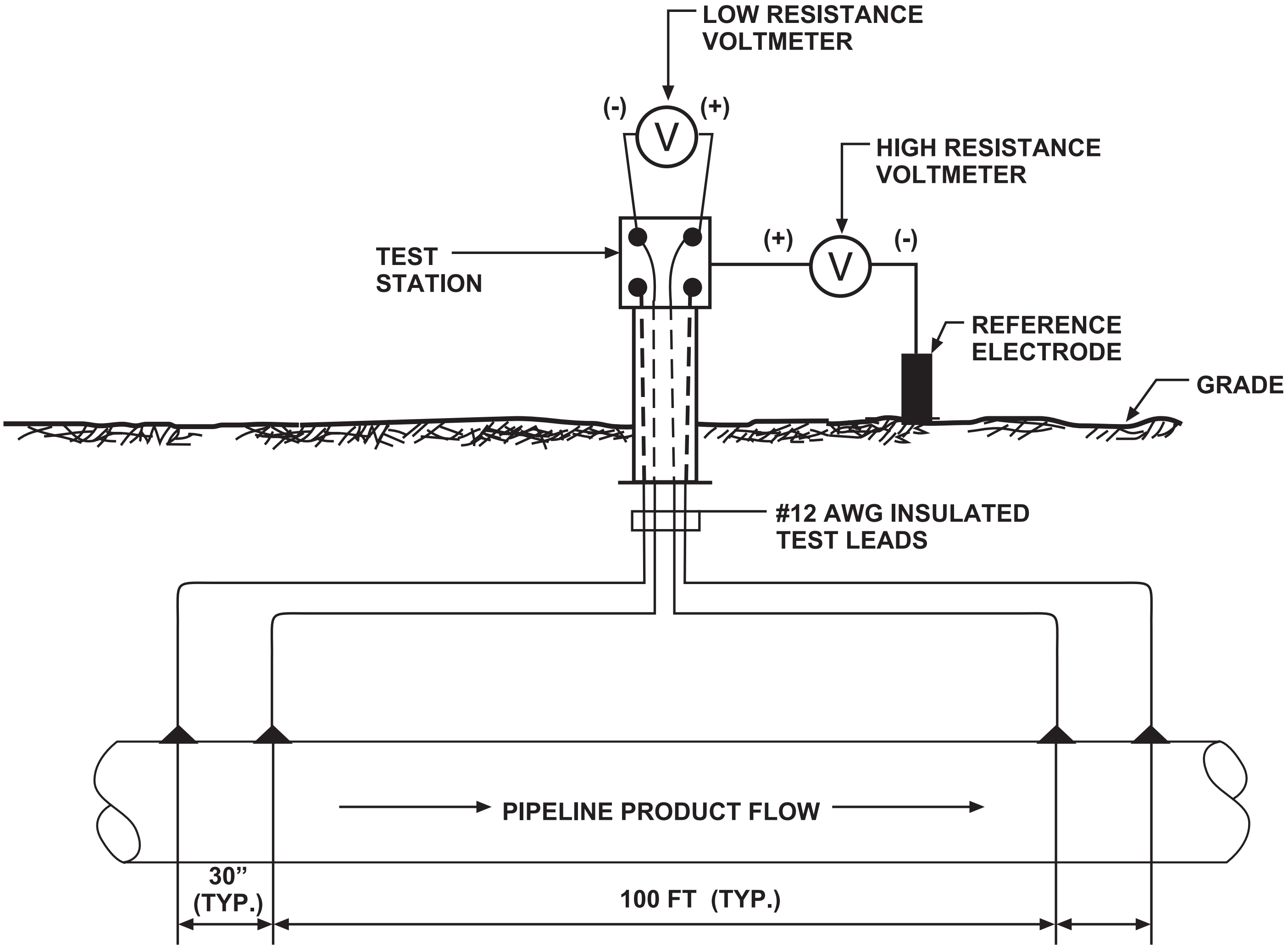
b. Close the switch (make contact to ammeter negative terminal).

c. Immediately after the circuit is closed, read current (I) and IR Drop (E_{mv}) simultaneously. Record the readings.

d. Open the switch (break contact).

e. Immediately after the circuit is opened, read the current (I) and IR drop (E_{mv}) again. The current will be "0", but there may be an IR drop (E_{mv}) because of existing line current flow.

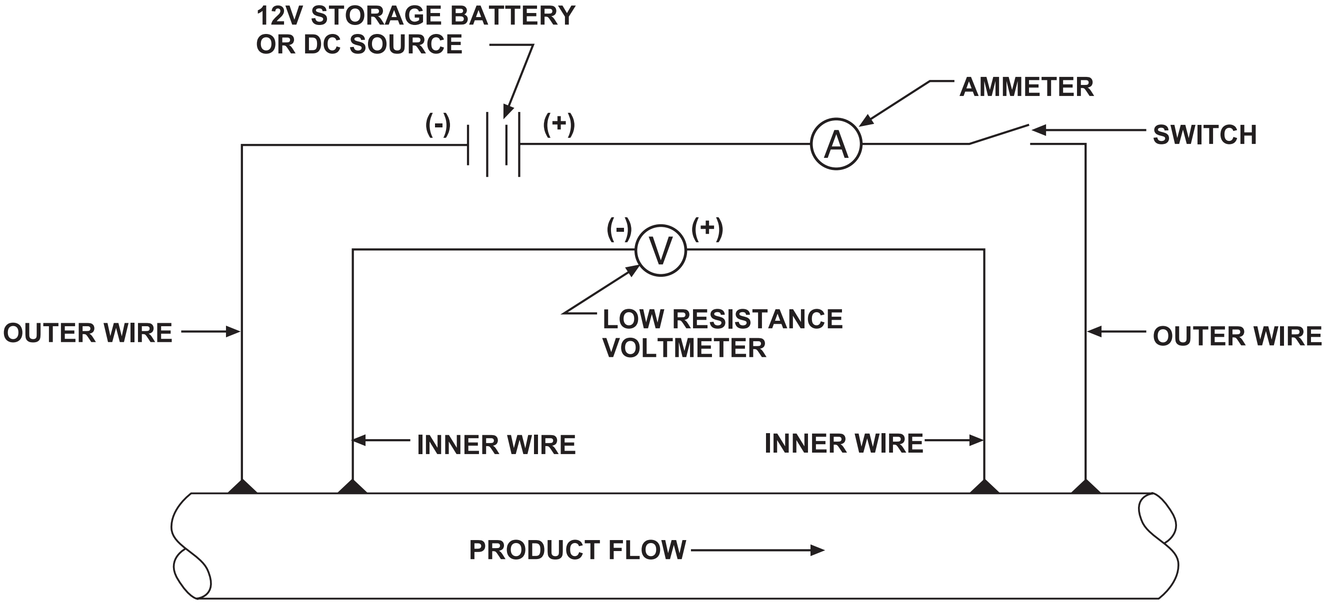
f. Record these readings.



NOTE: TEST LEADS SHOULD BE COLOR CODED

IR DROP TEST STATION

FIGURE 6-16



CALIBRATION OF IR DROP SPAN

FIGURE 6-17

Repeat steps a, b, c, d, and e several times in order to avoid possible errors. If there are no apparent errors, and if the readings vary slightly, (a normal occurrence because of battery weakening) calculate average readings for I and E_{mv}.

g. Calculate the calibration factor (K) as follows:

$$K = \frac{I_{on} - I_{off}}{E_{mv\ on} - E_{mv\ off}} = \frac{\Delta I}{\Delta E_{mv}} = \text{amps / mv}$$

Applying typical numbers that might be found on a 12-inch pipeline:

$$K = \frac{+40 - 0}{+16.5 - (-0.05)} = \frac{40}{16.55} = 2.417\ \text{amps / mv}$$

Note that there was some residual current flow on the pipe after the circuit was opened ($E_{mv\ off}$ was not 0). Note also that the $E_{mv\ off}$ reading was of the opposite polarity, indicating that the residual line current flow (caused by factors other than the test current) is flowing in the direction of line product flow, as determined by the polarities observed for this test.

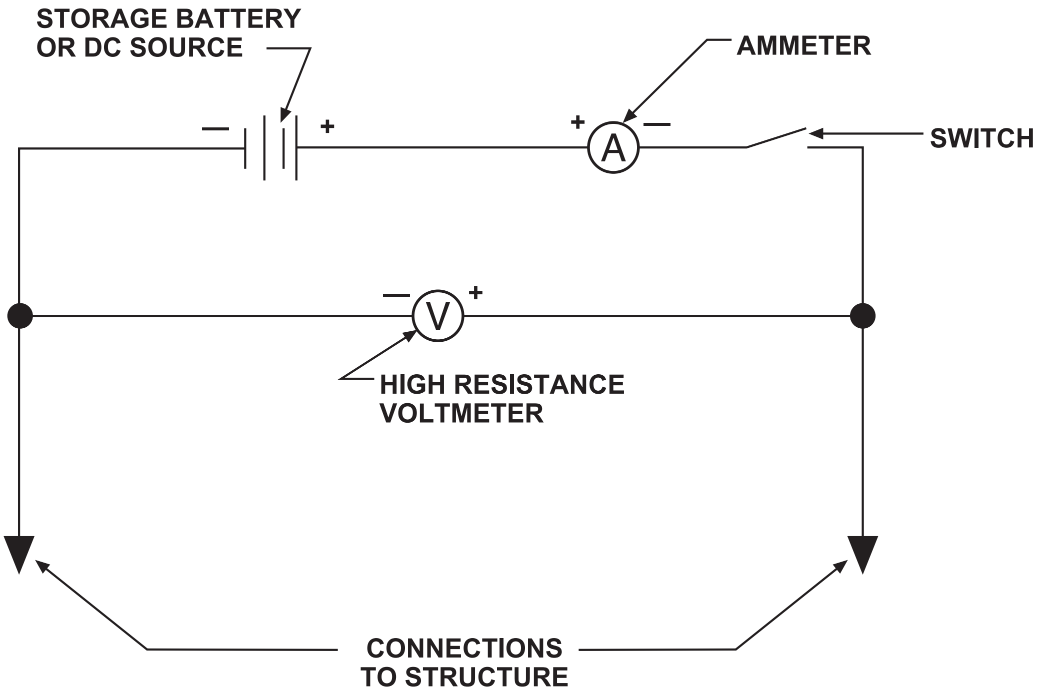
The magnitude of the residual line current flow is easily determined:

$$I = 0.05\,\text{mv} \times 2.417\ \text{amps / mv} = 0.121\ \text{amps}$$

A test station having only 1 wire on each side of the measurement span can be used in lieu of a four-wire calibrated span test station. This requires the use of tables that indicate the amount of current required for a one millivolt drop for a given length, size and wall thickness of pipe. Therefore, if the spacing between the test wire connections is known, and the pipe size and wall thickness are known, the calibration factor of the measurement span can be calculated.

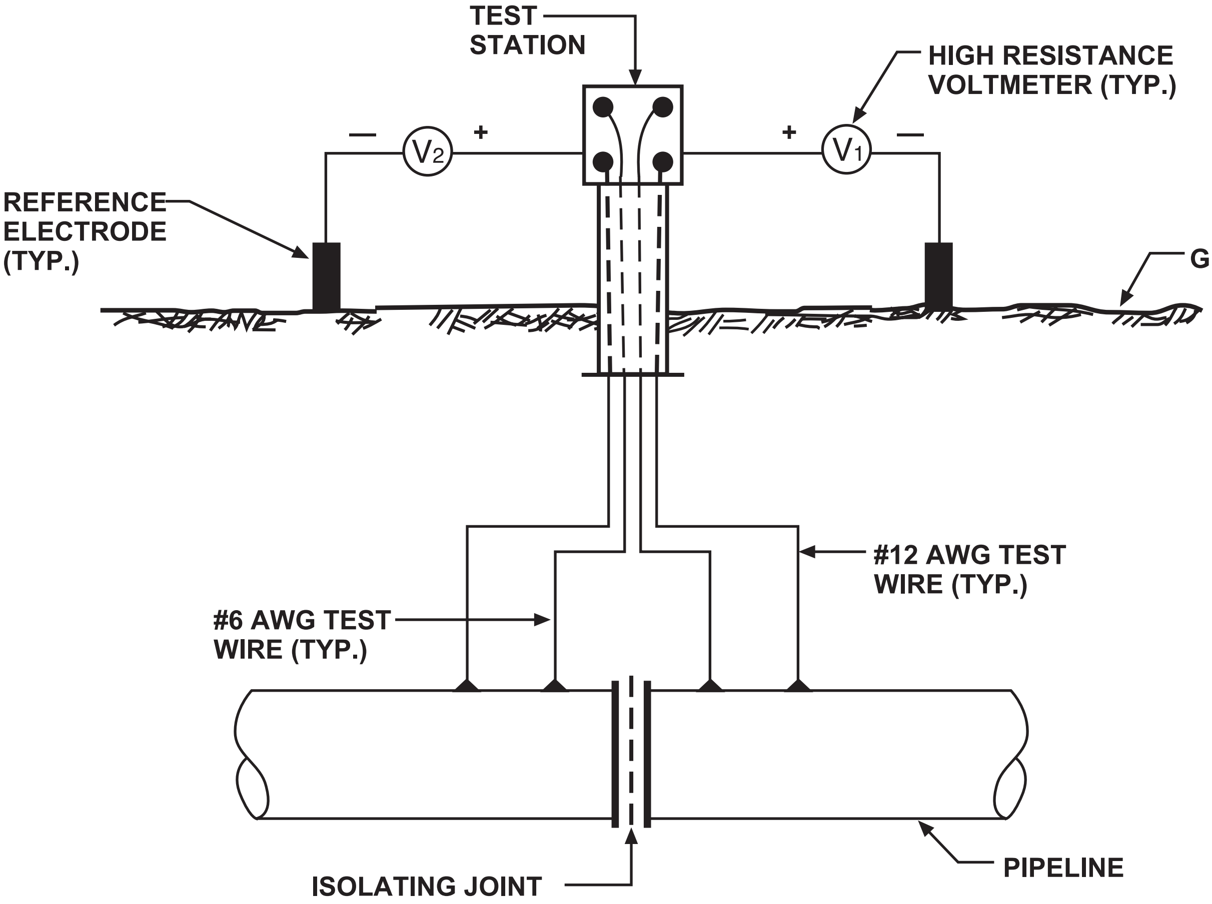
3. Isolating Joint Test Point

As mentioned earlier, isolating joints are used to electrically isolate a pipe for cathodic protection sectionalizing purposes, or when ownership of the pipe changes, such as at a delivery point at a gas metering station or oil terminal. The inner wires on the diagram (Figure 6-19) are usually heavier (for low resistance purposes) in case it is necessary to insert a resistance bond across the isolator.



DETERMINING CIRCUIT RESISTANCE OF TWO WIRES CONNECTED TO THE SAME STRUCTURE

FIGURE 6-18



NOTE: TEST LEADS SHOULD BE COLOR CODED.

TYPICAL ISOLATING JOINT TEST STATION

FIGURE 6-19

TESTS PERFORMED:

Pipe-to-soil potential (P/S) on each side of the isolator

Internal Resistance (R_{INT}) of the isolator (for checking isolation resistance) by:

Measurement of Resistance Across Isolating Joint or

Pipe-to-Soil Measurement Method (Figure 6-20)

In an isolating joint, the effective internal resistance measured will be the sum of the resistance to earth (R_E) of each pipe section. These resistances are in series with each other and in parallel with the actual resistance of the isolating joint. The resistance to earth of each pipe section is shown in Figure 6-20 for illustrative purposes.

Procedure:

a. Connect ammeter, battery and voltmeter No. 1 as shown in Figure 6-20.

b. Close switch (make contact).

c. Read current and pipe-to-soil potential (P/S) values simultaneously. Record the data.

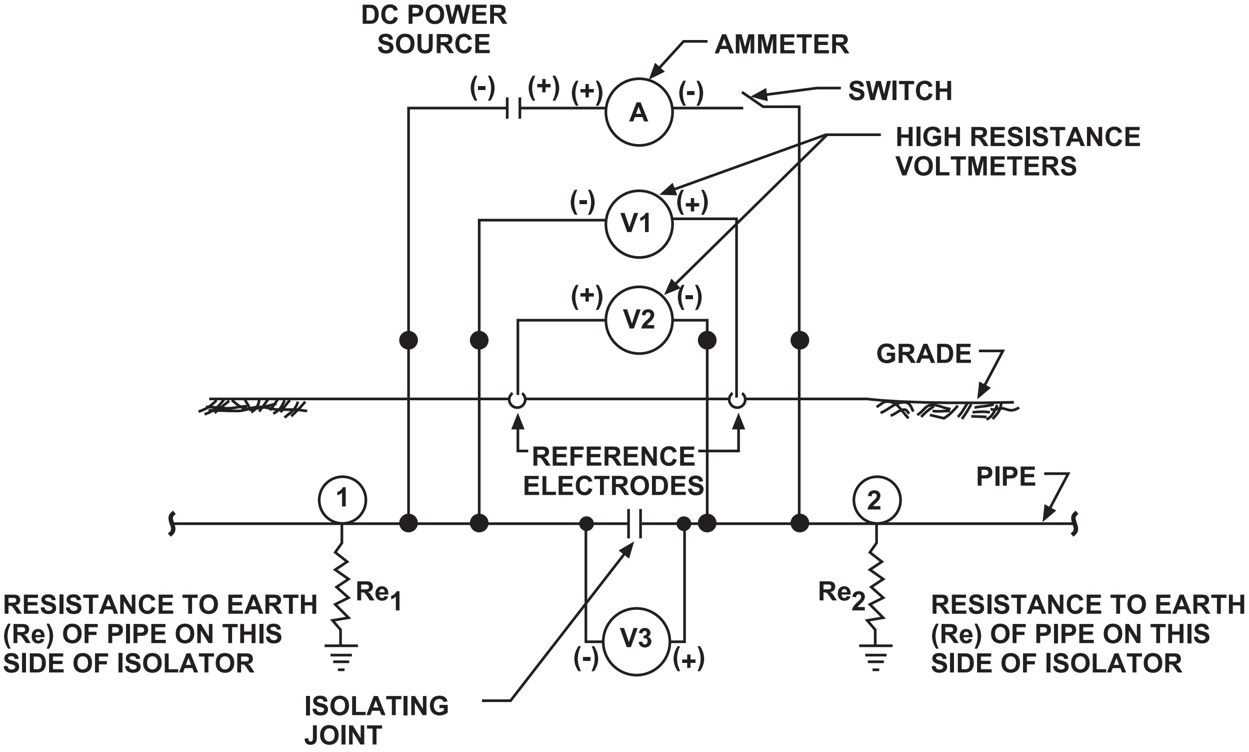
d. Open switch (break contact).

e. Read current (should be "0") and pipe-to-soil potential (P/S) simultaneously. Record the data.

f. Repeat the last four steps several times to ensure there are no errors.

g. Remove voltmeter No. 1. Connect voltmeter No. 2 as shown.

h. Repeat the above procedure.



MEASUREMENT OF RESISTANCE ACROSS ISOLATING JOINT

FIGURE 6-20

Calculation:

$$R_{INT} = \frac{(P/S_{1\,ON} - P/S_{1\,OFF}) + (P/S_{2\,ON} - P/S_{2\,OFF})}{I_{ON} - I_{OFF}}$$

$$R_{INT} = \frac{\Delta P/S_1 + \Delta P/S}{\Delta I}$$

It is very important to make a sketch of the polarities used for the test, because these must be taken into account when algebraically adding $\Delta P/S_1$ and $\Delta P/S_2$. With the test arrangement polarities as shown, $\Delta P/S_1$ will be of the opposite polarity to $\Delta P/S_2$.

In effect, with the polarities shown, pipe No. 2 is being made an anode with respect to pipe No. 1 when the switch is closed (contact made). Hence, cathodic protection is being applied to pipe No. 1. The needle on voltmeter No. 1 will move to the right, while the needle of voltmeter No. 2 will move to the left.

Potential Across Joint Method

Where it is fairly certain that the isolator is effective, the following procedure may be used to determine resistance.

a. Connect ammeter, battery and voltmeter No. 3 as shown in Figure 6-20.

b. Close switch (make contact).

c. Read current and voltage values simultaneously.

d. Open switch (break contact).

e. Read current (should be “0") and voltage simultaneously.

f. Repeat the last four steps to ensure there are no errors.

Calculation:

$$R_{INT} = \frac{V_{3\,ON} - V_{3\,OFF}}{I_{ON} - I_{OFF}} = \frac{\Delta V_3}{\Delta I_3}$$

Note: In the absence of heavy stray current, a reading other than 0 of $V_{3\ OFF}$, or a voltmeter reading alone (without battery or ammeter) is usually indicative of an effective isolator.

4. Pipeline Casing Test Station (Figure 6-21)

Casings are used on pipelines where they cross under railroads, highways or other locations where heavy loads are expected. Some authorities require casings in front of schools (to carry product a distance away in the event of carrier pipe rupture).

Test stations are normally installed at casings in various configurations. If the casing is 50 feet long or longer, a test station similar to the one shown in Figure 6-21 is also installed at the other end of the casing.

Some casings are installed with vent pipes. Sometimes there are vent pipes at one end only, and sometimes there are vent pipes at both ends. The vent pipe can serve as one of the two wires connected to the casing.

TESTS PERFORMED:

P/S - Pipe-to-Soil Potential, as previously described.

C/S - Casing-to-Soil Potential, as previously described for pipelines.

$R_{P\text{-}C}$ - Pipe-to-Casing Resistance - The test arrangement and procedures are exactly the same as described for measuring the internal resistance (R_{INT}) of an isolating joint.

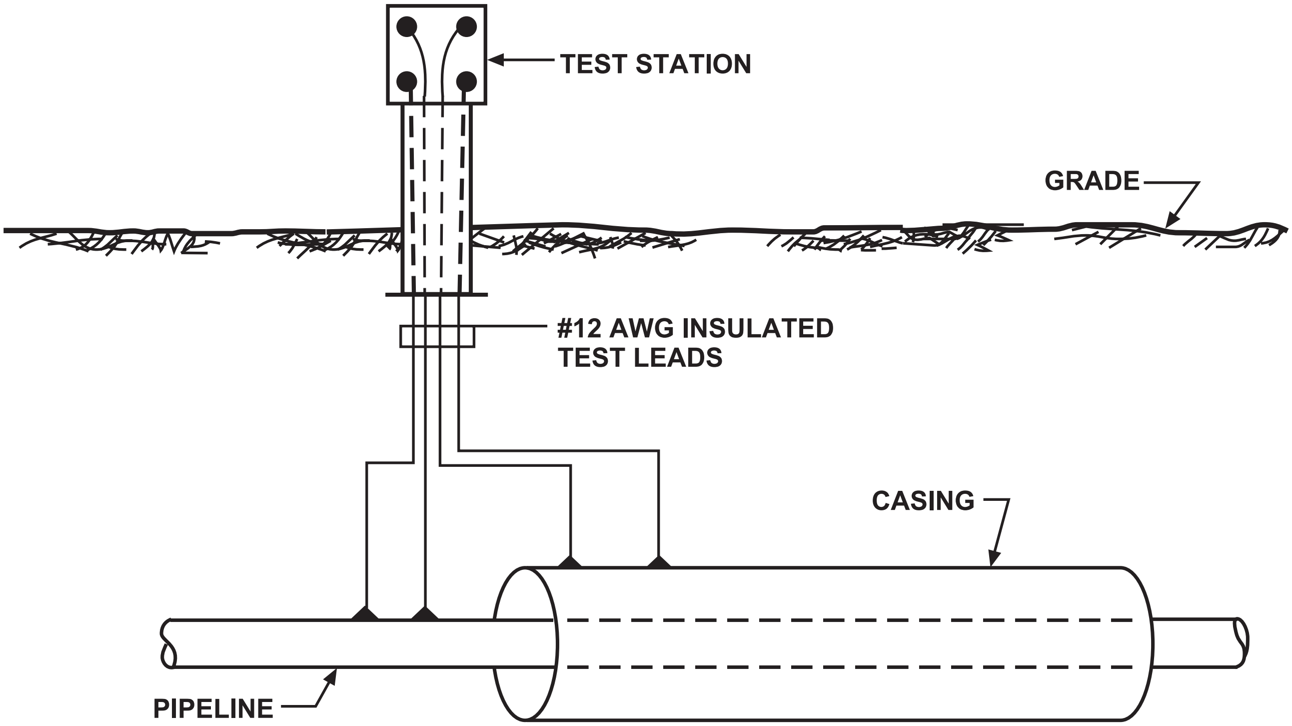
5. Foreign Pipeline Crossing Test Station (Figure 6-22)

For purposes of this discussion, a "foreign" pipe is any pipe which is not electrically connected to the pipe under test or under cathodic protection.

Test stations are necessary at all crossings of foreign pipelines. If cathodic protection is applied to either one of the pipes, there is always a possibility of stray current interference and corrosion on the other pipe.

TESTS PERFORMED

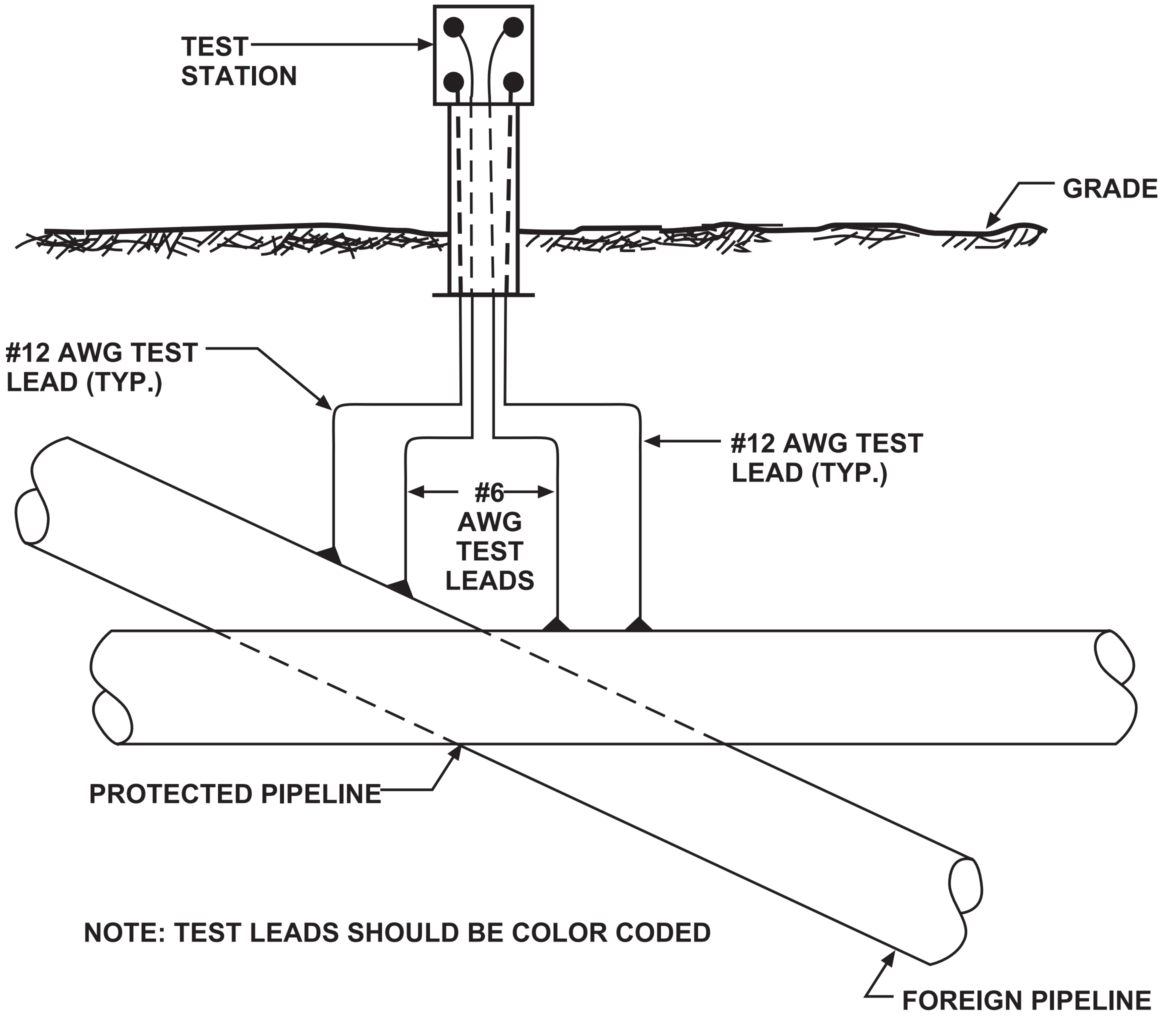
P/S - Pipe-to-Soil Potential - Pipe under test



NOTE: TEST LEADS SHOULD BE COLOR CODED

TYPICAL PIPELINE CASING TEST STATION

FIGURE 6-21



TYPICAL FOREIGN PIPELINE CROSSING TEST STATION

FIGURE 6-22

P/S - Pipe-to-Soil Potential - Foreign pipe

R_{INT} - Internal resistance between pipes

E_{OC} - Open circuit potential between pipes

Combinations of these tests and the calculations of the test results are used for determining if stray current interference exists, and if the interference exists, the calculation of the resistance of the bond required to clear the interference (R_{BOND}) can be made (See Chapter No. 5).

Pipe-to-soil potential measurements at foreign crossings should be made with the reference electrode placed directly over the crossing.

For Open Circuit potential tests, the voltmeter is connected between one wire of the pipe under test and one wire of the foreign pipe, and the reading is taken.

6. Galvanic Anode Test Station (Figure 6-23)

Galvanic cathodic protection anodes are sometimes connected to pipes through test stations so that their performance may be monitored. Groups of galvanic anodes are also sometimes connected to a single header cable, which is usually brought up to a test station for testing purposes.

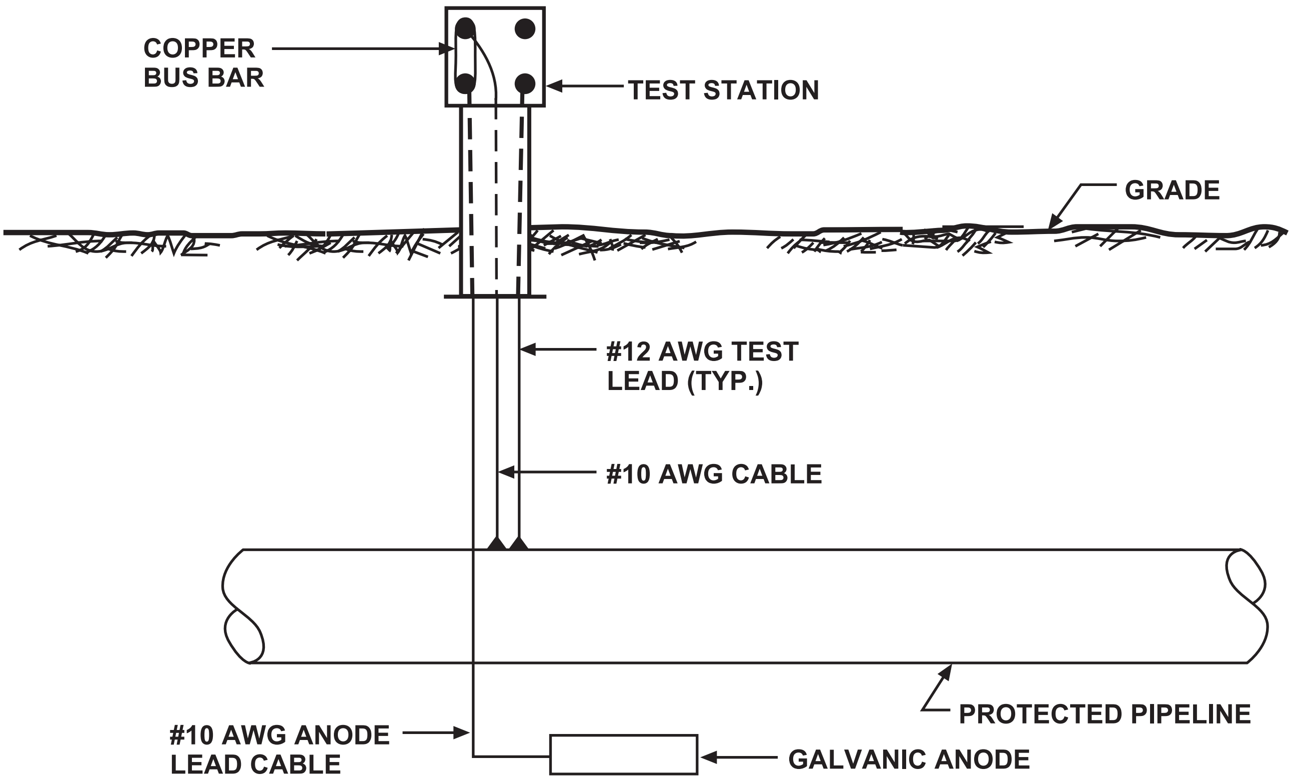
TESTS PERFORMED:

P/S - Pipe-to-soil potential, with anodes connected or disconnected. Pipe-to-soil potentials are always measured through a wire, which is not carrying current.

I_{ANODE} - Anode current. This is measured by breaking the anode to pipe connection and inserting an ammeter between the pipe wire and the anode wire. Current flow through the ammeter should be from pipe to anode. See Figure 6-24 - Method A.

Depending on the resistance involved, the ammeter resistance can significantly alter the circuit resistance, resulting in a current reading that is lower than the actual current.

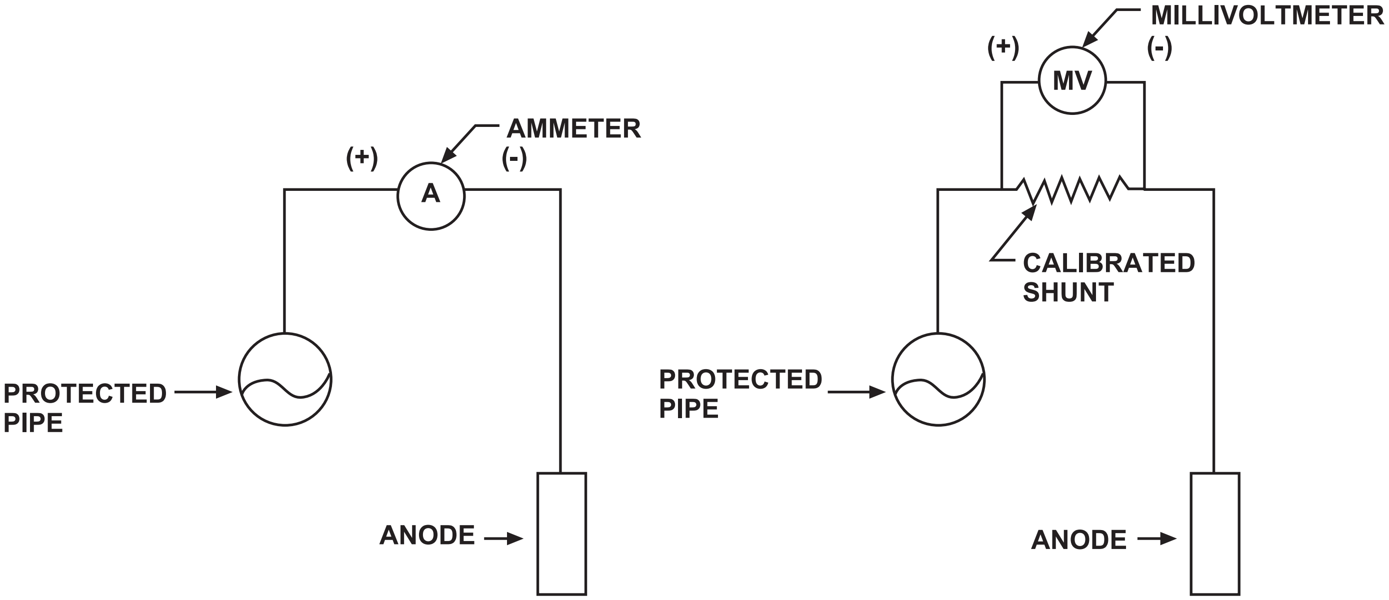
Small current measuring shunts can be permanently installed in test stations so that the anode current can be measured by the IR drop method without disturbing the



NOTE: TEST LEADS SHOULD BE COLOR CODED

TYPICAL GALVANIC ANODE TEST STATION

FIGURE 6-23



METHOD A

METHOD B

ANODE CURRENT MEASUREMENT METHODS

FIGURE 6-24

anode circuit. (See Figure 6-24 - Method B). The resistance of the chosen shunt should be dependent upon the current anticipated at the test station. Anode currents usually vary between a few milliamperes up to several hundred milliamperes, depending upon the number of anodes and the soil resistivity. The shunt must be selected to provide a good indication on the millivoltmeter.

Installation of Test Points

Test points/stations should be located so that they are readily accessible for testing. Test stations can be either aboveground mounted or flush mounted.

Flush mounted test stations are normally used in areas where an aboveground mounted test station may not be feasible due to vehicular traffic in the area or due to right-of-way limitations. Flush mounted test stations are less vulnerable to vandalism and therefore, their use in problem areas may be desirable. Figure 6-25 illustrates a typical flush mounted test station installation.

Aboveground post mounted test stations, as shown in Figure 6-26, are normally used on cross country pipeline installations to facilitate the locating of test points for testing.

Regardless of the type of test station installed, the following basic installation practices should be followed:

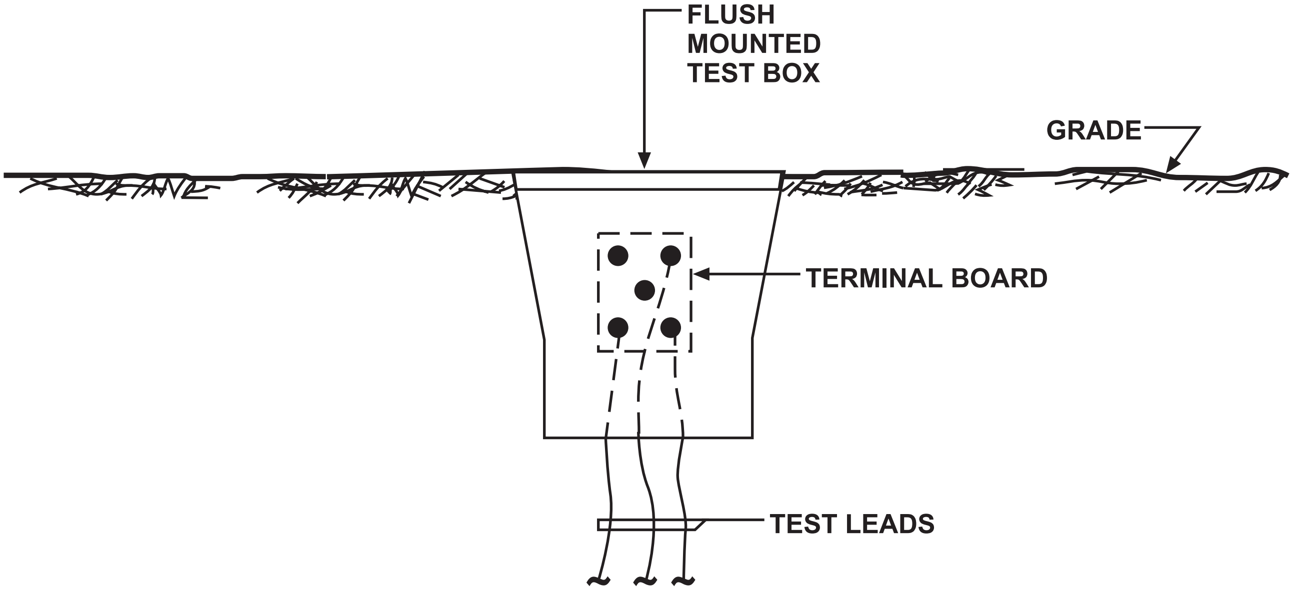
1. Test stations should be located as close as possible to the pipeline(s) being tested, preferably directly above it. This will reduce the chances of test leads being damaged by construction in the area of the pipeline. Installation costs would also be reduced and any required troubleshooting simplified.

2. Test lead connections to pipe should be made using an exothermic weld process. The weld connection should be thoroughly inspected and tapped lightly with a nonferrous metal hammer to make sure it is secure.

3. The weld and surrounding exposed pipe and wire should be coated with a coating system that is compatible with the existing coating.

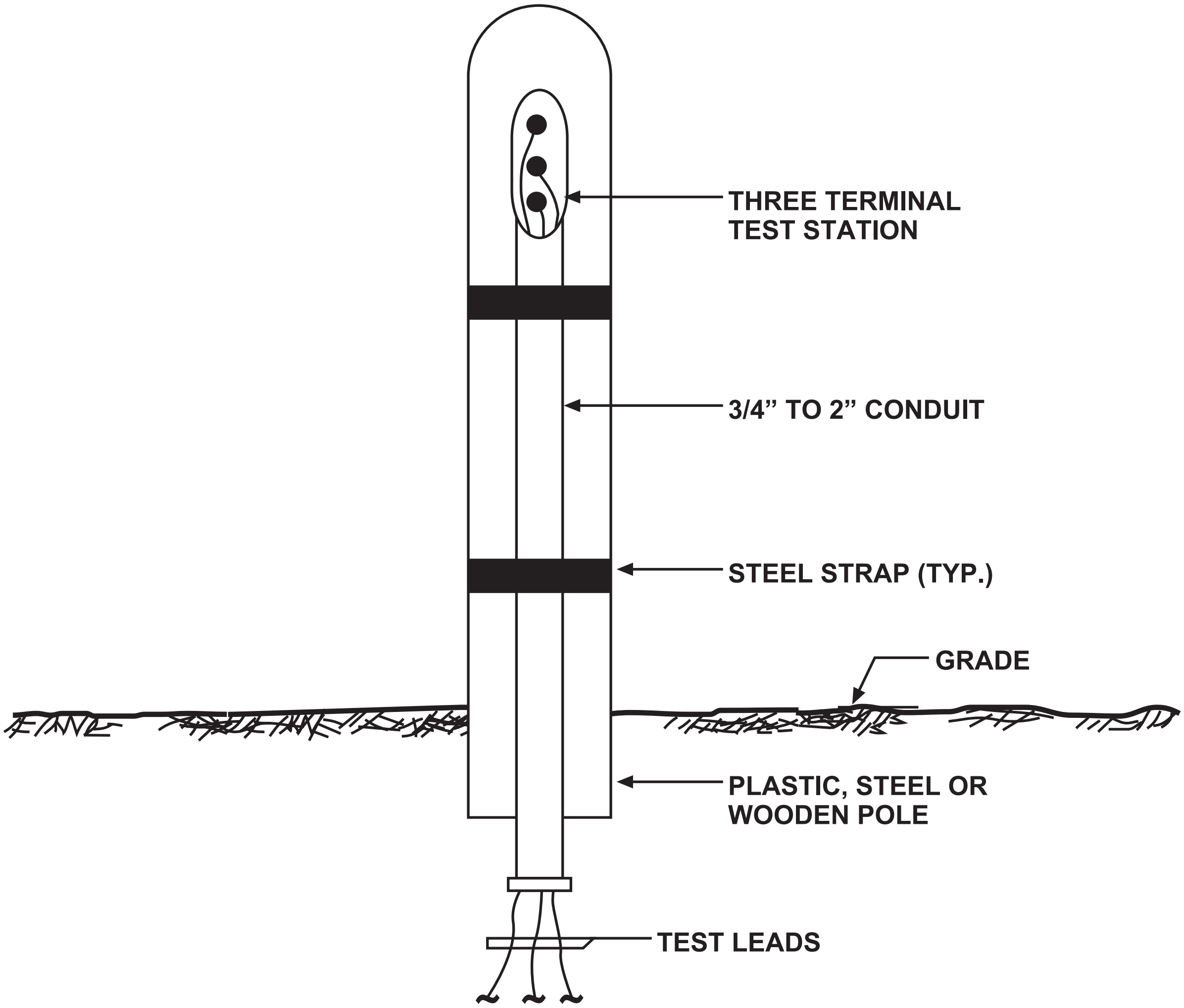
4. Sufficient slack should be left in the test wires just below the test points, to prevent any damage or breaks due to soil settlement after backfill.

5. Any damage to test wire insulation during installation must be repaired. Repairs



TYPICAL FLUSH MOUNTED TEST STATION

FIGURE 6-25



TYPICAL POLE MOUNTED TEST STATION

FIGURE 6-26

should be made using two half-lapped layers of rubber electrical tape followed by two half-lapped layers of plastic electrical tape.

6. Approximately 9 inches of coiled test wire should be provided inside the test box so that the wires can be raised out of the box for testing.

7. Backfill for test wires should be free of stones larger than ¼ inch and other foreign material which may damage the wire insulation.

8. Accurate test station location drawings and electrical termination details should be prepared showing each test point. The importance of color coding and recording wires and their positions on the pipe cannot be overemphasized. Inaccurate data may be worst than none at all. Drawings should be kept for permanent record, to be referred to for future testing.

CONCLUSIONS

Counter corrosion methods should be considered when designing a new pipeline installation. Corrosion control measures should include, but not be limited to, the use of protective coatings. A knowledgeable coatings engineer should make the selection of the protective coating system to be used. Cathodic protection systems must be used in conjunction with a good protective coating to ensure that the pipeline meets its designed life expectancy.

Cased crossings are used for mechanical protection of a pipeline and isolating joints are used to electrically separate sections of a pipeline. Both of these appurtenances can short out and tests should be conducted to ascertain isolation. Test points are installed along a pipeline to allow conducting tests. Others may be required for cathodic protection purposes.

Chapter 7 - Rectifiers

INTRODUCTION

This chapter will discuss the basic operation of cathodic protection rectifiers, preventive maintenance procedures and important information that is necessary when specifying and purchasing rectifiers.

CATHODIC PROTECTION SYSTEM POWER SUPPLIES

As discussed in Chapter 3 of this course, various types of equipment can be used to provide DC power for impressed current cathodic protection systems. These sources include the following:

1. Rectifiers

   Sometimes called transformer/rectifiers, these are the most commonly used DC source for cathodic protection system applications. A rectifier converts AC power to DC power.

2. Solar Power Supplies

   These units are used in areas where sunlight is available for a large percentage of the time. Photovoltaic solar arrays convert sunlight to DC power.

3. Thermoelectric Generators

   Thermoelectric Generators produce power by the direct conversion of heat into electricity. Power is produced by maintaining a temperature difference across a thermopile, an assembly of semi-conductor thermoelectric elements. Combustion of Natural Gas or Propane provides the heat while natural convection provides the cooling required to create this temperature differential.

4. Engine Generator Sets

   These units consist of a fuel-powered engine and an AC generator used to provide the input power to a rectifier unit.

5. Turbine Generator Sets

   Turbine generator sets utilize the product flow or gas pressure in the pipeline to drive a small turbine that in turn drives a DC power generator.

6. Wind Powered Generators

   These units are used in areas where a fairly constant breeze/wind is blowing. The wind drives a turbine assembly that in turn drives a generator assembly that provides the input to a rectifier unit.

REVIEW OF ELECTRICAL FUNDAMENTALS

Following is a review of the fundamentals concerning the generation of AC power and its conversion to DC power. The review of these principals will help corrosion personnel understand the operation of a cathodic protection rectifier.

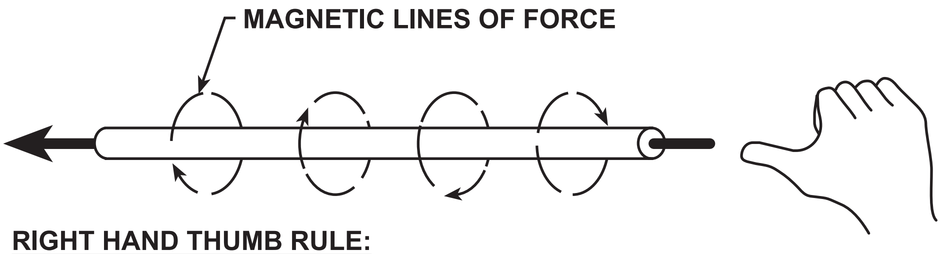
THEORY

A rectifier converts or rectifies alternating current (AC) electricity to direct current (DC). DC current is defined as a current that is always flowing in the same direction. AC current on the other hand is current which periodically reverses its direction of flow. In the United States, our AC power is supplied at a frequency of 60 cycles per second, which means that the direction of the current flow reverses every 8.33 milliseconds.

The following discussion will review the principles of converting AC power to DC power. During this discussion, we will be assuming “conventional” current flow where current is assumed to flow from positive to negative through the load.

A relationship exists between electricity and magnetism. This relationship provides the means of converting electrical energy into mechanical energy and vice versa. We can also convert electrical quantities to magnetic and back to electrical quantities again.

Current can be defined as the flow of electrons through a conductor, and when current flows through a conductor, a magnetic field is formed around it. The direction of the invisible magnetic lines of force can be determined by using the “right hand thumb rule” as shown in Figure 7-1. The magnitude and direction of the magnetic field is directionally proportional to the amount and direction of electric current flow.



RIGHT HAND THUMB RULE:

GRASP THE CONDUCTOR WITH THE RIGHT HAND. WHEN THE THUMB POINTS IN THE DIRECTION OF CURRENT FLOW, THE FINGERS POINT IN THE DIRECTION OF THE INVISIBLE MAGNETIC LINES OF FORCE.

MAGNETIC FIELD AROUND A SINGLE CONDUCTOR

FIGURE 7-1

An extension of the "right hand thumb rule" is shown in Figure 7-2. When a current flows through a coil of wire, an additive effect occurs between adjacent turns of wire thus creating a stronger magnetic field.

Just as current flow creates a magnetic field around a conductor, magnetic lines of force across a conductor creates a voltage or electromotive force (EMF) in it. If there is an electrical path or circuit, electrical current will begin to flow. The direction of the EMF can be determined using Fleming's "3-Finger Rule" as shown in Figure 7-3.

These relationships are always the same and are used in the operation of generators, motors, transformers, meters, and many other pieces of electrical equipment. This is illustrated by Figure 7-4. Figure 7-4A shows that a current is induced or caused to flow when magnetic lines of force are cut by a conductor. This principal is used in the operation of a current generator that converts mechanical energy to electrical energy.

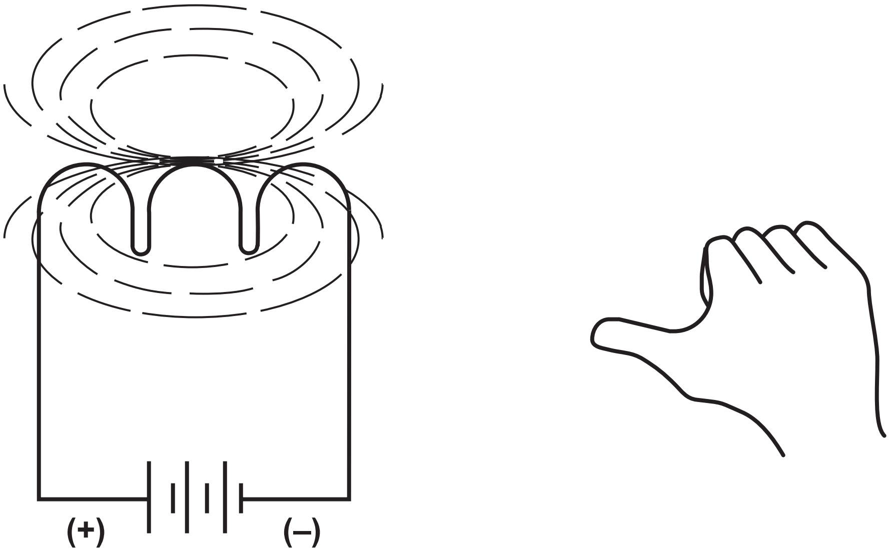
Figure 7-4B illustrates that when a current flows in a magnetic field, a force is exerted on the conductor. This is the opposite effect of that shown in Figure 7-4A. Electrical energy is converted to mechanical energy. This is the principal behind the operation of an electric motor.

If the magnetic field influencing the conductor were changed in direction alternately, the induced current in the conductor would be alternating. This principal is used in the operation of electric transformers and is illustrated in Figure 7-4C. Figures 7-3 and 7-4 show how electrical current can be generated by moving a conductor within a magnetic field, cutting lines of flux. This principal can be extended to generate alternating current.

AC power is generated as follows (refer to Figure 7-5). Starting clockwise from the position shown, "A" first moves up through the magnetic field as "B" moves down until they have exchanged positions. Continued rotation brings "A" down as "B" moves up, reversing the polarity of the generated voltage. Each revolution of this simple generator represents one cycle of alternating current. Alternating current is plotted with respect to time in the form of a sinusoidal (sine) wave form, as shown in the figure.

The frequency of the AC current refers to the number of complete cycles per second (hertz). Half a cycle is the period of time during which the AC flows in one direction before reversing.

Figure 7-6 shows a pure sine wave before and after rectification. If rectification is perfect, meaning there is no forward voltage drop across the diodes used for

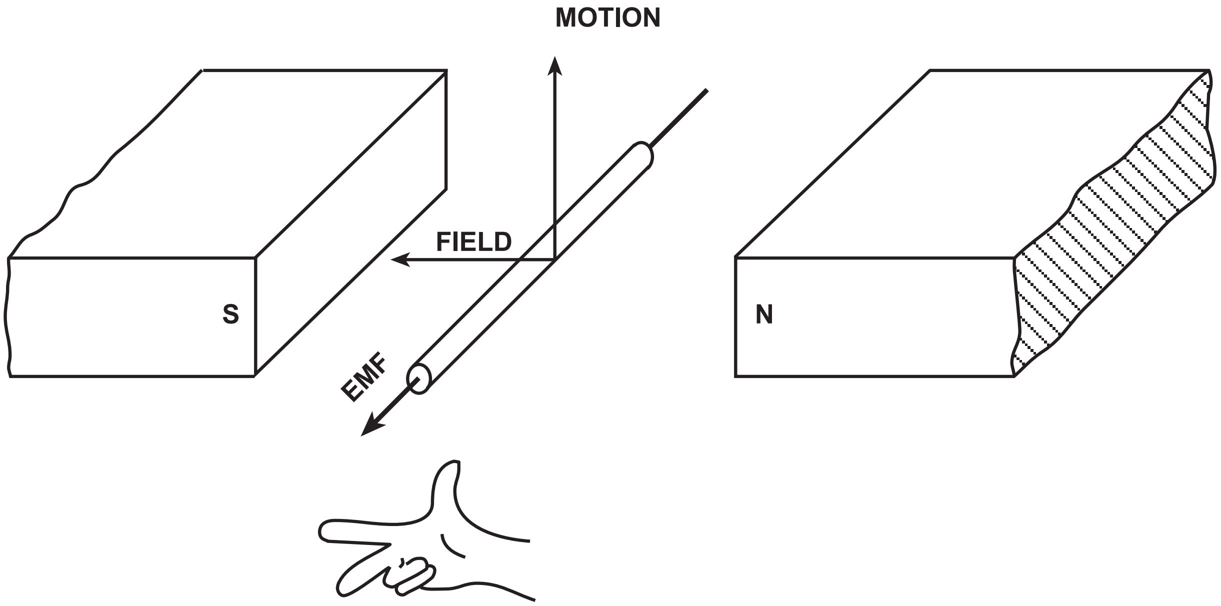


RIGHT HAND THUMB RULE:

GRASP THE COIL WITH THE RIGHT HAND. WHEN THE FINGERS POINT IN THE DIRECTION OF CURRENT FLOW IN THE TURNS, THE THUMB POINTS IN THE DIRECTION OF THE MAGNETIC FIELD IN THE CENTER OF THE COIL.

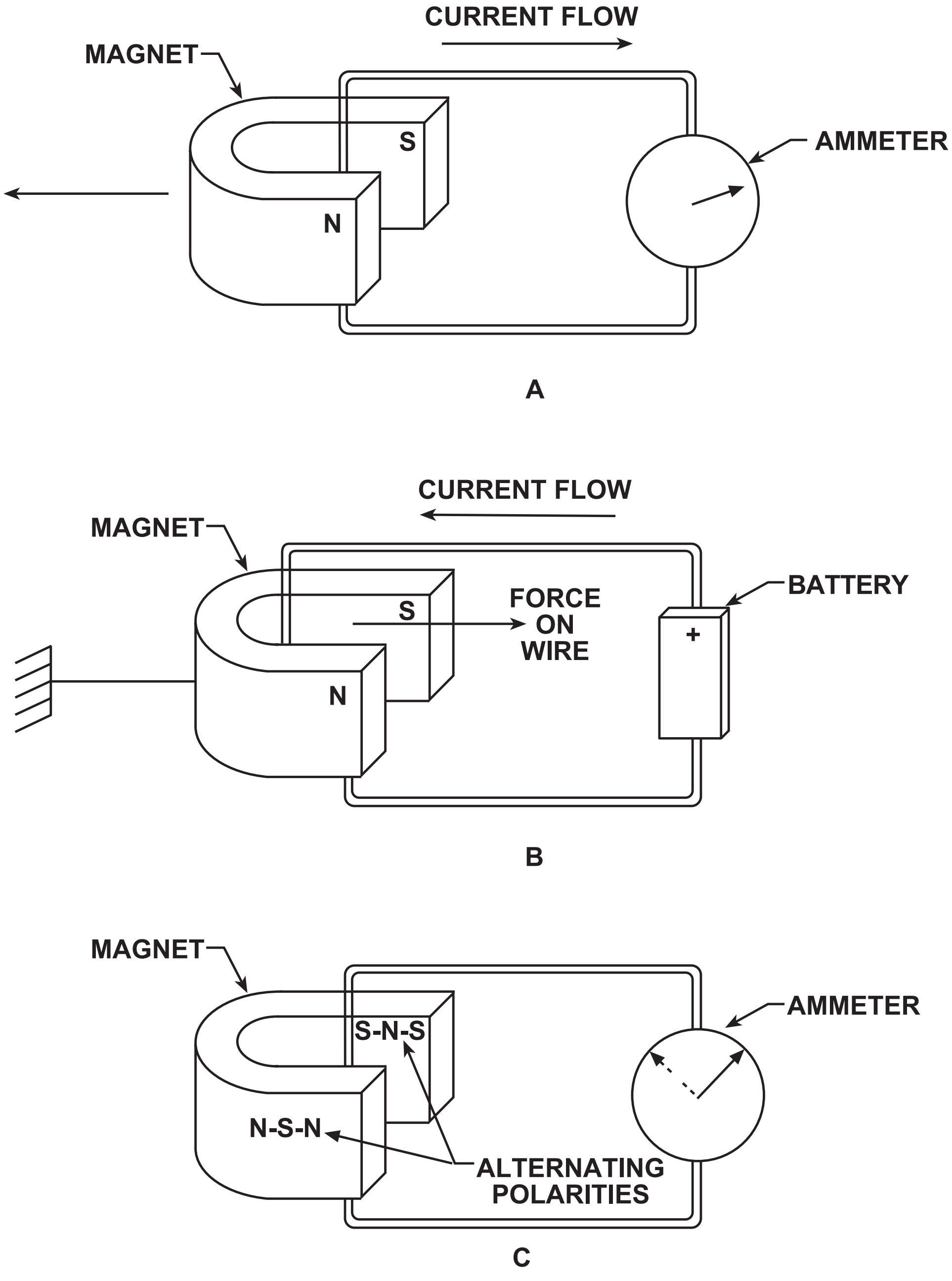
MAGNETIC FIELD AROUND A SINGLE CONDUCTOR

FIGURE 7-2



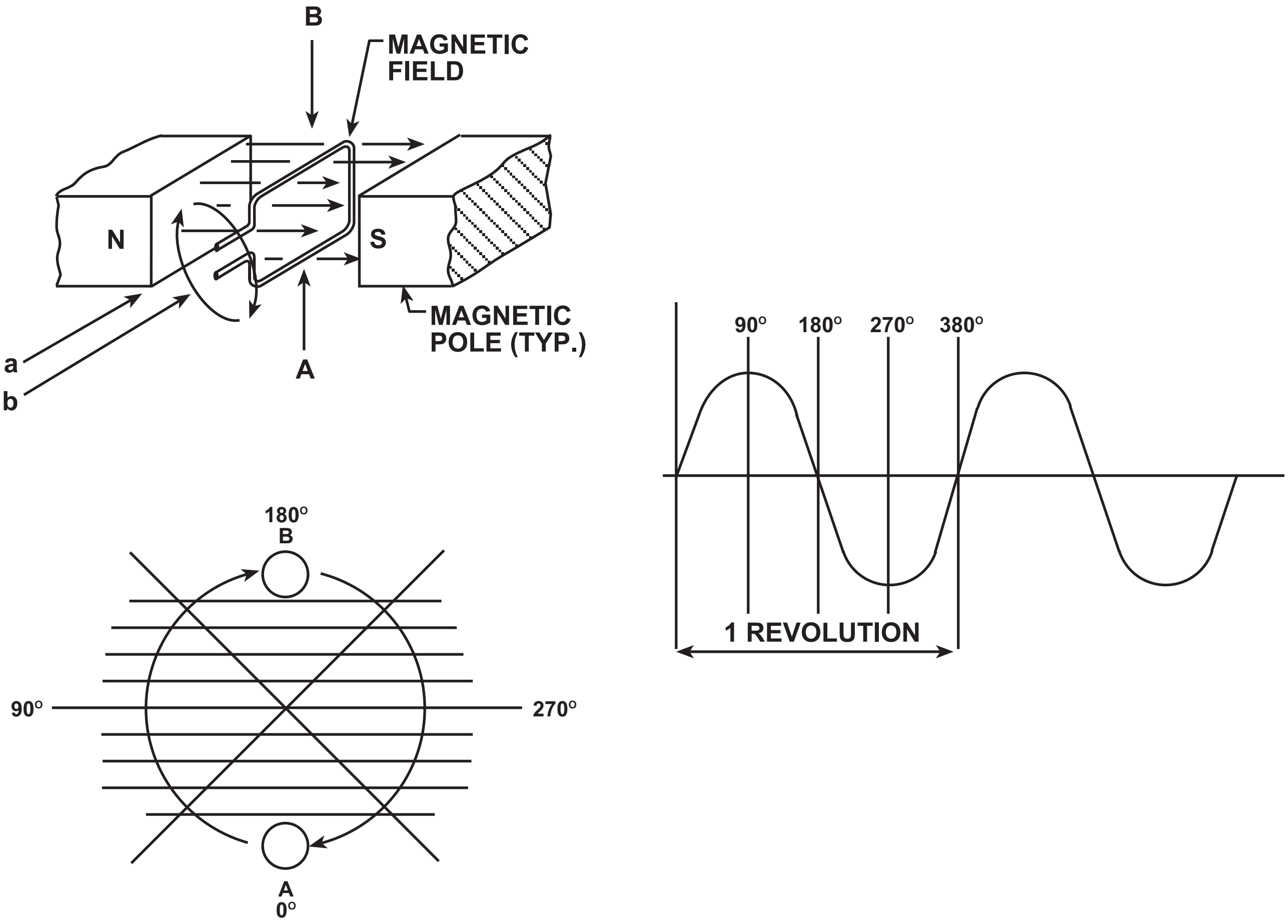
FLEMING’S 3 FINGER RULE

FIGURE 7-3



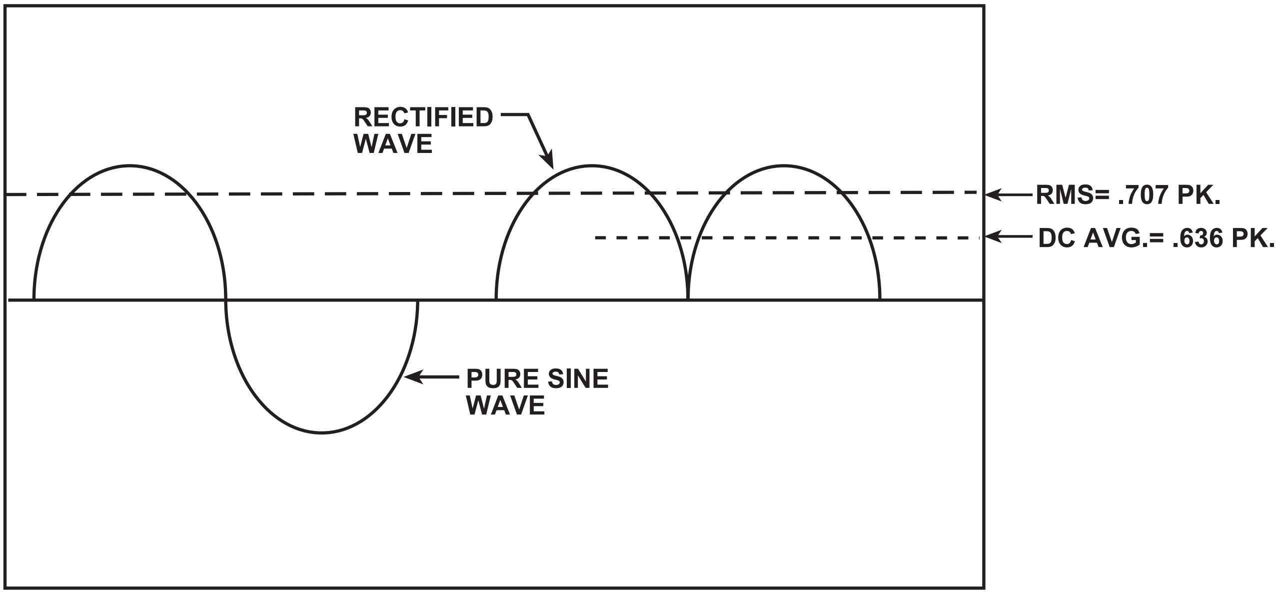
PRINCIPLES OF ELECTRICAL INDUCTION

FIGURE 7-4



GENERATION OF AC POWER

FIGURE 7-5



AC RECTIFICATION

FIGURE 7-6

rectification, certain relationships will exist between the peak value of the voltage waveform and the root mean square value (RMS - see next paragraph) and the DC average as shown in the figure. The average value of the unrectified sine wave is zero, and that is what a DC voltmeter would read at the output of a sine wave source. The rectified wave does have an average value that can be measured with a DC voltmeter. This average value can also be calculated by multiplying the peak value of the full wave rectified sine wave by 0.636.

A full wave rectified sine wave has been found to produce more heat (dissipate power) in a specific resistor than a pure DC voltage (as produced by a battery) of the same average value as the rectified sine wave. For this reason another way of expressing the true value of the waveform is expressed as the RMS value. RMS stands for “root mean square”, which is a mathematical description of the process used. The value of the waveform is first squared. Squaring the value of the waveform determines its mean or average value. If this value were used, it would be a voltage squared term. Since an equivalent voltage is what is desired, the square root must be taken, thus the meaning of RMS.

When using the root mean square process for a sine wave or a full wave rectified sine wave, the RMS value is found to be 0.707 times the peak value of the waveform. For a single phase full wave rectifier, the RMS voltage value is greater than the DC average by a factor of 1.11.

All of the factors discussed above with respect to voltage are also valid for current calculations. The RMS value of the current from a single phase full wave rectifier is 1.11 times the DC average value. Therefore, the total output power from a single phase full wave rectifier can be calculated as follows:

Total Power Output =

$$1.11\ E_{DC} \text{ x } 1.11\ I_{DC} = 1.23\ E_{DC} \text{ x } I_{DC}$$

<u>Note:</u> There is really 23% more power being delivered from a single-phase full wave rectifier than the DC values of the voltage and current would indicate.

Since it is the average DC power which contributes to the electrolytic polarization necessary for cathodic protection, we state conversion efficiency rather than rectification efficiency. The maximum theoretical conversion efficiency of a single phase full wave rectifier is calculated as:

$$\frac{\text{DC Power Output} \times 100}{\text{Total Power Output}} = \frac{E_{DC} \times I_{DC} \times 100}{1.11\,E_{DC} \times 1.11\,I_{DC}} = 81\%$$

This percentage can be increased by the use of efficiency filters in the DC output circuit. Filters reduce the amount of ripple voltage in the output and are able to reduce the input power of the rectifier while essentially maintaining the same DC power output.

Note: The above formulas apply only to single phase full wave rectifiers and cannot be used for single phase half wave or three phase circuits.

Rectifying Circuits

The following sections discuss the four most commonly used rectifying circuits. These circuits include the single-phase bridge, single phase center-tap, three phase bridge, and the three phase wye.

1. Single Phase Bridge

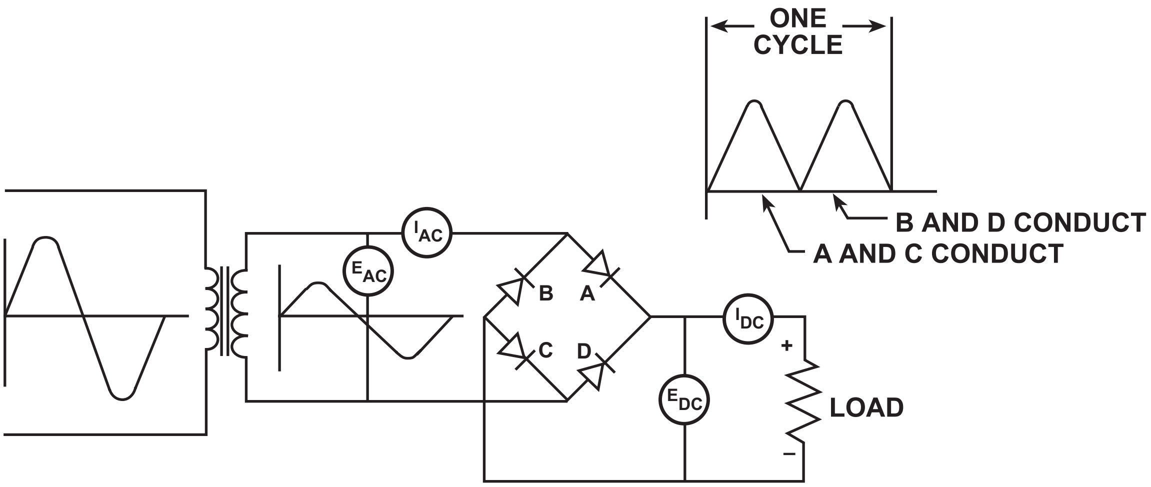
   The rectifying stack in single phase bridge consists of four legs. A leg is a circuit element, which conducts or allows the flow of current in only one direction. As AC is applied to the stack, two of these legs are used on each half cycle. Figure 7-7 illustrates the wiring diagram and the operation of the single phase bridge rectifying circuit. The DC produced by a single-phase bridge is not pure DC, as is a battery output. It is a full wave pulsating current. The single-phase bridge is by far the most common single phase rectifying circuit available today.

2. Single Phase Center-Tap

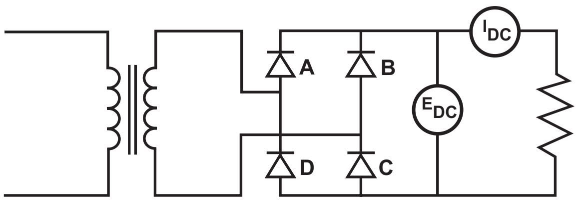
   The single phase center-tap rectifying circuit, as shown in Figure 7-8, also produces full wave rectification. This center-tap configuration however, requires only two legs instead of four. Only one leg conducts during each half cycle.

   The single phase center-tap transformer is larger in size than the single phase bridge transformer and tapping is more difficult. It is however, an efficient circuit and offers many design opportunities in rectifiers which are electronically controlled and where tapping is not required.

   Single phase center-tap rectifying circuits are an older technology that is not commonly used in industry today.

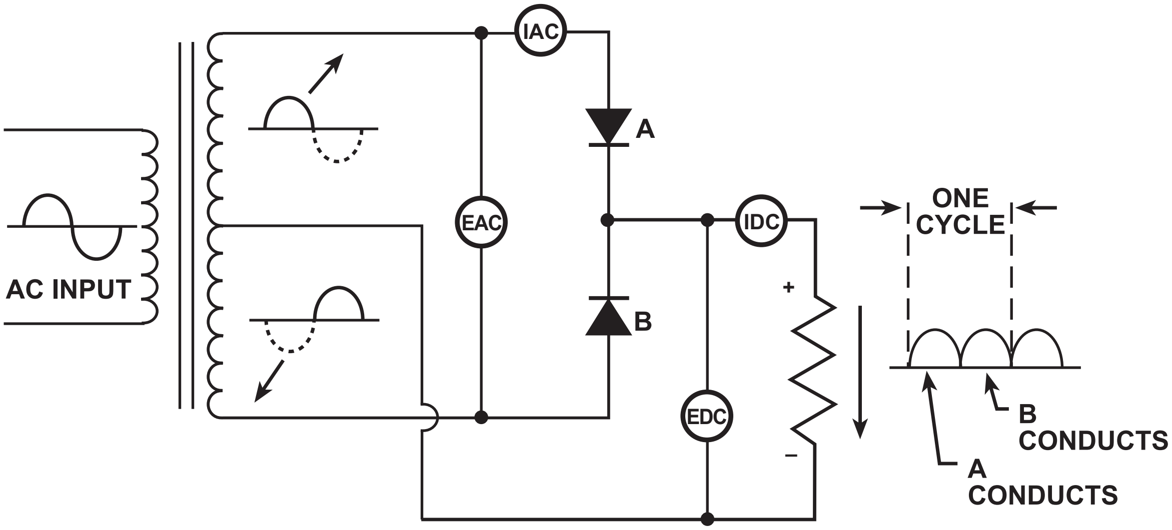


ALTERNATE SCHEMATIC ARRANGEMENT



SINGLE PHASE BRIDGE CIRCUIT

FIGURE 7-7



SINGLE PHASE CENTER-TAP CIRCUIT

FIGURE 7-8

3. Three Phase Bridge

The most commonly used circuit in cathodic protection rectifiers when three phase power is available, is the three phase rectifying bridge circuit. This circuit consists of six legs, but as with the single phase bridge, only two legs conduct current at any specific time. Figure 7-9 shows a typical three phase bridge wiring diagram and associated waveforms.

The three phase rectifying bridge circuit is very efficient and seldom requires filtering.

4. Three Phase Wye

The rectifying stack in a three phase wye circuit consists of three legs, as illustrated in Figure 7-10. The DC output of this circuit is not as smooth as that of the three phase bridge, but it is much better than that of the single phase circuits.

The transformer for this type of rectifying circuit requires more iron than other rectifying circuits in order to prevent saturation of the core. This is due to the pulsating DC current present in each winding.

Components of a Rectifier

A standard cathodic protection rectifier is considered as being a simple electrical device. The heart of the rectifier consists of the transformer and the rectifying stack(s). These two components alone could provide the DC power required for a cathodic protection system. Other components, or accessories, are added to the unit to enhance its performance and provide safety functions.

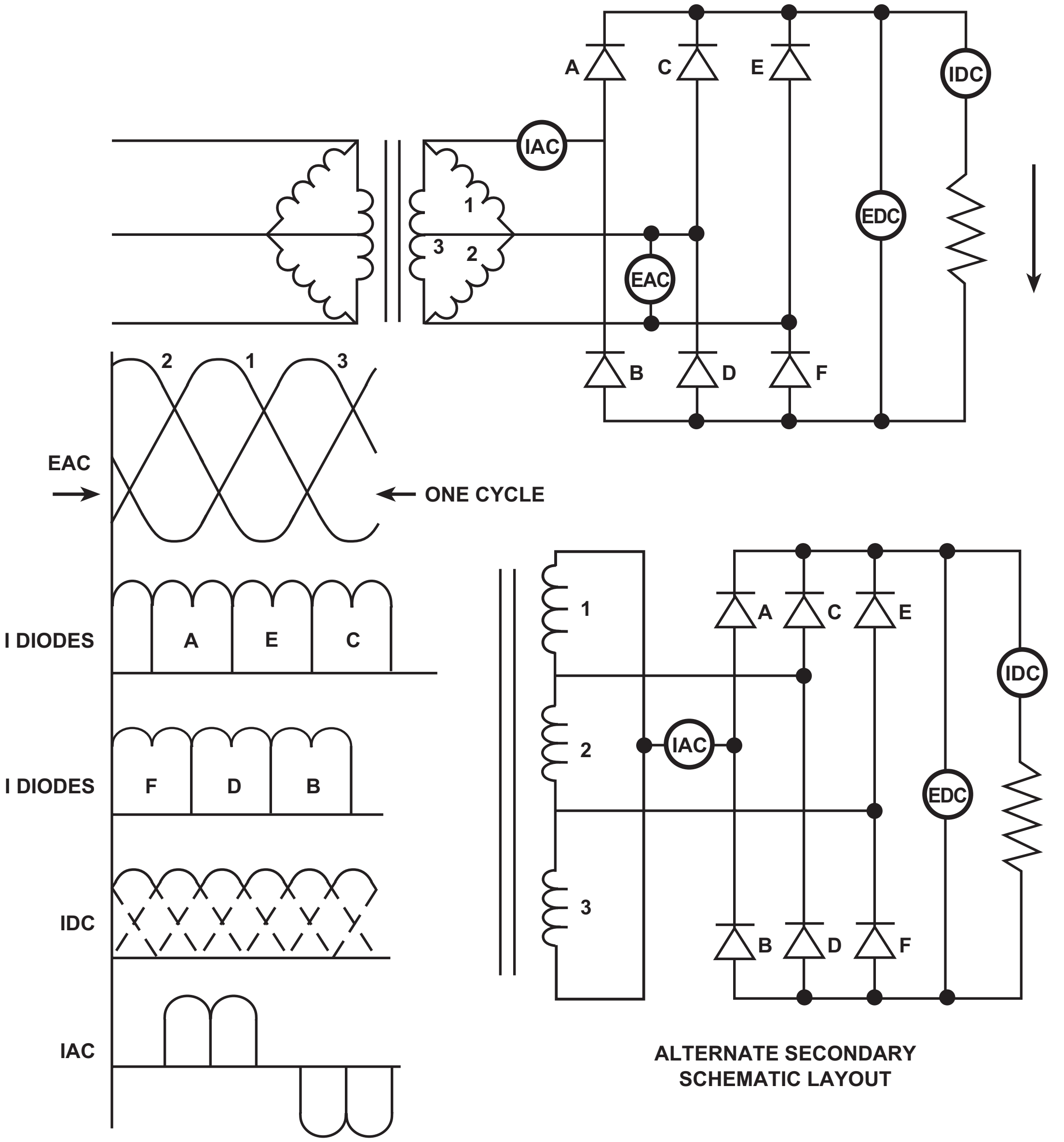
1. Circuit Breakers

The primary function of a circuit breaker is to provide overload protection for the circuit in which it is installed. It also serves as an on-off switch for the unit.

There are three types of circuit breakers that are commonly used in rectifiers. They are as follows:

A. Thermal Breakers

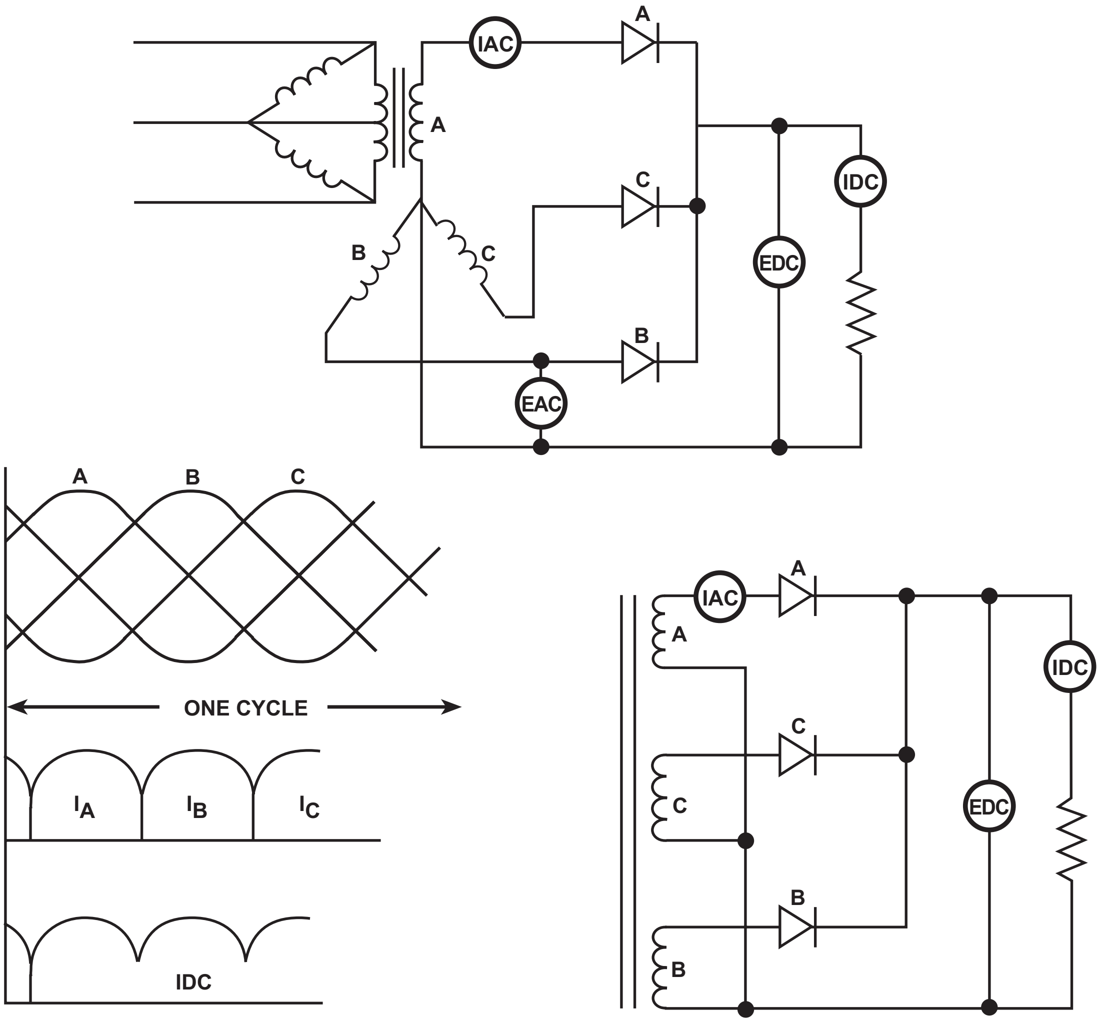
These breakers are constructed with a bimetallic element through which the circuit



ALTERNATE SECONDARY
SCHEMATIC LAYOUT

THREE PHASE BRIDGE (FULL-WAVE) CIRCUIT

FIGURE 7-9



THREE PHASE WYE CIRCUIT

FIGURE 7-10

current flows, with the breaker in the “On” position. Should the current rating of the breaker be exceeded, the heat generated by the excessive current flow will cause the two metals to expand. As a result of their differing temperature coefficients, one metal expands at a different rate than the other. This causes the bonded metallic strips to bend to one side, thus releasing a movable contact and opening the circuit. See Figure 7-11 for an illustration of a typical thermal breaker.

A disadvantage of this type of breaker is that it is very sensitive to ambient temperatures, tending to respond (open) quickly on warm days and slowly on cold days. Often this type of breaker cannot be reset immediately after tripping because it must be allowed to cool down.

B. Thermal-Magnetic Breakers

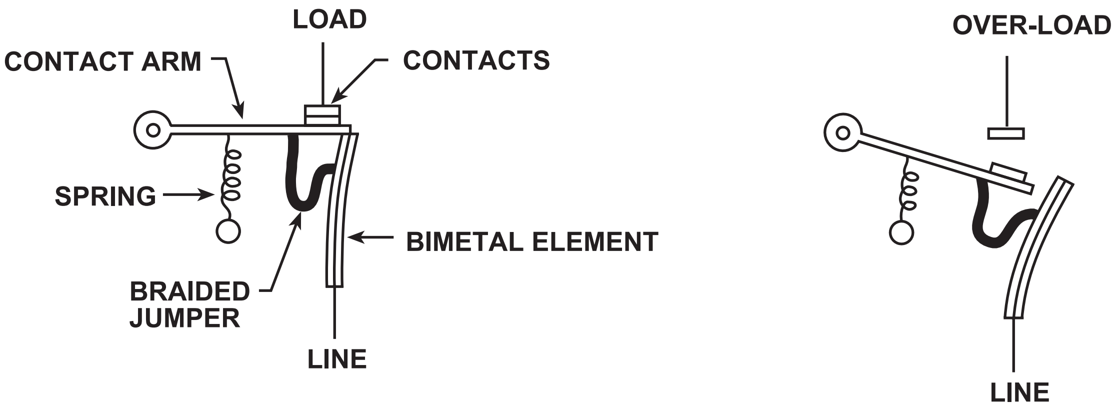
The operation of the thermal-magnetic breaker is nearly identical to that of the thermal breaker. Figure 7-12 shows a typical thermal magnetic breaker. Note the magnetic plate attached to the bimetal element. The purpose of this magnetic plate is to speed up the opening of the contacts in the event of a short circuit or extremely large current surge. A large surge of current will set up a magnetic field around the plate, which causes it to be attracted to another plate located near it, immediately opening the contact. During normal loads or light overloads, the magnetic plate performs no function whatsoever.

This type of breaker has a slower reaction time than the fully magnetic circuit breaker. For this reason they are recommended for use on rectifiers that will be interrupted during system testing, as these breakers will not trip during testing.

C. Fully Magnetic Breaker

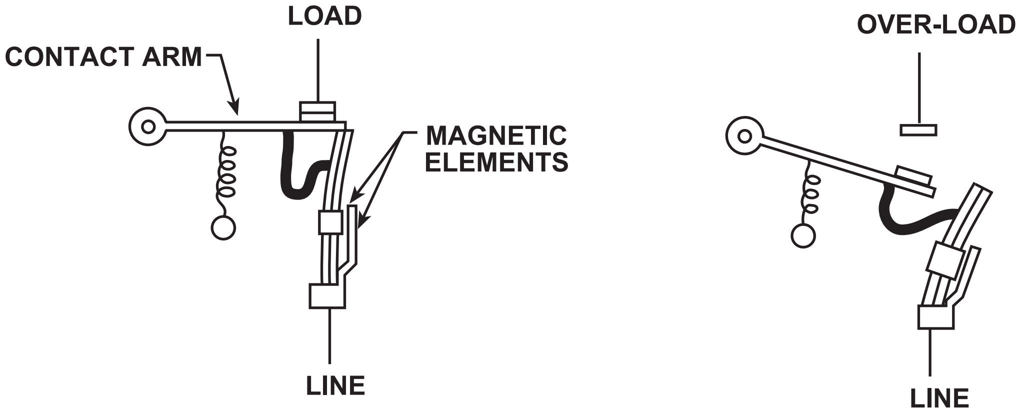
This type of breaker is considered the most suitable for cathodic protection rectifiers because it only responds to overload currents. The current rating of this type of breaker is determined by the number of turns and wire size of the magnetic coil which is wound around a sealed tube in the circuit breaker, as shown in Figure 7-13. This tube contains an iron core retained by a compression spring immersed in silicone fluid.

As long as the breaker operates within its rating, the iron core will remain stationary. Should an overload occur however, the core will be drawn towards the poleface on the end of the tube by the magnetic action of the coil. The closer the



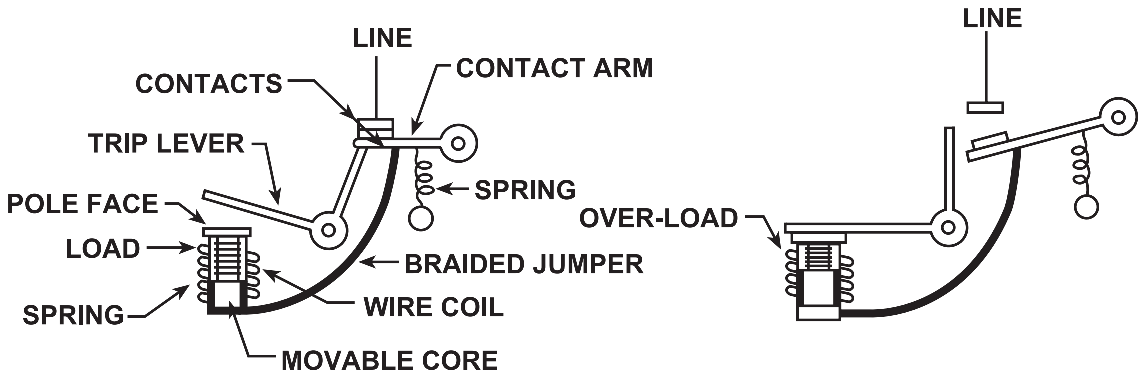
FULLY THERMAL CIRCUIT BREAKER

FIGURE 7-11



THERMAL MAGNETIC CIRCUIT BREAKER

FIGURE 7-12



FULLY MAGNETIC CIRCUIT BREAKER

FIGURE 7-13

core comes to the poleface, the stronger the magnetic pull becomes on the arm that holds the contacts closed. The lever will trip and the contact will open when the magnetic pull becomes great enough.

Under short circuit conditions, the magnetic action of the coil itself will trip the breaker instantaneously. The operation of this breaker is entirely independent of temperature, making it very suitable for various rectifier applications.

Circuit breakers are normally placed in every “hot” input line of a rectifier unit. In a 115 volt single phase circuit, one breaker would be placed in the “hot” line and none would be required in the ground or neutral lead. For higher single phase input voltages, such as 230, 460, etc., both input lines should be protected with a breaker. Three phase units should have breakers installed on all three input lines.

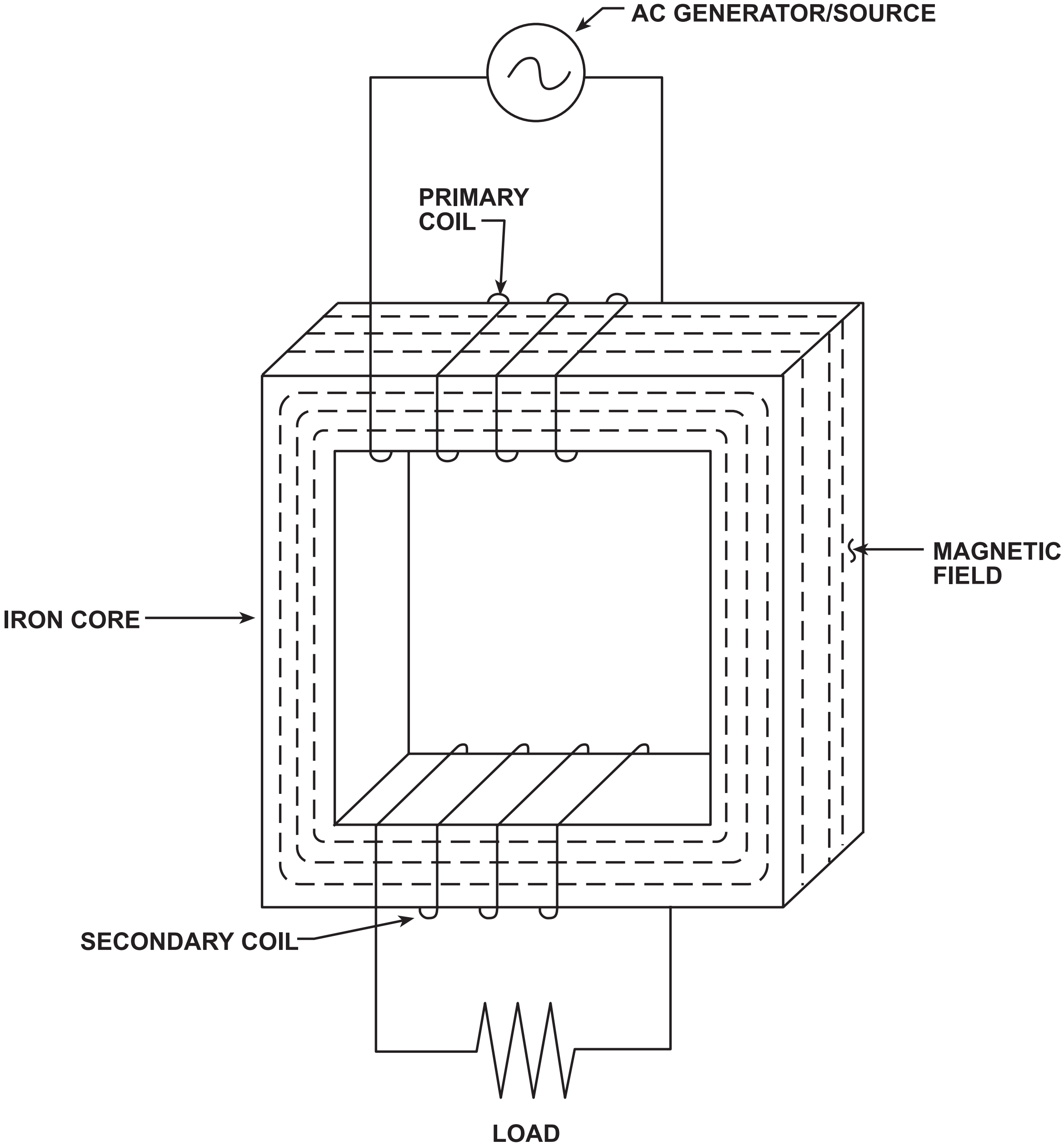
It is recommended that circuit breakers always be ganged (mechanically tied together) so that when one breaker “trips”, the breakers on all other input lines will be “tripped” or opened. This will help prevent personal injury and/or circuit damage.

2. Transformers

A transformer consists of a laminated iron core with one or more coils of wire wound around it as shown in Figure 7-14A. A transformer is used to step up a voltage, step down a voltage, or to isolate a voltage from its source.

The primary winding of the transformer is connected to the voltage source. The secondary winding of the transformer receives voltage from the primary winding through magnetic coupling. An alternating magnetic field is set up in the core when an AC voltage is applied to the primary winding of the transformer. The magnetic field induces a voltage into the secondary winding at the same volts per turn ratio as that of the primary. Therefore, the ratio of secondary volts to secondary turns is the same as the ratio of primary volts to primary turns. This is only true under no-load conditions. Under load conditions a reduced voltage is seen on the secondary. This reduced voltage is due primarily to losses in the core and in the lamination.

Placing taps at intervals along the secondary winding will produce or supply voltages corresponding to the number of turns at which they are connected. By locating the taps in “coarse” and “fine” arrangements, it is possible to produce a considerable number of evenly spaced voltage adjustments with relatively few taps.



TYPICAL TRANSFORMER DIAGRAM

FIGURE 7-14A

The voltage output of the transformer can be determined by using the following ratio:

$$\frac{\text{Primary Voltage}}{\text{Secondary Voltage}} = \frac{\text{Number of Turns on Primary}}{\text{Number of Turns on Secondary}}$$

Example:

An ideal transformer (no losses) has 10 turns on the primary and 30 turns on the secondary or output. A 120 volt, 60 cycles per second (hertz) power supply, is connected to the primary. The output voltage can be calculated as follows:

$$\text{Secondary Voltage} =$$

$$\frac{\text{Primary Voltage} \times \text{Number of Turns on Secondary}}{\text{Number of Turns on Primary}}$$

$$\frac{30 \times 120}{10} = 360 \text{ volts}$$

The transformer in this example would be referred to as a step-up transformer with a 1:3 turns ratio.

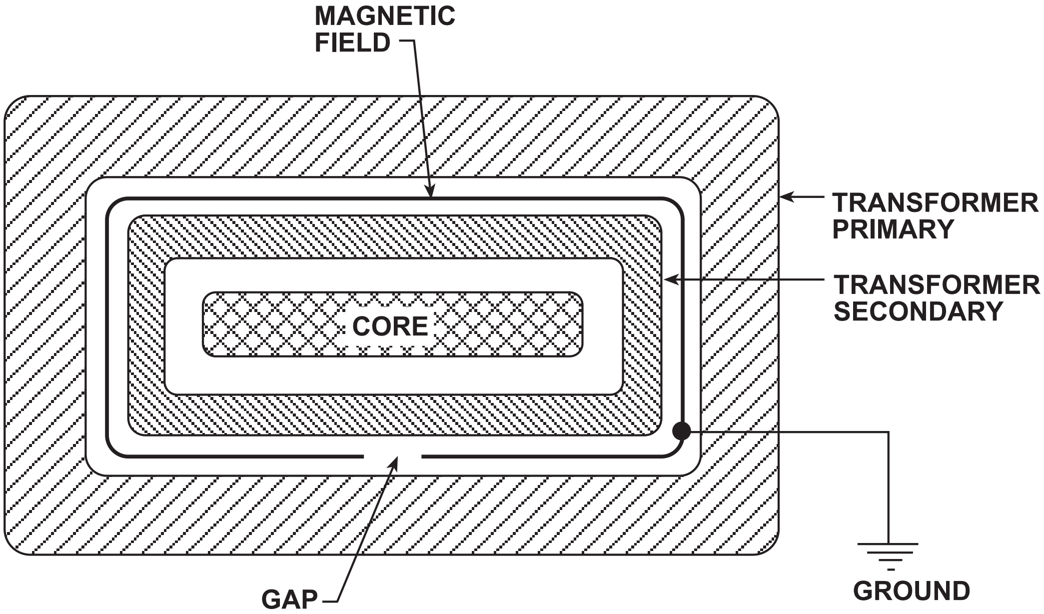
A desirable feature sometimes added to rectifier transformers is a grounded shield. The grounded shield is installed between the primary and secondary windings, as shown in Figure 7-14B, to intercept high voltage pulses (switching surges or lightning initiated pulses). These pulses could otherwise damage rectifying elements, particularly silicon diodes.

3. Rectifying Elements

The function of a rectifying element or cell is to allow current to flow in a circuit in only one direction. This can be accomplished with the use of various materials, but the most commonly used materials in cathodic protection rectifiers are selenium and silicon.

Selenium Cell

The selenium cell is generally made up of an aluminum plate varying in size from 1 to 8 inches square, with a deposit of selenium crystals covered with a metal film to provide



TRANSFORMER WITH GROUNDED SHIELD

FIGURE 7-14B

a contact area. Special processing creates a barrier layer on the selenium side of the plate, which prevents current from passing from the selenium to the aluminum. Figure 7-15 shows a typical selenium cell. Advantages of the use of selenium stacks over silicon stacks are as follows:

a. Selenium stacks will withstand surges due to possible lightning strikes much better than silicon stacks.

b. Selenium stacks are more economical in lower voltage output circuits where current requirements are small.

c. Selenium stacks can withstand severe short term circuit overloads.

Some of the disadvantages associated with the use of selenium stacks are:

a. High voltage and current output units are very expensive due to the number of cells which must be arranged in series and parallel to achieve these ratings.

b. Selenium stacks cannot be practically replaced.

c. Maintaining an adequate stock of replacement stacks can be expensive.

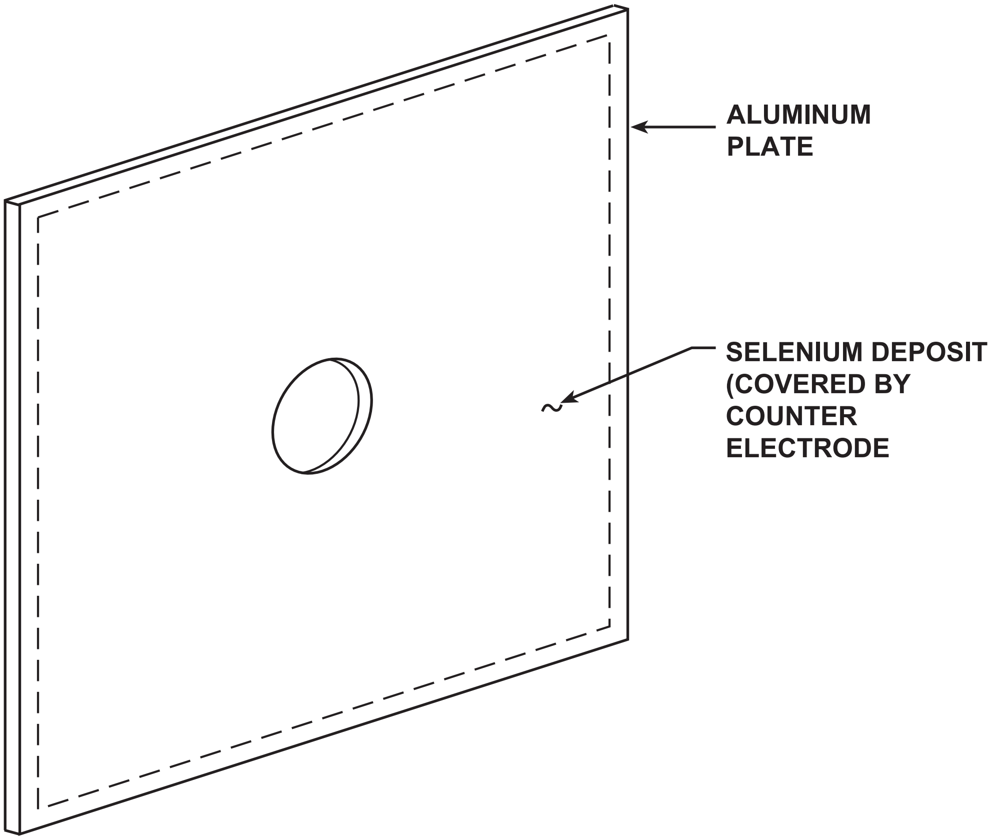
Silicon Diodes

Figure 7-16 illustrates a typical silicon diode rectifying element. Unlike the selenium plate, the silicon diode has a single crystalline rectifying junction. The rectifying area of the diode is many times smaller than that of the selenium plate. As shown the figure, the diode is manufactured in a physical configuration that allows it to be installed in a tapped metal plate. The mounting of the diode on the plate will serve as heat sink which draws heat away from the junction area thus increasing its power handling capacity.

The following list indicates some of the advantages of silicon diodes over selenium stacks:

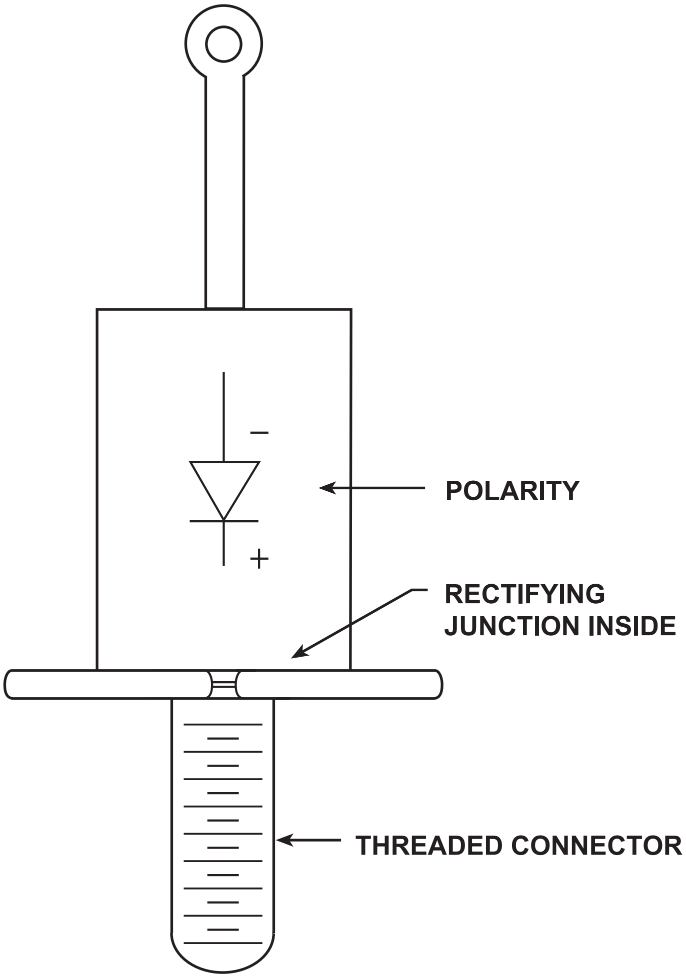
a. The use of silicon diodes in units providing high current and voltage outputs is more efficient and therefore, more economical.

b. Replacement cells are more easily installed and stored.



TYPICAL SELENIUM CELL DIAGRAM

FIGURE 7-15



TYPICAL SILICON DIODE DIAGRAM

FIGURE 7-16

c. Silicon diodes have a longer operating life than selenium stacks.

Some of the disadvantages of silicon diodes are:

a. Additional protection must be added to these units to protect them from lightning strikes or other overvoltages.

b. The use of silicon diodes may be more expensive initially.

4. Accessory Equipment

Optional equipment such as meters, lightning arresters, filters, and shunts can be supplied with the rectifier unit.
Voltmeters and ammeters are normally installed on the rectifier to facilitate the monitoring of its voltage and current output. Sometimes, only one meter is supplied which, through the use of a selector switch, will read both volts and amperes.

Lightning arresters are normally installed on both the AC input and the DC output circuits of the rectifier when, due to the location of the unit, the possibility of lightning surges exists. Lightning surges can enter the cathodic protection rectifier from both the AC and DC sides. Installation of lightning arresters will prevent damage to the unit and its components due to these surges.

Efficiency filters can be added to single phase bridge and center-tap circuits. The filters improve the conversion efficiency by reducing the ripple component in the rectifier output. Ripple in the output can be reduced as much as 20 to 25 percent.

Filters can be used to eliminate electronic noise/interference on electronic circuits and at the same time provide increased lightning protection to the DC circuits of the unit. The installation of these efficiency filters may increase the cost of the rectifier, but in most cases they will pay for themselves within the first year of operation. Conversion efficiency is usually increased by 10 to 15 percent.

Rectifier units can be provided with shunts installed in series with the positive output terminals of the unit. These shunts provide a means of measuring the output current of the rectifier, using a portable voltmeter, without interrupting the service of the unit. The size/rating of the shunt selected must be compatible with the output rating of the rectifier.

The current output rating of the rectifier must not exceed the ampere capacity of the shunt. For example, a typical shunt installed at the output of a rectifier rated 40 amps, would be rated 50 amps – 100 millivolt. If an 8.7 millivolt drop where measured across the shunt with a voltmeter, the current output of the rectifier can be calculated as follows:

$$\frac{I_{SHUNT}}{E_{SHUNT}} = \frac{I_{OUTPUT}}{E_{DROP}}$$

Solving for I_{OUTPUT} :

$$I_{OUTPUT} = \frac{I_{SHUNT} \times E_{DROP}}{E_{SHUNT}}$$

$$I_{SHUNT} = \frac{50\text{ A} \times 8.7\text{ mv}}{100\text{ mv}} = 4.35\text{ A}$$

TYPES OF RECTIFIERS

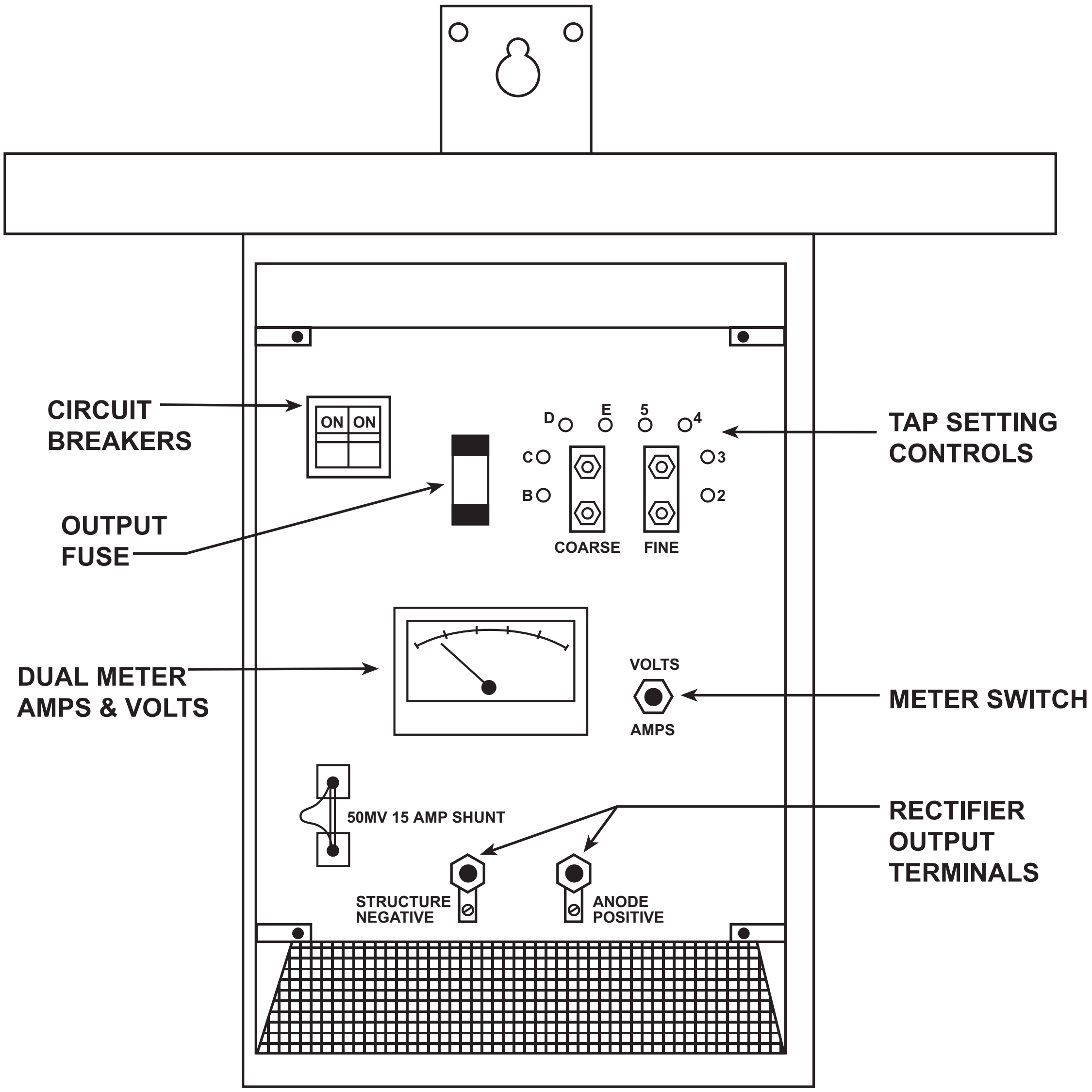
Cathodic protection rectifiers are available with specialized features and in various configurations/designs. The most commonly used types of rectifiers are:

1. Air-Cooled Rectifier

   This type of unit and its components are enclosed in a steel enclosure with doors that provide access to the unit for testing and repairs. The bottom of the enclosure is usually constructed of steel screening to allow for the circulation of air. This type of unit can either be wall, pole, or pedestal mounted depending on the size and weight of the unit. See Figure 7-17.

2. Oil-Cooled Rectifier

   This type of rectifier is used in areas where dust, salt air, corrosive fumes, or excessive moisture may shorten the operating life of an air-cooled unit. The rectifier and its components are installed in a steel enclosure and are completely immersed in oil,



TYPICAL AIR COOLED RECTIFIER

FIGURE 7-17

thus isolating them from extreme environments.

Modified oil-cooled rectifiers are available with explosion proof fittings. These explosion proof rectifiers are for use in refineries, chemical plants, and other areas where explosive or flammable vapors, liquids or powders are present.

Oil-cooled units are normally pedestal mounted due to their weight. See Figure 7-18 for a typical oil-cooled rectifier detail.

3. Constant Current Rectifiers

   These rectifiers have a special circuit that enables the rectifier to provide a nearly constant current output regardless of load resistance. This type of unit is used in applications where the load resistance changes drastically and the output current would be exceeded with a normal rectifier. A typical constant current rectifier circuit is shown in Figure 7-19.

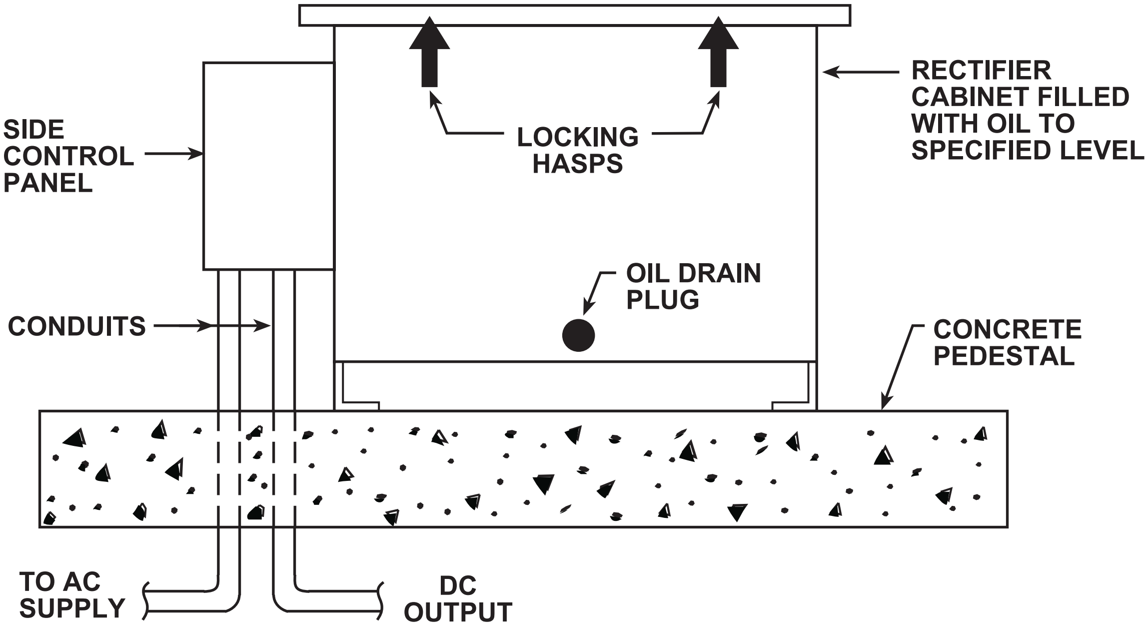
4. Automatic Potential Controlled Rectifiers

   This type rectifier monitors the structure-to-electrolyte potential and maintains it at a desired level. The use of this type of rectifier requires the use of a permanently installed reference electrode and an additional test wire connection to the structure. Both are connected to a transistorized control circuit as shown in Figure 7-20. The controller adjusts the output voltage to keep the reference cell potential at a preset desired level. Automatic potential controlled rectifiers are very useful in the control of corrosion on structures such as water storage tanks, harbor structures, and where it is necessary or desirable to maintain a constant potential on the structure.

RECTIFIER SAFETY

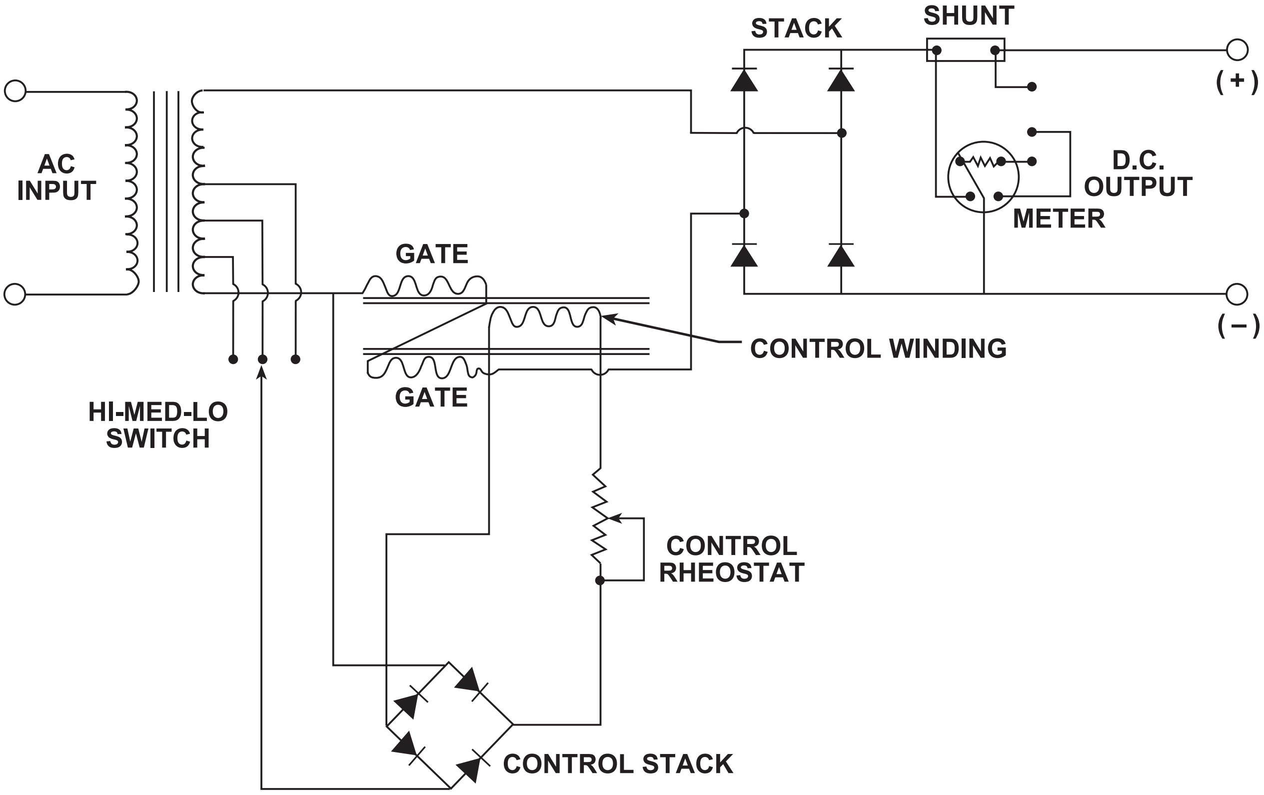
Cathodic protection rectifiers can pose electrical shock and arc flash hazards. Only qualified personnel should access cathodic protection rectifiers. Qualified personnel accessing cathodic protection rectifiers must follow appropriate safety procedures.

Most companies have developed safety procedures for personnel accessing cathodic protection rectifiers.



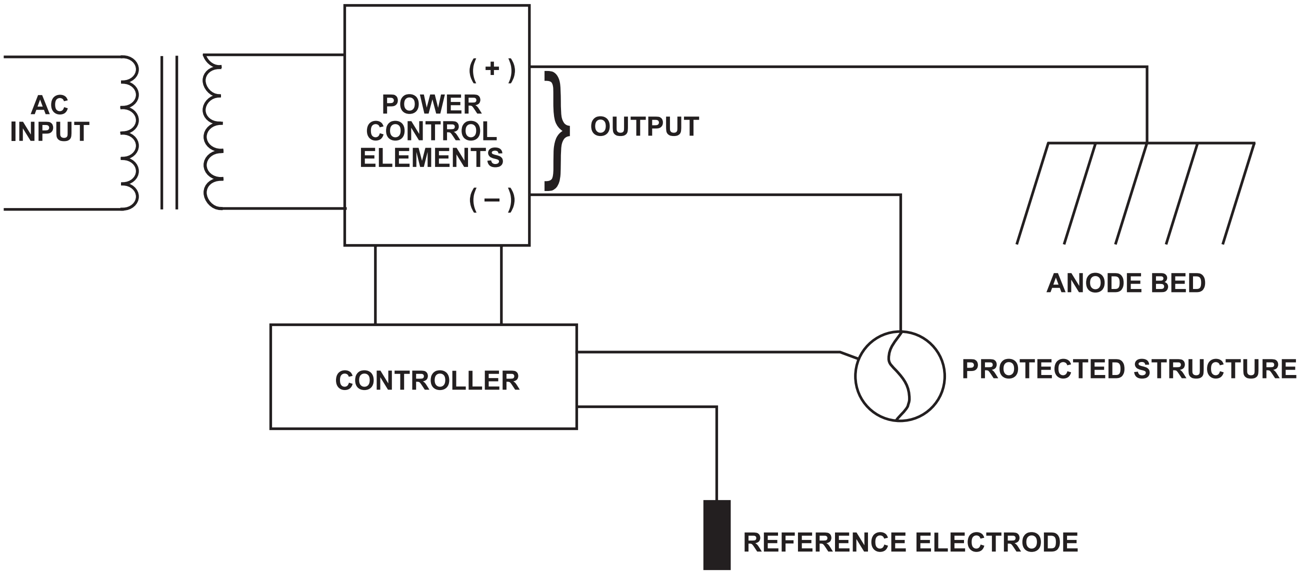
TYPICAL OIL COOLED RECTIFIER

FIGURE 7-18



TYPICAL CONSTANT CURRENT RECTIFIER CIRCUIT

FIGURE 7-19



TYPICAL AUTOMATIC POTENTIAL CONTROLLED RECTIFIER CIRCUIT

FIGURE 7-20

PREVENTIVE MAINTENANCE

In order to maintain proper operation, rectifiers must be inspected on a regular basis. Rectifiers that are subject to PHMSA regulations must be inspected at least six times each year with no more than 2½ months between inspections to insure the units are operating properly.

Inspecting a rectifier at least every 2 months is a good practice even if it is not subject to any regulations.

Units that are located in areas that are prone to lightning strikes or power surges may need to be inspected more frequently. This is necessary so that loss of protection (as from a blown fuse or component failure) will not go undetected for long periods of time.

Rectifiers can also be fitted with remote monitoring units (RMUs). RMUs are devices that will measure the operating parameters of a rectifier and allow that information to be accessed remotely. RMUs are available in radio, satellite and cellular communication configurations. Some systems allow the measurement data to be accessed through an internet web interface. Some systems will send notification of rectifier operating anomalies by email or text messaging.

A routine inspection of a rectifier should include, at the least, measuring and recording the DC voltage and current output of the unit. These values can be determined by reading the built in voltmeter and ammeter but it is more reliable to use a portable multimeter. The DC voltage output is determined by measuring the voltage across the rectifier output terminals with a multimeter. The DC current is determined by measuring the millivolt drop across the rectifier shunt with a multimeter and converting to amperes. Readings should be recorded in a permanent log and compared to previous readings to observe unusual variations.

If, during maintenance rounds, a rectifier is found to be off, the inspector should check to see if the trouble is due to a blown fuse or a tripped circuit breaker. These are the two most common causes of rectifier malfunctions. If this is the case, resetting the breaker or replacing the fuse may be all that is required in order to restore the rectifier to service.

If the inspector can restore the rectifier to service he/she should do so. Regardless of whether or not he/she can do so, the responsible corrosion engineer should be notified as soon as possible so that he/she can investigate the trouble and take corrective action as required.

At least once each year a rectifier should be thoroughly inspected. The following is a typical list of items that should be checked in order to ensure that the rectifier continues to function properly.

1. Clean and tighten all bolted current-carrying connections.

2. Clean all ventilating screens in air-cooled units so that airflow will be completely unobstructed.

3. Check all meters for accuracy by using a properly certified portable meter to “zero” meters that are built into the rectifier unit.

4. Replace all wires on which the insulation has been damaged.

5. If the unit is an oil immersed unit, the oil level and cleanliness of the oil should be checked. The oil should be clear and nearly colorless. Failing oil is usually characterized by a murky or cloudy appearance with loss of transparency and should be replaced with good grade oil. Facilities are available for testing the oil and salvaging it by filtration where practical.

6. Check all protective devices (fuses, circuit breakers, and lightning arresters) to be sure that they are undamaged and in satisfactory operating condition. Defective devices should be replaced immediately.

7. Turn the rectifier off and feel the components. Watch for excessively hot components or uneven heating of rectifier stacks. Temperatures of electrical connections are also important. No component should be too hot to touch.

8. Inspect all components, including lightning arresters, for signs of lightning damage – arc traces across insulators or panels; discolored parts. If their appearance has been altered or if damage is suspected, the component should be replaced.

9. Remove excessive dust accumulations and any type of insect nests. Plug any holes through which insects or rodents can enter the rectifier.

The objective of any good maintenance program should be the prevention of unit failures before they occur, and prompt repair in the event that a failure does occur.

RECTIFIER EFFICIENCY

As rectifiers get older they tend to become less efficient as the rectifier stacks age. At some point, due to the decrease in efficiency, it may become economical to replace the rectifying stacks. Many manufacturers recommend stack replacement when an efficiency drop of 20% is experienced.

An abrupt decrease in rectifier efficiency may also indicate the unit is malfunctioning. In order to detect any changes, the efficiency may be calculated and recorded during periodic inspection/maintenance.

If the rectifier has an analog watt-hour meter, its efficiency can be determined by using the following formula:

$$\text{Efficiency} = \frac{E_{DC} \times I_{DC} \times 100\%}{\frac{3600KN}{T}}$$

Where:

E_{DC} = DC output voltage measured across the terminals

I_{DC}= DC output current calculated by measuring the voltage across the total output shunt, using a voltmeter, and calculating the current.

K = K_h of watt-hour meter. Shown on face of watt-hour meter.

N = Number of revolutions of watt-hour meter disk. For this method N =1.

T= Time for disk to make one revolution

Example:

The measured DC output of a rectifier is 12 amperes @ 32 volts. A watt-hour meter has a constant (K) of 14, and it takes 89 seconds for the disk to make one complete revolution.

$$\text{Efficiency} = \frac{32 \times 12 \times 100\%}{\frac{3600 \times 14 \times 1}{89}} = 67.8\%$$

Note: When checking efficiency, care must be taken so that the original load will be duplicated at each efficiency check because efficiency varies with output voltage and current. If loading is not the same, comparison with previously recorded efficiencies will be meaningless.

RECTIFIER SELECTION

Selecting the correct rectifier is a very detailed and important task. It is important to provide the manufacturer with a specification which is as detailed as possible. This will help assure that the unit supplied is exactly that which is required. The following list indicates the minimum information that should be included in a rectifier procurement specification.

1. AC Input – Specify voltage, number of phases (single or three phase), and frequency. Example: 480 volts, 3 phase, and 60 hertz.

2. DC Output – Specify in volts and amperes. Remember to include spare capacity.

3. Rectifier Type – Air-cooled, oil cooled, oil cooled and explosion proof, constant current, or automatic potential controlled.

4. Rectifying Elements and Configuration – Specify element: silicon or selenium. Specify configuration: full wave bridge or full wave center tap.

5. Mounting – Indicate desired mounting hardware to be included for either pole, wall, or pedestal mounting.

6. Operating Temperatures – Minimum and maximum ambient operating temperatures.

7. Instruments – Voltmeter and ammeter. Specify scales and accuracy.

8. Voltage and Current Control – Specify number of transformer taps required for manual adjustments.

9. Protective Devices – Specify ratings and types of circuit breakers, fuses, lightning arresters, and filters as required. Shielded transformer winding if required.

10. Output Terminals – Specify number of positive and negative terminals/circuits required.

11. Shunts – Specify the number of shunts required and their ratings.

When possible, units should be ordered from the manufacturer’s standard line. Custom made units will be more costly and delivery time may be lengthy.

CONCLUSIONS

A cathodic protection rectifier converts AC power into DC power, which is required for cathodic protection of a metallic structure.

Typical rectifiers utilize either full wave bridge or full wave center tap rectifying circuits with selenium or silicon rectifying elements.

There are various types of rectifiers such as air cooled, oil cooled, constant current, and automatic potential controlled. Each type is designed for use in a specific environment/application. Rectifiers can be purchased with optional features that will facilitate testing during periodic maintenance, protect the unit from power surges (lightning), and increase its efficiency.

To make sure that the manufacturer supplies the exact type of rectifier desired, a detailed procurement specification should be written and forwarded to the supplier. The effective operation of the impressed current cathodic protection system depends on the proper operation of the rectifier. Therefore, a good maintenance program should be developed to help keep the rectifier operating. Malfunctioning rectifiers should be repaired as soon as possible, as long outages may be detrimental to the protected structure. Rectifier troubleshooting techniques will be discussed in Chapter 8 of this course.

Chapter 8 - Cathodic Protection System Maintenance and Troubleshooting Procedures

INTRODUCTION

Corrosion control measures as discussed in the previous chapters, will be highly effective providing they are properly designed and installed as well as adequately maintained. Without a suitable maintenance program, the funds spent in the design and installation of any corrosion control system could be wasted. There have been many instances, for example, of system Owners spending the money to have a cathodic protection system designed and installed on a section of their system without establishing any procedures for looking after it. Although the Owner may feel that his/her corrosion related problems are over, this false sense of security will be short-lived if corrosion failures continue to occur. Although the tendency is to blame the design, the fault in most cases is simply the failure of keeping the system(s) operating continuously and effectively. The purpose of this Chapter is to present suggestions for maintenance programs that will help keep corrosion control systems operating at maximum effectiveness.

MAINTENANCE PROGRAM

A corrosion control system maintenance program should include but not be limited to the following items, as applicable:

Periodic Surveys

Periodic Surveys are performed to determine the status of cathodic protection and related items. Periodic surveys will be discussed in detail in one of the following sections.

Coating Maintenance

Steps should be taken to maintain coating systems on aboveground structures as well as on buried or submerged structures.

Coating maintenance on buried or submerged structures is more difficult to perform, but steps can be effectively taken. During normal operations of buried structures such as pipelines, there are frequent occasions when it is necessary to uncover or make accessible various appurtenances for other maintenance work. This work may involve damage to or removal of the coating.

Any apparent damage to the coating, be it on a buried, submerged, or an aboveground structure, should be repaired or the coating replaced. Coating repair or replacement should be of a quality at least as good as the original coating system. In addition, it is important that any repair coating be compatible with the original coating. Maintenance crews should be trained in good coating application procedures including allowing time for certain materials to cure before backfilling, care of materials, and compliance with the manufacturer's specifications. As previously discussed, when certain hot applied enamels are used, particular care is essential when heating small quantities to be sure that the material is not overheated and rendered useless. If this happens, much of the effectiveness of this type of coating may be lost.

Keeping a factual performance record of coating systems will help the corrosion engineer to prepare and present recommendations for materials to be used for new construction. The general condition of the coating system in terms of its effective resistance-to-earth can be obtained from the periodic corrosion surveys. Other specific information may be obtained by training all system maintenance crews to report on coating conditions whenever possible, such as when coated pipelines are excavated. Information to be included in such a report is the date and specific location of the work, coating type and description, and other identifying information as available or applicable. The report should also include data on environmental conditions surrounding the pipe/structure that could have an adverse effect on the coating system, evidence of soil stress effects, bond quality, evidence of cold flow, and evidence of moisture under the coating. If there is evidence of corrosion damage at coating faults (holidays), i.e., pitting, the report should include data on the number of pits, depth range and range of pit diameters.

This information will enable the corrosion engineer to assess the condition/quality of the existing coating system and determine what corrective measures are required, if any.

Rectifier and Anode Bed Maintenance

Rectifier maintenance should be conducted as discussed in the previous chapter. Impressed current anode bed maintenance is normally limited to the visual inspection of the anode bed site during maintenance rounds.

Any abnormal activity or occurrences should be reported to the responsible corrosion engineer as soon as possible so that he or she can determine the effect, if any, on the anode bed and take corrective action as required. For example, if any part of an anode bed is subject to washout by storm water that will result in exposure of the DC output cable(s), arrangements should be made to have this area inspected regularly and to have the cable(s) recovered when necessary. This should be done only after making sure that there has been no damage to the cable insulation. Any damage found should be repaired. Keep in mind that if the anode cable conductor is exposed to the electrolyte, this then will discharge current and eventually result in a cable break. Corrective action should also be taken to prevent re-exposure of the cable(s) if at all possible.

If construction activity is to be performed in the vicinity of an anode bed, the corrosion engineer should have the location of the anode bed staked out so that inadvertent damage may be avoided.

If the construction activity involves the installation of new underground or submerged metallic structures, the corrosion engineer should be notified. New structures in the vicinity of the anode bed may be subject to possible stray current damage. Provisions should be made in the design of the new structures so that there are adequate facilities available to test for and to mitigate stray current interference.

Galvanic Anode Maintenance

Other than routine electrical tests conducted during periodic surveys, maintenance of galvanic anode installations, as in the impressed current anode beds previously discussed, is limited to visual observations by maintenance personnel. When damage to anode lead cables, anode header cable(s), pipeline lead wires, etc. is found, it should be reported to the corrosion engineer so that prompt repairs can be scheduled.

At test stations that contain galvanic anodes, a clean connection must be maintained between the anodes and the structure. Because of the low driving potentials associated with galvanic anodes, any resistance in the connections can cause a marked decrease in anode current output. The connections should be checked on an annual basis and cleaned when required.

The use of a test station allows for the measurement of polarized potentials on the structure as well as measurement of the current output from the galvanic anode system. Measurement of the anode system current output will aid in determining both the anode consumption rate and prediction of expected service life.

Test Station Maintenance

Test stations are the principal means by which the protection afforded to a structure can be evaluated. If they are to continue to fulfill this function, they must be maintained in good order.

Test stations may, from time to time, require replacement of box covers or cover retention screens, cover gaskets or terminal nuts or screws within the receptacle. Occasionally, a receptacle may be broken or missing as a result of vandalism. Flush mounted or grade level test stations often become filled with silt or covered by paving material when located in roadways. Efforts should be made to keep these test points accessible for testing. Corrosion personnel making routine surveys should carry spare parts and hardware so minor maintenance can be performed while still on site. In this way, especially on systems utilizing a large number of test stations, this type of maintenance can be kept up to date. Screws should be kept greased for ease of operation (using graphite lubricant or petrolatum) and contacting surfaces in electrical circuits should be kept clean to ensure the lowest practicable contact resistance.

If electrically discontinuous test leads are found during periodic surveys or troubleshooting testing, these test leads should be replaced as soon as possible. Leaving invalid test leads in place can lead to erroneous data that may indicate a lack of cathodic protection, a possible open circuit, or other types of problems.

PERIODIC SURVEYS

Federal and State laws dictate what surveys must be made on facilities such as gas piping, oil lines and tanks containing hazardous material. All cathodic protection systems need to be tested periodically, however, and the following data, as required and applicable, should be taken at least on an annual basis. The most common test employed to evaluate the effectiveness of an existing cathodic protection system is the structure-to-electrolyte or pipe-to-soil potential measurement. In fact, the majority of the existing criteria for determining whether a structure is cathodically protected are all based on the this particular measurement.

1. A pipe-to-soil potential survey should be conducted on the protected structure. The potential survey is conducted using a high resistance voltmeter and a portable reference electrode, typically a saturated copper/copper sulfate reference electrode (CSE). The reference electrode should be placed directly above the pipe in contact with the soil. Where the soil is dry, the electrode should be dug in slightly. If the soil is extremely dry, moisten the soil with water to assure good reference electrode contact with the earth. It is important to minimize any inaccuracy in the potential measurement by insuring that the reference electrode is in good contact with the

electrolyte. There should be no loose stone or debris between the tip of the reference electrode and the soil. The presence of petroleum products or chemical contaminants may also affect the measurement.

The recommended connection to the voltmeter has the reference electrode connected to the negative terminal of the meter and the structure to the positive terminal. This will normally result in a negative value.

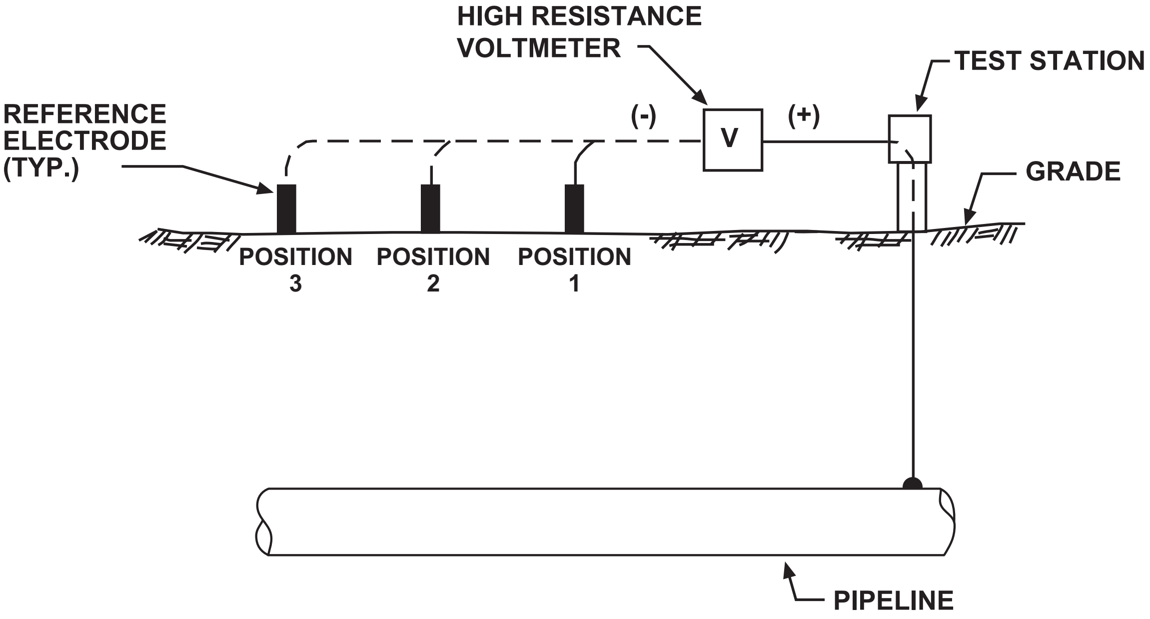
Figure 8-1 depicts how a potential survey is sometimes conducted over a long length of pipeline. During this type of survey, potentials are taken along the length of the pipeline and then plotted as a function of structure-to-earth potential versus reference electrode location. The connection to the structure under test can be a valve, riser pipe, test station, etc., any place that is electrically continuous with that portion of pipe being evaluated. It is important to insure that the structure under evaluation is electrically continuous for the length of pipe to be surveyed. Potentials measured on the other side of an electrically discontinuous point such as an isolating flange, are essentially potentials measured to remote earth and are not indicative of the actual pipe-to-soil potential.

During the potential survey, the pipeline's resistance-to-earth can be calculated if it is possible to interrupt the current source(s). Figure 8-2 shows the method for interrupting a rectified system. The resistance-to-earth value provides historical data on changes in system parameters such as failures at isolating joints. Using the change in the potential readings measured while interrupting the current, and the value of the current, the resistance-to-earth is calculated. The resistance-to-earth is equal to the potential change (ΔV) divided by the output current (I). The unit is ohms.

The resistance-to-earth can be used to determine the amount of current required to change the potential of an unprotected structure.

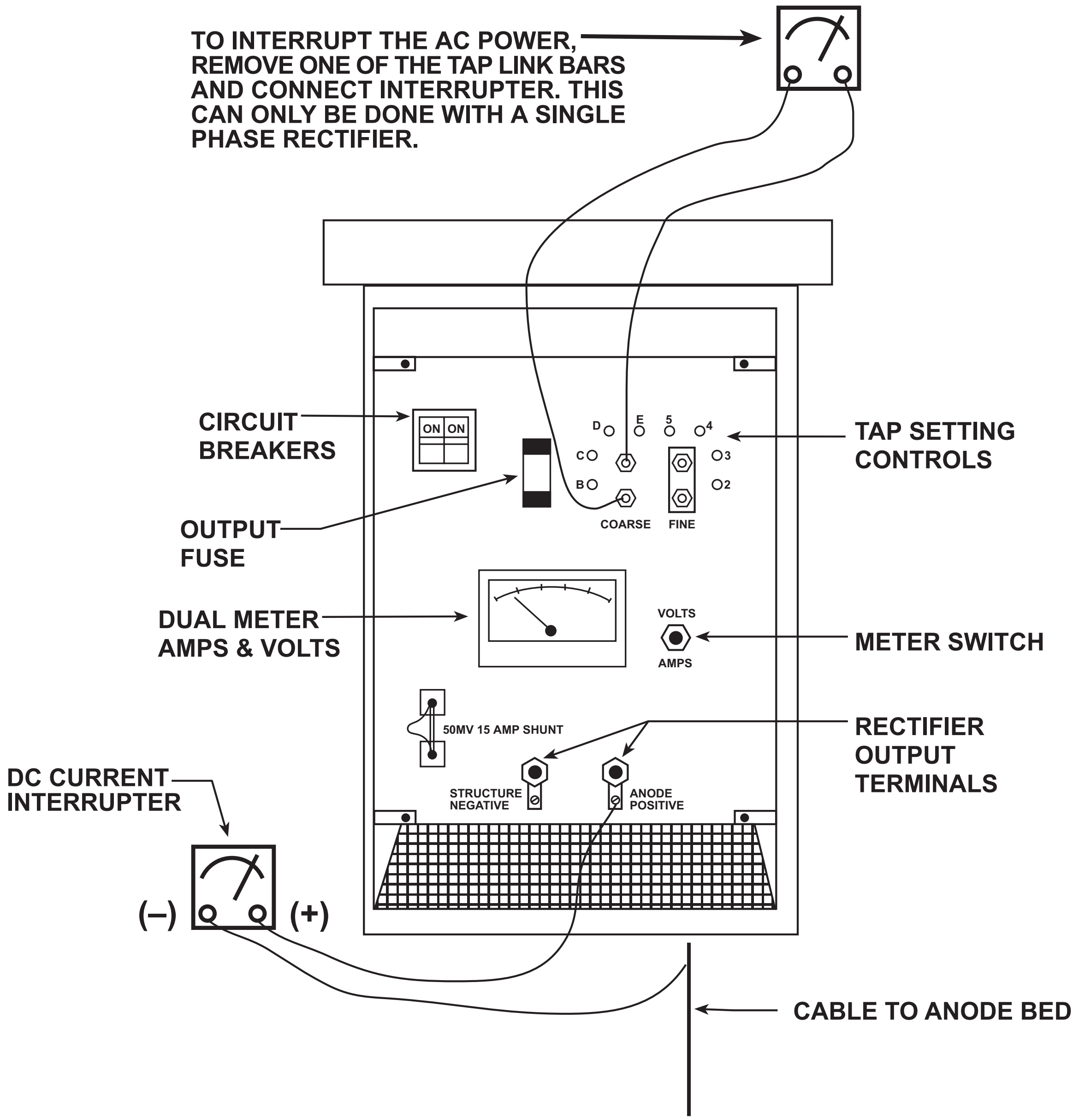
EXAMPLE

The current output of a rectifier is 3 amps. Measured pipe-to-soil potentials are -0.82 V On and -0.65 V Off with the rectifier output interrupted. Determine the additional amount of current required (ΔI_{rqd}) to change the On potential of the structure to -0.85 V ($\Delta V_{rqd} = 0.03V$).



PIPE-TO-SOIL POTENTIAL SURVEY

FIGURE 8-1



TO INTERRUPT THE AC POWER, REMOVE ONE OF THE TAP LINK BARS AND CONNECT INTERRUPTER. THIS CAN ONLY BE DONE WITH A SINGLE PHASE RECTIFIER.

INSTALLATION OF THE CURRENT INTERRUPTER AT EITHER THE AC TAPS OR IN A DC LEG WILL INTERRUPT THE DC CURRENT OUTPUT.

RECORD THE RECTIFIER CURRENT OUTPUT WITH AND WITHOUT THE INTERRUPTER IN THE CIRCUIT.

INTERRUPTING A RECTIFIER

FIGURE 8-2

Step #1 - Calculate the potential change (ΔV):

$$\Delta V = V_{on} - V_{off} = -0.82 - (-0.65) = 0.17 \text{ volt}$$

Step #2 - Calculate the resistance-to-earth (R_{vg}):

$$R_{vg} = \frac{\Delta V}{I} = \frac{0.17 \text{ V}}{3 \text{ A}}$$

$$= 0.057 \text{ ohms}$$

Step #3 - Calculate the additional current required to change the On potential of the structure to the 0.85 volt value:

$$I_{rqd} = \frac{\Delta V_{rqd}}{R_{vg}} = \frac{0.03 \text{ volts}}{0.057 \text{ ohms}}$$

$$= 0.53 \text{ amps}$$

2. On coated structures, data required for the calculation of effective coating resistance should be taken. Although not essential, this information is valuable for monitoring the performance of a specific coating system.

   This measure of coating effectiveness or quality is based on considering the resistance-to-earth of the line as if it were comprised of many parallel resistances, each section having a surface area of one square foot.

   The quality of the coating (average resistance = R_c) can be calculated using the following formula:

   $$R_c = R_{vg} \text{ x Surface Area of the Structure}$$

   Normally, good construction practices will result in average coating resistance values of 300,000 ohm-ft² and greater, upon completion of the installation. The acceptable resistance value for a given set of conditions is a function of various factors and must be determined by experience and the judgement of the corrosion engineer. One of the most influential factors is soil resistivity. For example, a line laid in 1000 ohm-cm soil will have a lower average coating resistance than an identical line laid in 10,000 ohm-cm soil.

EXAMPLE

A 12-inch pipeline has a resistance-to-earth (R_{vg}) of 8 ohms. The length of the pipeline is 32,000 feet. Determine the average coating resistance.

Step #1 - Calculate total surface area (SA) of the pipeline.

$$SA = \Pi \text{ x diameter (ft) x length(ft)} = (3.14) \text{ x } (1) \text{ x } 32{,}000 = 100{,}480 \text{ ft}^2$$

Step #2 - Calculate average coating resistance (R_c).

$$R_c = R_{vg} \text{ x Surface Area} = 8 \text{ x } 100{,}480 = 803{,}840 \text{ ohm-ft}^2$$

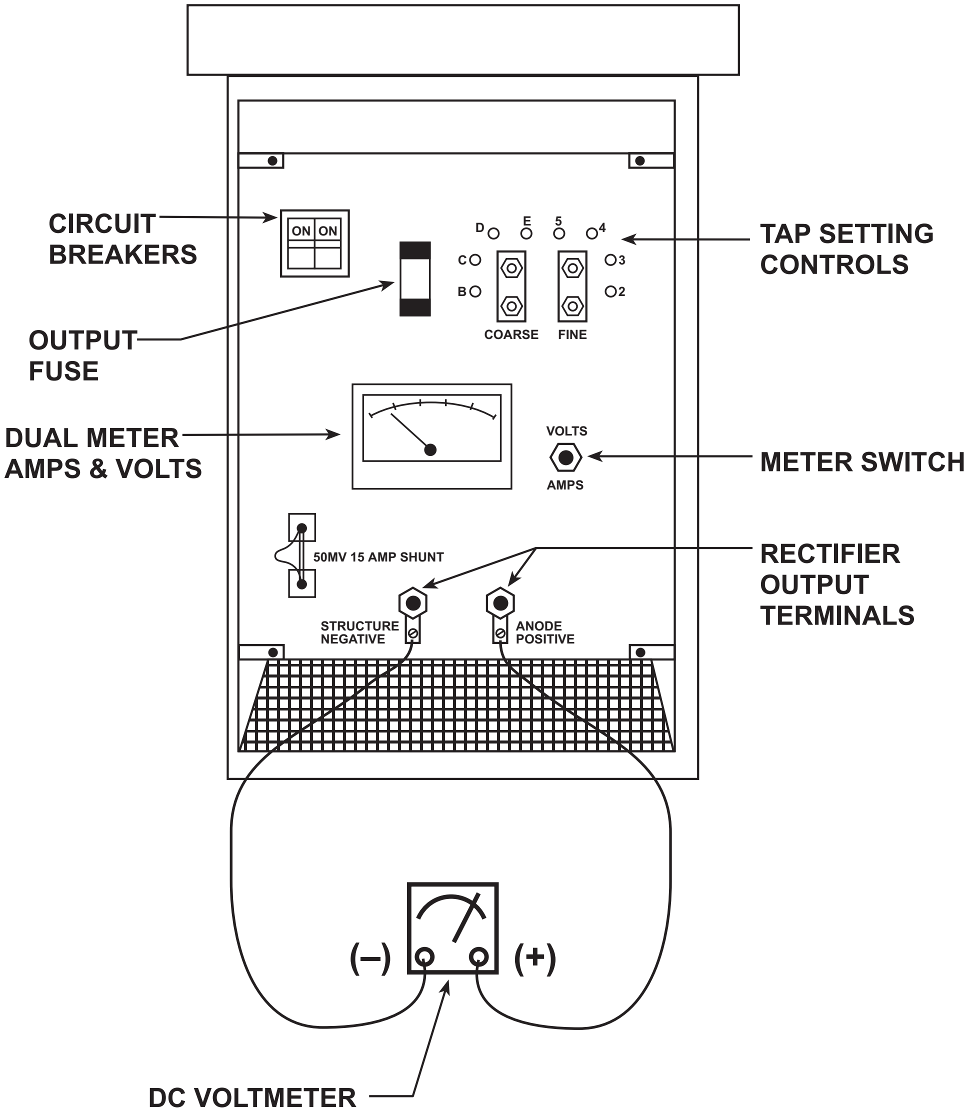
The sample calculated resistance indicates a coating of good quality.

3. At each rectifier installation, DC current and voltage should be measured. See Figures 8-3 and 8-4 for the methods to measure the rectifier voltage and current. The kilowatt hour meter reading should be taken and the rectifier efficiency calculated, as described in an earlier chapter. The rectifier should be visually examined for any signs of damage such as a burnt or blistered stack, loose wiring connections, missing equipment locks, etc. If it is an air-cooled unit, the bottom screen should be free of any obstructions. If it is an oil-cooled unit, check the oil level and examine the oil for any evidence of foreign material such as water or debris.

4. At other DC power sources, the DC current and voltage as well as pertinent supplementary information that may apply to the particular power source should be taken.

5. Data to calculate the resistance of each impressed current anode bed should be taken.

6. The current output and resistance of each galvanic anode installation should be measured. The current output of the anode is measured by placing an ammeter in series with the anode lead, as shown in Figure 8-5, or by connecting a voltmeter across current shunts installed in an anode distribution box as shown in Figure 8-6.

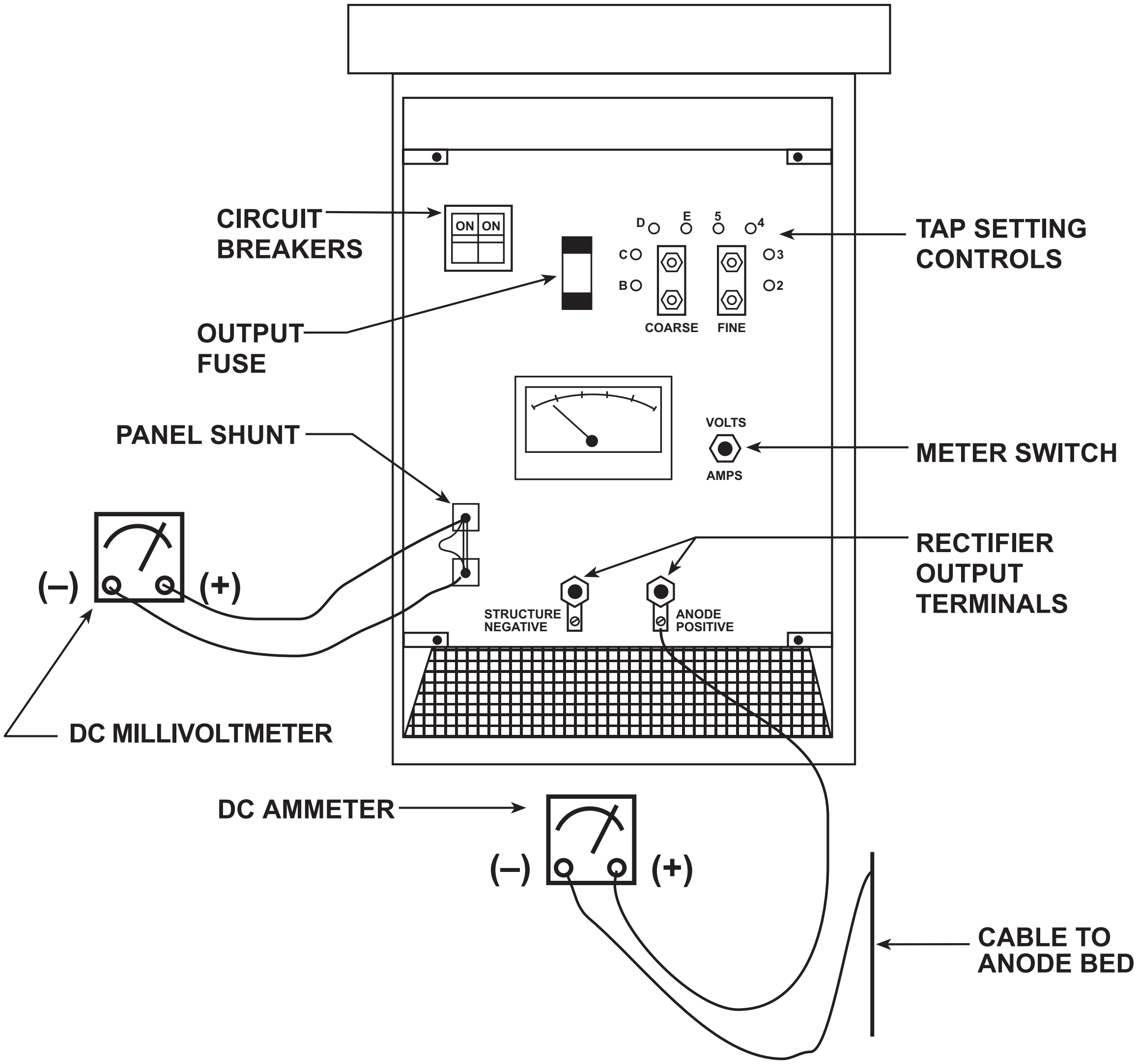


MEASURING RECTIFIER VOLTAGE

FIGURE 8-3

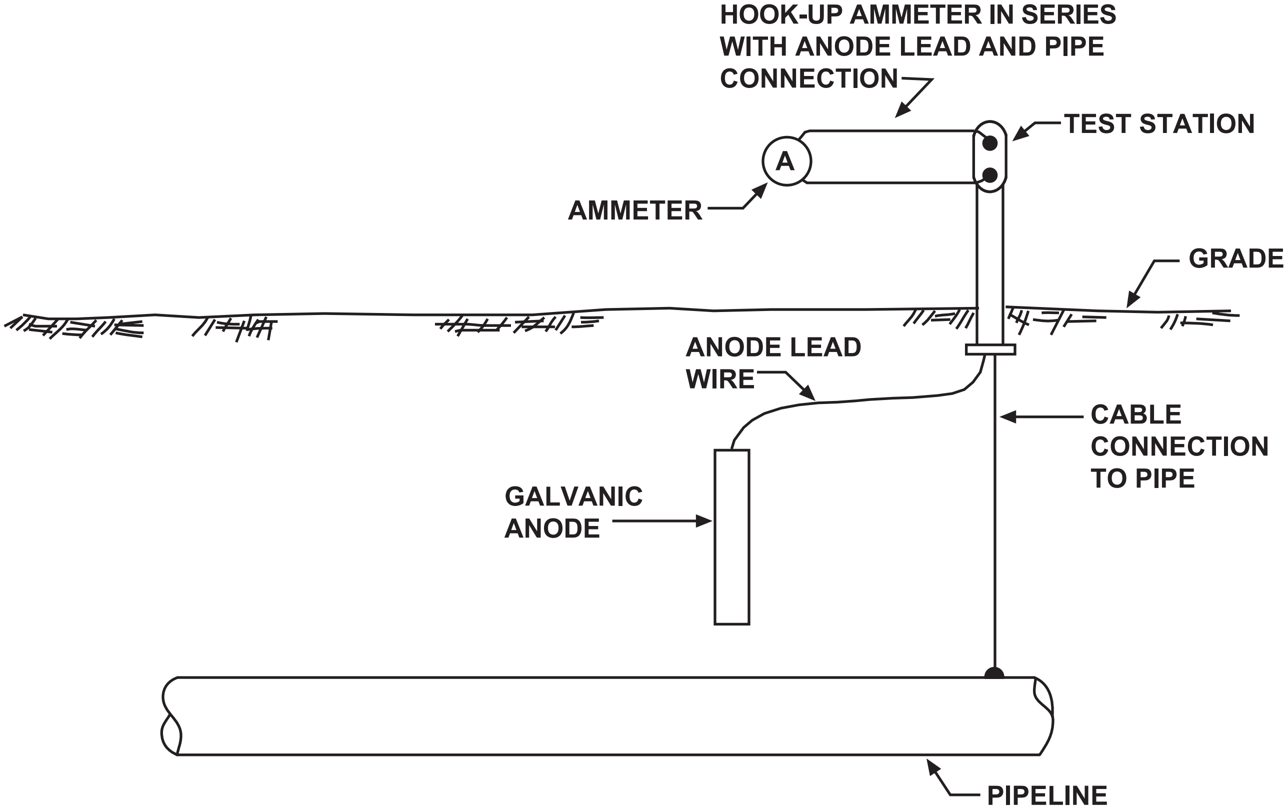
TWO METHODS:

1. DC AMMETER IN SERIES WITH ONE OF THE DC LEGS. CURRENT READ DIRECT IN AMPERES.
2. DC MILLIVOLTMETER IN PARALLEL WITH PANEL SHUNT. RATING OF SHUNT WILL USUALLY BE STAMPED INTO THE SHUNT.



MEASURING RECTIFIER CURRENT

FIGURE 8-4



MEASURING CURRENT OUTPUT OF GALVANIC ANODE

FIGURE 8-5

7. Potentials of the protected pipeline and of foreign lines at any crossing points should also be measured. Where inter-system bonds exist, measure the bond current and direction of current flow.

8. At pipeline cased crossings, the resistance between carrier pipe and casing should be measured plus the potential to a close reference electrode of both the pipeline and casing.

9. In dynamic stray current areas, verify that bonds, electrolysis switches or other corrective measures are operating properly and are providing the required degree of protection. In those areas, recording voltmeters should be used for potential and current measurements.

10. Verify that isolating joints are effective and that any protective lightning arresters, spark gaps or grounding cells are performing their function effectively.

11. In an impressed current anode system measure the current output of each anode at the anode distribution box, if available. Again, see Figure 8-6 for the proper meter connections.

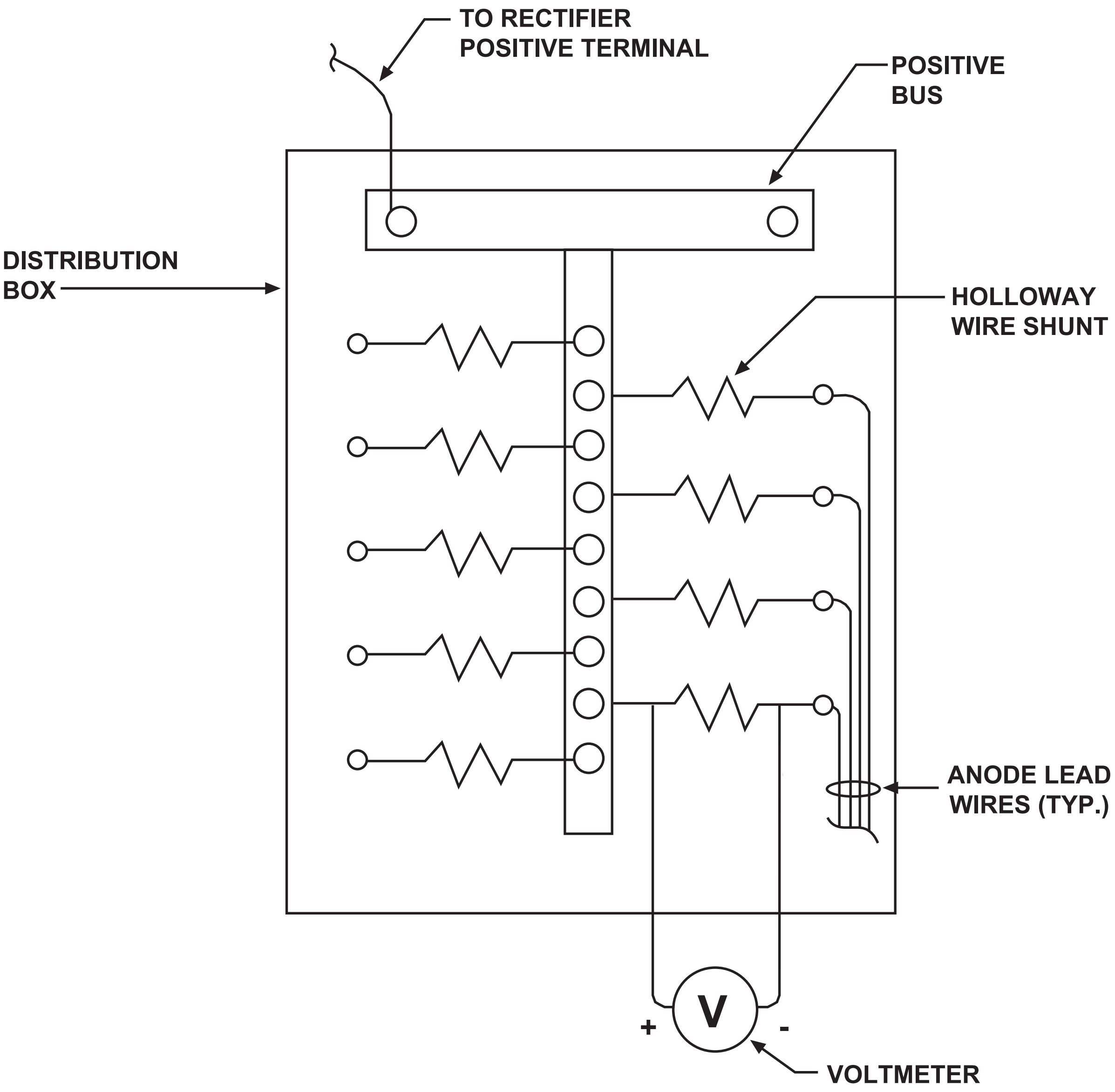
12. Verify continuity between structures where jumpers were installed as part of the cathodic protection system.

13. Make notes on maintenance records of any special physical features associated with the corrosion control system. Maintain these notes with the associated circuits.

The corrosion engineer should establish as part of his/her maintenance program a list containing the items listed above that are applicable to each installation/system, and the frequency at which each test should be performed.

In addition to the complete annual survey, a recheck of protective potentials may be made at intermediate intervals. The need for intermediate surveys may be a matter based on operating experience. In general, intermediate surveys are usually conducted in congested areas where stray current interference may be a problem, or where particularly critical or hazardous environmental conditions exist. At areas that are considered critical, more frequent checks should be made.

The above compiled data should be recorded in a permanent log so that previous survey data can be compared and analyzed. As soon as a periodic survey is completed, data



MEASURING IMPRESSED CURRENT ANODE CURRENT OUTPUT AT DISTRIBUTION BOX

FIGURE 8-6

should be analyzed promptly. The data can be computerized. With the use of the proper software, the computer can compare the data with that of previous surveys and indicate the problem areas. Corrective action should be taken immediately.

The importance of clear, accurate, and understandable data cannot be over-emphasized. Record all pertinent information on approved forms. Field sketches that may accompany data sheets must be as complete as possible with dimensions given to "permanent" objects. Data sheets should make sense and be clear enough to be analyzed well after the fieldwork has been completed.

Information to be included on the data sheets:

- Date and time taken (and by whom)
- Structure/circuit designation
- Where/at what point on the structure (sketches are often necessary with dimensions to "permanent" objects)
- Instruments used with model and serial numbers
- Polarity of all measurements (+/-)
- Meter scale used for each reading
- Shunt used
- Under what conditions was the data taken:
  - Rectifier On/Off
  - Bonds In/Out
  - Current source
  - Type of reference electrode and its placement
  - Soil conditions: wet, dry, frozen
  - Any other unusual conditions that are pertinent

REPAIRS AND/OR REPLACEMENTS

Based on data compiled during the periodic survey or as a result of routine maintenance, it may be deemed necessary to repair and/or replace various cathodic protection system components. Following is a brief discussion of repairs and/or replacements that may be required on a typical cathodic protection system.

Coatings

While recoating a buried structure such as a pipeline is expensive, it may be necessary in some instances. This is apt to be true where coating deterioration has been severe over a length of a pipeline or part of a structure due to unusual environmental conditions. If deterioration has been great enough to divert so much of the cathodic protection current that satisfactory protection of other parts of the structure has been lost, recoating the defective section could restore effective levels of cathodic protection to the entire structure with no change in the cathodic protection system. The economic justification for recoating versus simply adding local cathodic protection in the effected area would have to be studied by the corrosion engineer in each such instance. The material used for recoating buried structures should be selected specifically for its ability to stand up under the particular environmental conditions encountered. It is probable that the original coating, assuming that it was properly applied, was not a suitable selection for conditions in that environment.

Coating damage/failure on aboveground structures detected by maintenance personnel and reported to the corrosion engineer should be repaired or replaced promptly to maintain the integrity of the structure. Coating repair or replacement shall be made as per coating manufacturer's guidelines/recommendations.

Rectifiers

As previously discussed, any wires or components found to be damaged during maintenance checks of a rectifier should be repaired or replaced. If the reason for rectifier malfunction is not apparent, the following typical rectifier troubleshooting procedures should be followed.

a) Rectifier Troubleshooting Precautions

The following precautions should be observed when troubleshooting rectifiers:

1) Turn rectifier unit OFF when handling components within the unit. Open the AC disconnect switch ahead of the rectifier as well as the internal circuit breakers.

2) Consult the rectifier wiring diagram BEFORE starting to troubleshoot.

3) Make certain that meters used in troubleshooting are properly connected. The voltmeter should be connected across the points where the voltage is to be measured, while the ammeter should be placed in series with the circuit being tested. A millivoltmeter, when used to measure output current, should be connected across the terminals on the rectifier shunt. Correct polarity must be observed when using DC instruments. Turn the rectifier OFF before using an ohmmeter to avoid harming the instrument.

b) Troubleshooting Equipment

The following equipment is required for basic troubleshooting:

1) A multimeter for reading AC and DC voltages and DC current up to 10 amperes. This meter should also be capable of resistance measurements.

2) A millivoltmeter that can be used for checking rectifier DC output current by measuring the millivolt drop across the shunt on the rectifier panel.

3) Miscellaneous small tools, shorting cables and several jumper leads approximately three (3) feet long with booted alligator clips are also needed.

c) Simple Rectifier Troubleshooting Techniques

Many rectifier malfunctions have symptoms that are obvious. The obvious should never be overlooked. Strange odors, loose connections, charred components, signs of arcing, loose connections, etc., indicate problems which do not require elaborate test procedures to uncover. Some helpful troubleshooting techniques are:

1) If there is no current or voltage at the output terminals, the trouble and remedy may be:

a) Breaker tripped (or fuse blown). If apparently due to steady over-load, reduce the output slightly. If the breaker continues to trip or the fuse continues to blow even with the output reduced, the cause may be a short circuit in some component. Isolate the component and repair or replace as required.

If the breaker trips occasionally for no obvious reason, the cause may be:

- line voltage surges

- intermittent short circuits

Check for loose connections or brackets. Check connections using an ohmmeter while moving leads, connectors, etc. Check that power is turned OFF before using ohmmeter.

2) No AC line voltage. Check with AC voltmeter at rectifier input terminals. Do not overlook the possibility that the AC panel-board circuit breaker may have tripped.

3) Open circuited component or connection:

a) Check all connections, fine and course transformer tap adjustments and stack connections.

b) Rectifier stacks. Use an AC voltmeter to check if voltage is being supplied to the rectifying elements. If so, they may be open-circuited and should be checked using an ohmmeter and, if required, replaced.

4) Defective Meters

Faulty meters may give the indication that the unit is not operating properly when indeed it is. The rectifier meters should be checked with portable meters known to be accurate.

5) Defective Transformer

If AC line voltage, as checked with an AC voltmeter, is being applied to the primary of the transformer, but none is present at the secondary, check to see whether there is an audible hum coming from the transformer. If so, the primary is operating, but the secondary is probably open.

6) If DC voltage is measured at the output terminals of the rectifier but no current output is measured, there is an open in one of the external DC leads. In order to determine which external DC lead is open, proceed with the following steps:

- Turn off power to the rectifier. Disconnect the positive (+) lead from the rectifier and install a temporary jumper cable from the (+) output lug to some type of grounded structure, other than the pipeline to which the rectifier is connected, which can be used as a temporary anode. This would include structures such as a copper ground wire installed at the rectifier pole or a metal fence or guardrail. Reduce the AC tap settings to their lowest setting to prevent exceeding the rectifier rating. Restore power to the rectifier and measure the resultant current output. Increase the tap settings one increment at a time until the current can be measured.

- If installing a temporary anode jumper does not result in rectifier current, the problem may be in the structure lead. Reconnect the (+) lead wire and disconnect the structure (-) lead and install a temporary jumper cable from the (-) output lug to the pipeline. Restore power to the rectifier and measure the resultant current output. It is often convenient to have a structure connection point readily available near a rectifier in order to troubleshoot a rectifier system.

As previously indicated, most rectifier troubles are simple to detect and do not require extensive detailed troubleshooting procedures. If, however, the trouble is more difficult to locate it is usually better to systematically isolate the rectifier components until the defective part is found. See Figure 8-7 for a wiring schematic of a typical three-phase rectifier. The same schematic applies to a single phase rectifier although it is simplified since it will have only one transformer.

Impressed Current Anode Beds

Impressed current anode bed failure is usually a result of one of the following:

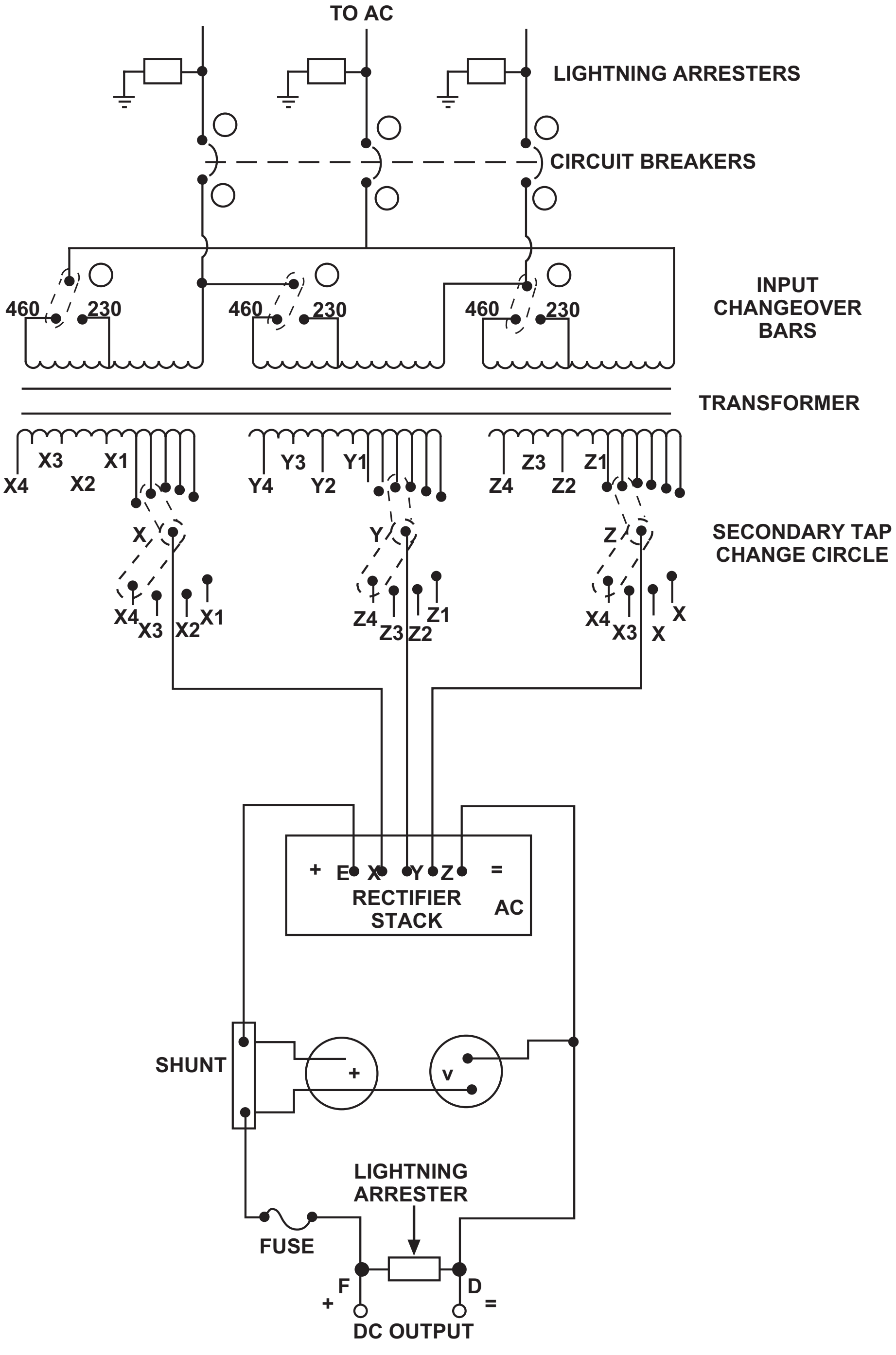
a) Broken or damaged anode leads or header cable

b) Physically damaged or broken anodes

c) Consumed anodes

Probably the most common reasons for premature failure are broken or damaged anode lead or header cables. These failures can often be tied to construction activity in close vicinity to the anode bed or to improperly made cable splices. All splices must be made completely waterproof using encapsulating resin splice kits or similar insulation.

Anodes may be damaged or broken during installation or as a result of construction activity near the anode bed. Damaged or broken anodes are not usually worth repairing and should be replaced. From a technical point of view, a consumed anode should not be considered a failure even though it will no longer provide adequate levels of cathodic



TYPICAL RECTIFIER CIRCUIT

FIGURE 8-7

protection current. Ideally, anode life calculations should have been conducted during system design so that anodes can be replaced before they are completely consumed or consumed to a point where they can no longer provide adequate protection.

Galvanic Anodes

As galvanic anodes approach the end of their useful life, current output will diminish. Replacement will be required when they no longer can furnish enough current to maintain protective potentials on the structure. Current output should be measured during annual surveys at those installations having test points installed for that purpose.

A marked decrease in the output of a galvanic anode which, based on anode life calculations, is not reaching the end of its life may be an indication of a broken header cable, lead cable, or possibly a physically damaged anode. As is the case with impressed current anode beds, header and lead cables can become damaged or broken. Repair or replace damaged cables as required, to restore system operation. Like impressed current anodes, physically damaged anodes should be replaced.

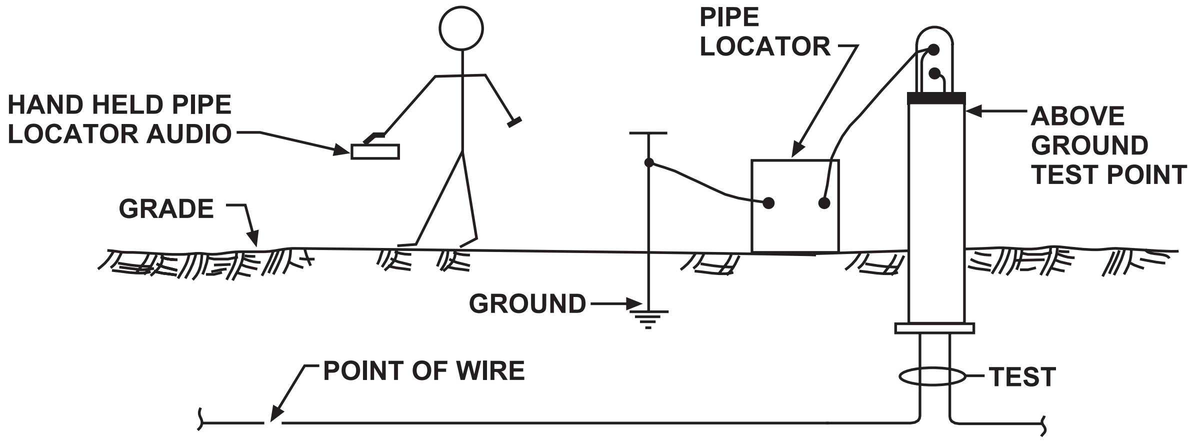
Test Stations

Broken wires at test stations can be hard to repair if the break location is not accessible. Test wires may snap if sufficient slack was not provided during installation to allow for soil settlement.

Occasionally, an open circuit indication at the test station may be the result of a defective or improperly made exothermic weld connection of the test lead to the structure.

At locations where the test station is located close to a buried structure, the excavation required to locate and repair the damage (unless the structure is very deep) is a relatively simple job requiring one relatively small excavation. If the break is in a long wire span, however, the question of where to dig becomes more difficult and additional tests are required to determine the location of the break.

Where the wire has been broken and pulled apart, the break in most cases can be located by conducting an "over-the-wire" survey using a pipe locator, see Figure 8-8. This is done by connecting the wire being tested to the pipe locator transmitter terminal labeled "pipe" and connecting the terminal labeled "ground" to a separate ground such as a ground rod. When the pipe locator transmitter is turned on, an audio frequency



OVER THE WIRE SURVEY USING PIPE LOCATOR

FIGURE 8-8

signal is transmitted along the wire being tested. Walking over the route of the wire carrying the pipe locator audio receiver, an audio signal will be heard. The audio signal level will gradually decrease as the distance from the transmitter increases. An abrupt decrease or loss of the audio signal will indicate the point of the wire break.

If the "over-the-wire" survey does not detect a break in the wire, the route of the wire must be excavated to locate the break. Excavation should start at the connection of the wire to the structure point so that the possibility of a defective exothermic weld connection can be ruled out. If the wire break is in the long lead wires used for millivolt measurements, it may prove to be more economical to install a new two wire test station at the point where the long lead connections were originally made. This is in lieu of excavating along the length of the pipeline to find the wire break. Testing done in the future would then require the use of a wire reel extended along the ground between the two test stations.

Where two test wires are thought to be shorted below ground at a test station, the distance from the terminal board to the point of the short circuit may be determined by measuring the resistance between the two wires, see Figure 8-9. Knowing the wire size, the resistance per foot for that particular size can be obtained from an electrical handbook or a cable manufacturer's manual. Based on this resistance, it is possible to calculate the number of feet of wire from the terminal board to the short circuit and back. Half of this length will be the distance from the terminal board to the short circuit.

<u>EXAMPLE</u>

Using an ohmmeter, the resistance between terminals 1 and 2 is measured at the test station shown in Figure 8-9. The measured resistance is 0.074 ohm. According to an electrical handbook, the resistance of No. 12 AWG wire is 0.00162 ohm/ft. Locate the short as follows:

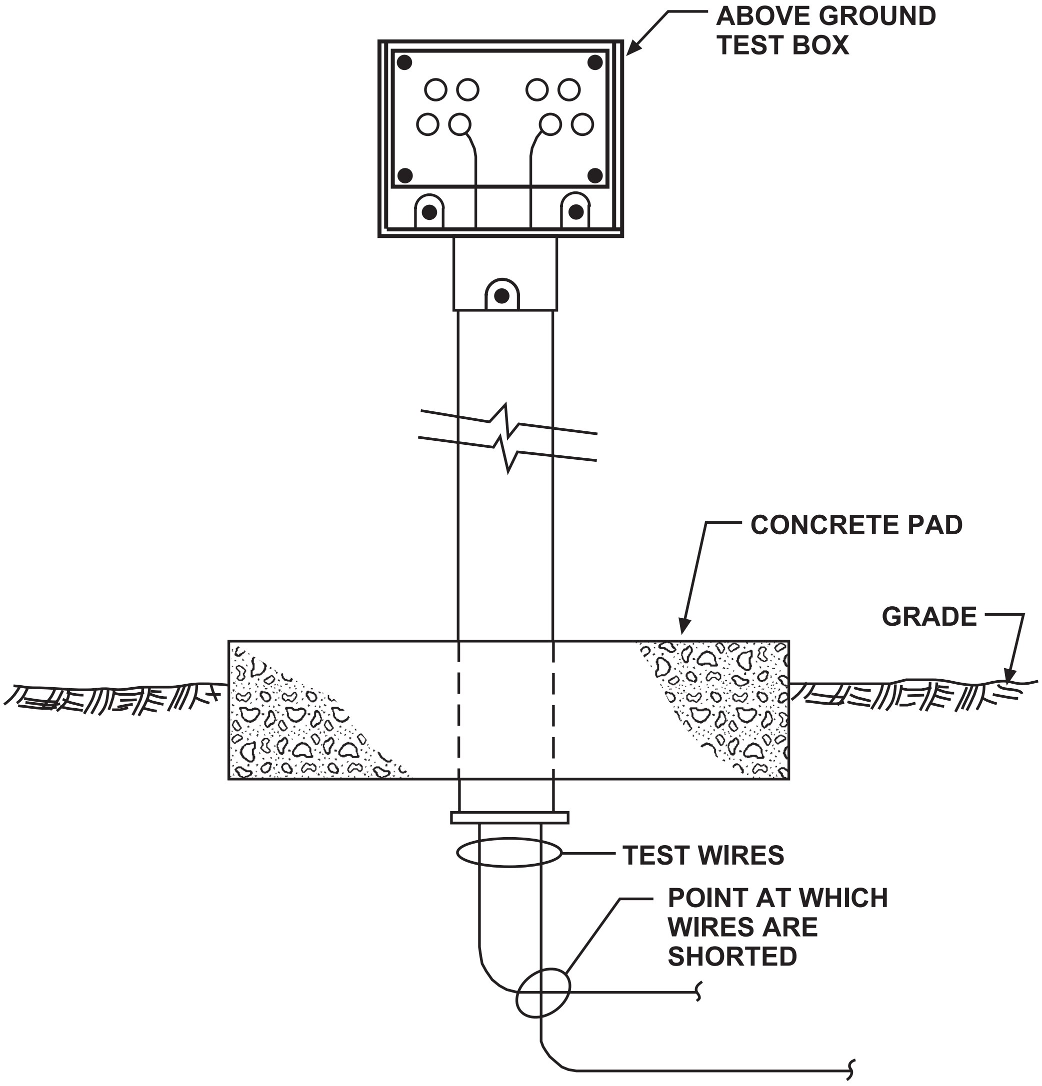
$$\text{Distance } (x) = \tfrac{1}{2}\,(\text{measured resistance}/\text{wire resistance})$$

$$x = \tfrac{1}{2}\,(0.074/0.00162)$$

$$x = 22.84 \text{ ft.}$$

The point at which the wires are shorted together is approximately 23 ft. from the test point terminals.

On occasion, test wires are found to be in contact or shorted to the test station conduit.



TEST STATION WITH SHORTED TEST WIRES

FIGURE 8-9

This usually occurs where the wires emerge from the conduit edges that have not been properly reamed to eliminate sharp edges. This is usually a result of incomplete provisions in the installation specifications or inadequate inspection during construction.

Test station repairs should be made as soon as possible. Failure to repair test stations may lead to cathodic protection system problems going undetected for long periods of time.

TESTS USED IN CATHODIC PROTECTION SYSTEM TROUBLESHOOTING

Percent Leakage Current Tests

Due to lightning or other causes, isolating joints or fittings may become partially or completely shorted. Because the integrity of these devices is generally critical to the proper operation of the cathodic protection system, they must be tested periodically. In order to measure accurately the percent of leakage, a test set-up similar to that shown in Figure 8-10 is used.

A calibration current (I_K) from an external DC source must be provided. This current is allowed to flow through a short section of the pipeline and return as shown in the figure.

Begin the test by measuring any voltage drop present in the calibration section (E_1). Then connect the calibration current (I_K). The current flow will cause a voltage drop (E_K). Both the current flow and its associated voltage drop are measured so that a calibration factor for the test set-up can be calculated using the following formula:

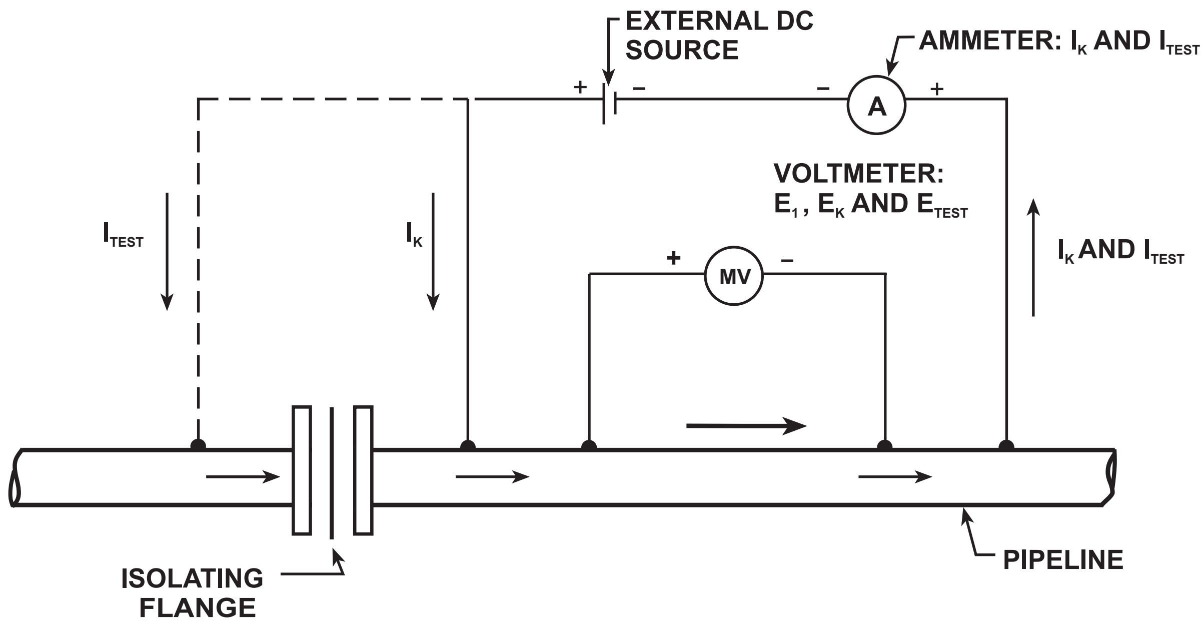
$$K\ (\text{amp} / \text{mv}) = \frac{\text{calibration current}}{\text{calibration voltage drop}}$$

or

$$K = \frac{I_k}{E_k - E_1}$$

Using the external DC source again, make connections to the pipe as shown in the figure to enable test current to flow from one side of the isolating joint to the other. The voltage drop across the calibrated section (E_{TEST}), and the test current (I_{TEST}) are then measured. The percent leakage through this isolating joint can then be calculated using these measured values and the previously calculated calibration factor as follows:

$$\text{Percent Leakage} = \frac{K \times (E_{TEST} - E_1)}{I_{TEST}} \times 100$$



MEASURING PERCENT LEAKAGE
THROUGH ISOLATING JOINT

FIGURE 8-10

EXAMPLE

A calibration current of 34 amperes (I_K) is allowed to flow from the line side of the isolating joint through the pipeline causing a voltage drop of 28 millivolts (E_K). A test current of 5 amperes (I_{TEST}) is allowed to flow across the isolating joint through the pipe causing a voltage drop of 4.7 millivolts (E_{TEST}). Determine the percent leakage current. E_1 was found to be 1.0 mV.

Step #1 - Calculate the calibration factor (k):

$$K = \frac{I_k}{E_K - E_1} = \frac{34}{28 - 1} = 1.26 \text{ amps / mv}$$

Step #2 - Calculate percent leakage current:

$$\text{Percent Leakage} = \frac{K \times (E_{TEST} - E_1)}{I_{TEST}} \times 100$$

$$= \frac{1.26 \times (4.7 - 1)}{5} \times 100$$

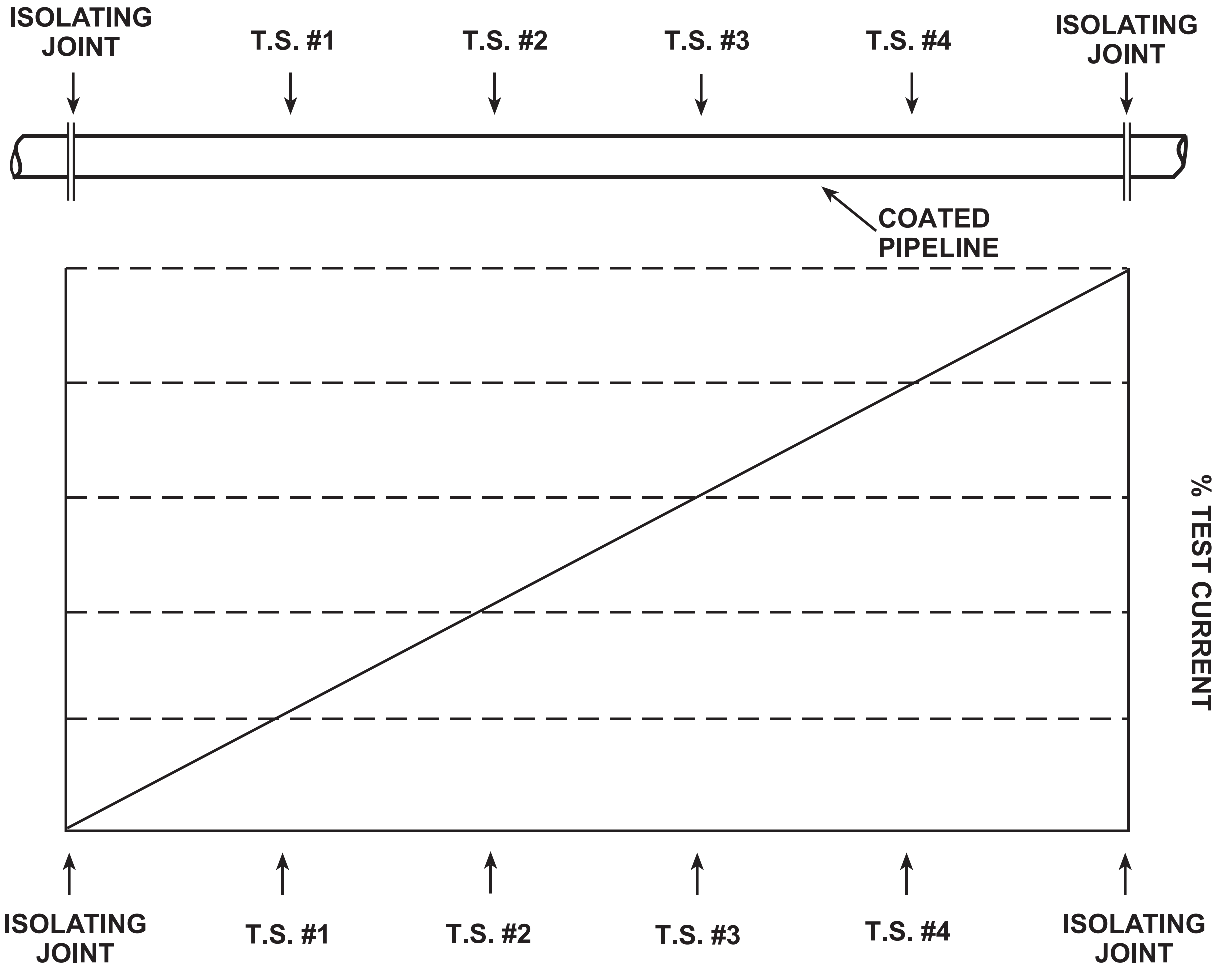
$$\text{Percent Leakage} = 93.2\%$$

System Current Profile

The plotting of the system current profile can help to isolate a corrosion problem area within a system. The current profile is developed using millivolt drop measurements along the pipeline system.

The current profile is a plot of test station location versus percent test current. The current profile of a pipeline section with a perfect coating and no electrical contact with foreign structures would look like the plot shown in Figure 8-11.

This plot shows that a uniform amount of current is entering onto the pipeline per unit length of pipe.



IDEAL CURRENT PROFILE FOR
PROTECTED PIPE SECTION

FIGURE 8-11

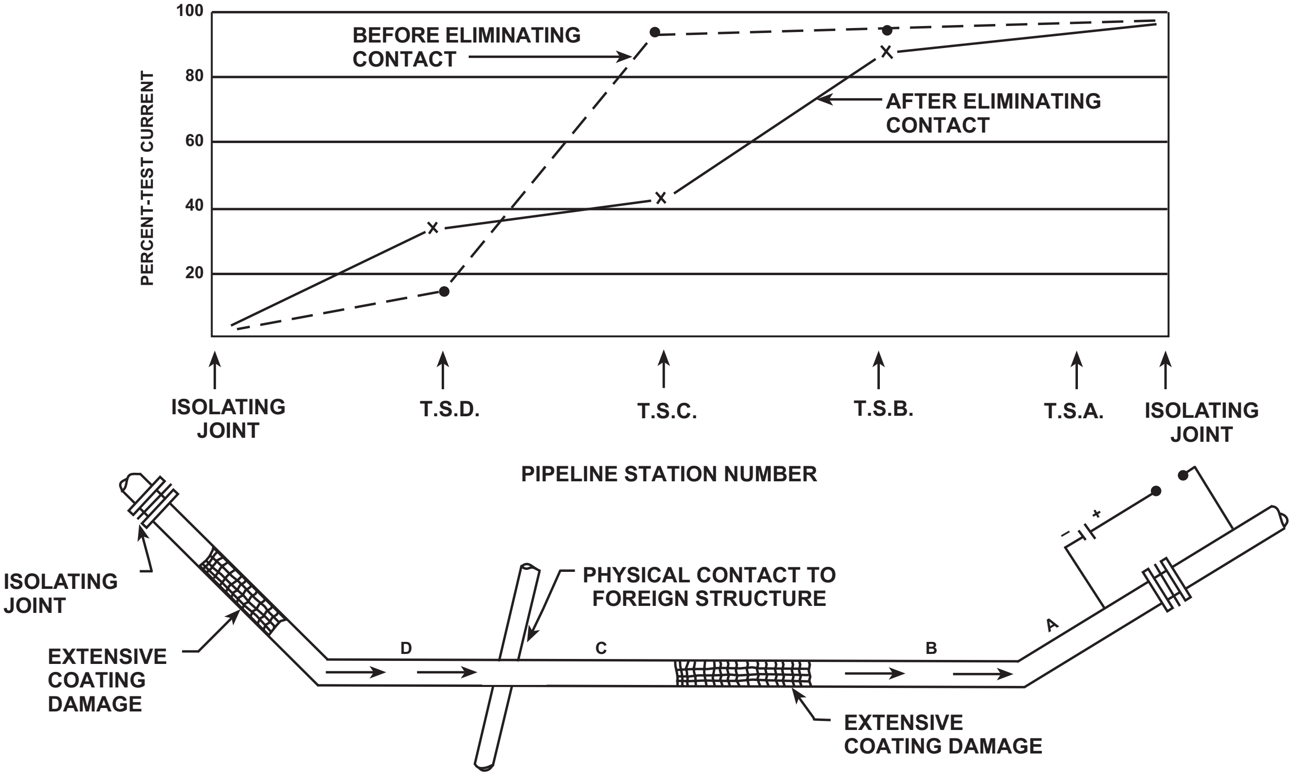
Figure 8-12 shows a more typical current profile of a protected pipeline section. The profile, when analyzed, provides the following information:

1. The large drop of current between test stations C and D (dashed line) indicates that a large amount of current is flowing onto the pipeline in this area. This may be a result of physical contact with a foreign structure. In the case of a "short" to another underground metallic structure, there will be very little to no current from the protection system on the other side of the contact point. Current will pick up on the lower resistant structure such as a bare water distribution pipe and return to the source via the metallic contact point.

2. The large drop of current and the increased slope of the plot between test stations C and B (solid line) indicates that a coating problem exists in this area. A larger percentage of the current will be required to protect the bare steel in that particular area.

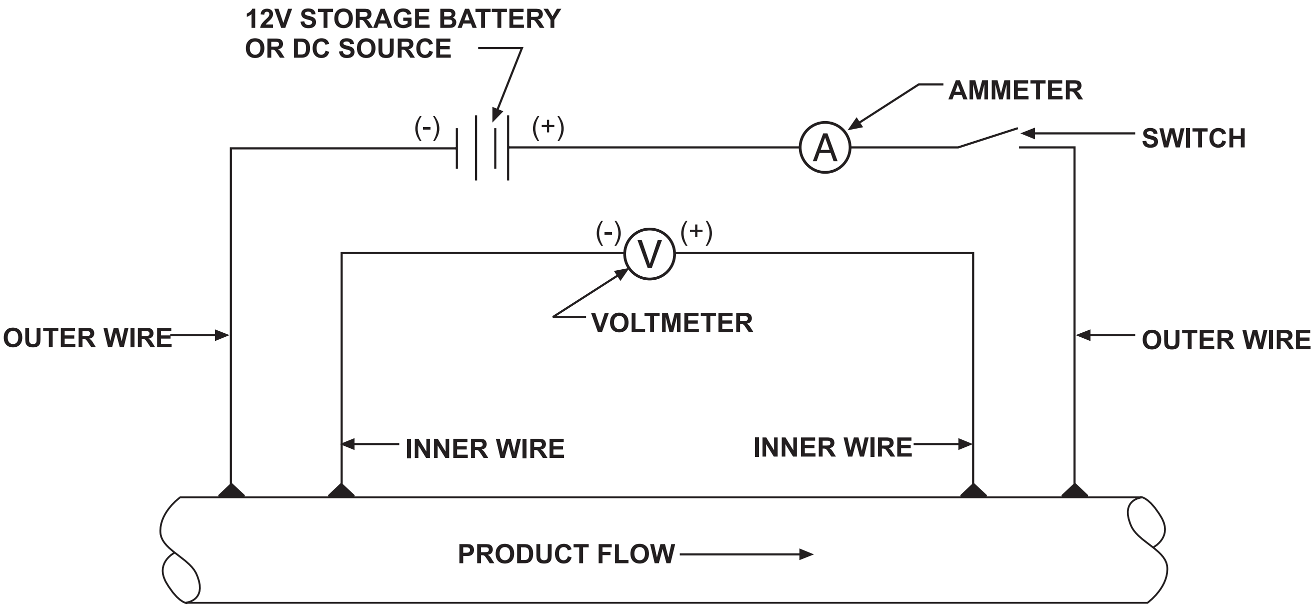
After problem areas are located through the use of the current profile, further tests should be conducted in these areas. These tests should include the use of special electronic equipment such as short locators and/or surface potential survey techniques, or more extensive mill-volt drop tests.

To determine the amount of current, the resistance of the pipeline span must first be calculated as shown for the Percent Leakage Test. Figure 8-13 depicts the typical testing arrangement for the calculation of resistance for a particular pipeline span. To insure the accuracy of the calibration factor, it is recommended that four (4) separate connections be made to the structure under test. The calibration test begins with the connection of a power source such as a 12-volt battery in series with an ammeter. The source of current is then interrupted and the resulting voltage drop caused by the current flow is then measured between the inside test wire connections. Calculation of the calibration factor or "K" factor is determined by dividing the change in the test current by the change in the voltage drop. This calculated K factor then becomes part of the permanent record of the pipeline system. Any future testing which requires determination of the amount of current flow on the pipeline at this particular point can use this K factor to calculate the current flow. This is provided that the voltage drop is measured across the same original inside test wires. The original calibration test should be repeated a sufficient number of times to insure that the data is accurate, particularly in stray current areas. The units for the K factor are in amps/mV. See Figure 8-14 for a typical millivolt drop test.



"CURRENT PROFILE"
TO EVALUATE COATING QUALITY

FIGURE 8-12



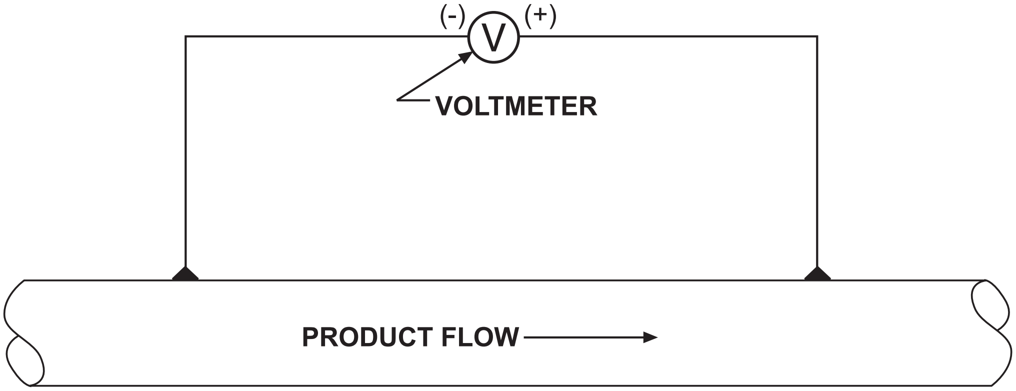
$$K = \frac{\Delta I}{\Delta E_{MV}} = X \;\; A/mv$$

WHERE: ΔI = AMPS

ΔE_{MV} = MILLIVOLTS

CALIBRATION OF IR DROP SPAN

FIGURE 8-13



$$I_{CALCULATED} = \Delta E_{MV} \times K$$

$$\%I_{TEST} = \frac{\Delta E_{MV} \times K \times 100\%}{I_{TEST}}$$

WHERE: K = CALIBRATION FACTOR IN AMPS / MV

INDIRECT MEASUREMENT OF CURRENT

FIGURE 8-14

The direction of current flow can be determined by noting which polarity connection on the voltmeter results in a positive meter deflection. The direction of current flow will be from positive to negative. Therefore, if the upstream test lead is connected to the positive terminal of the voltmeter and the resulting voltage drop has a positive polarity, then the direction of current flow is upstream to downstream.

Knowing the direction of the current flow is always useful information, particularly when tracing galvanic currents caused by an underground contact to another metallic structure. In this case the ultimate goal of the testing is to determine the point of contact or "short" and eliminate it. Endwise galvanic current flow on a structure can be tracked by measuring voltage drops along the structure at various points where a physical connection to the structure can be made. Provided that your structure is electrically continuous, the point of underground contact will be between those two test locations where the polarity of the measured voltage drop will reverse.

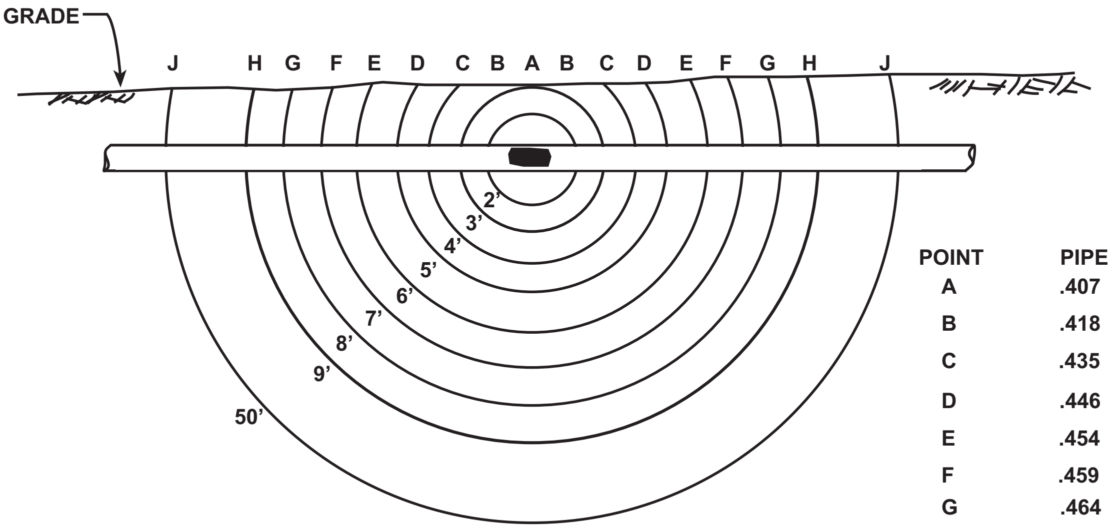
The data obtained can be used to calculate the resistance-to-earth of either the entire piping system or of individual sections of pipe within the system. By incorporating Ohm's Law, Kirchhoff's current law, and current profile measurements, data can be compiled. When making these calculations it is important to remember that calculations involving the entire system must use total system current and voltage measurements. On the other hand, data calculations for individual sections must incorporate only the current and voltage measurements obtained in that section of the system.

Surface Potential Surveys

Surface potential surveys are conducted using two identical reference electrodes and a high resistance voltmeter. The potential measured between the electrodes, due to a test or protective current applied to the structure under test, can be used to locate coating holidays or anodes.

Holiday (cathodic) gradients are caused by the flow of current onto a pipeline, leading to voltage drops in the earth. If cathodic protection current is applied to the pipeline that has holidays, about one-half of the total voltage drop will occur within one foot of the pipe surface, see Figure 8-15.

The voltage gradients caused by an anode(s) dissipating current will follow the same pattern as at a holiday except the directions will be reversed. The largest gradient potential will be measured closest to the operating anode.



POINT	PIPE
A	.407
B	.418
C	.435
D	.446
E	.454
F	.459
G	.464
H	.480
J	.500

VOLTAGE GRADIENTS DEVELOPED AT A HOLIDAY FROM CATHODIC PROTECTION CURRENT CHANGING PIPE TO SOIL POTENTIAL OF PIPE 0.50 VOLTS.

HOLIDAY GRADIENTS

FIGURE 8-15

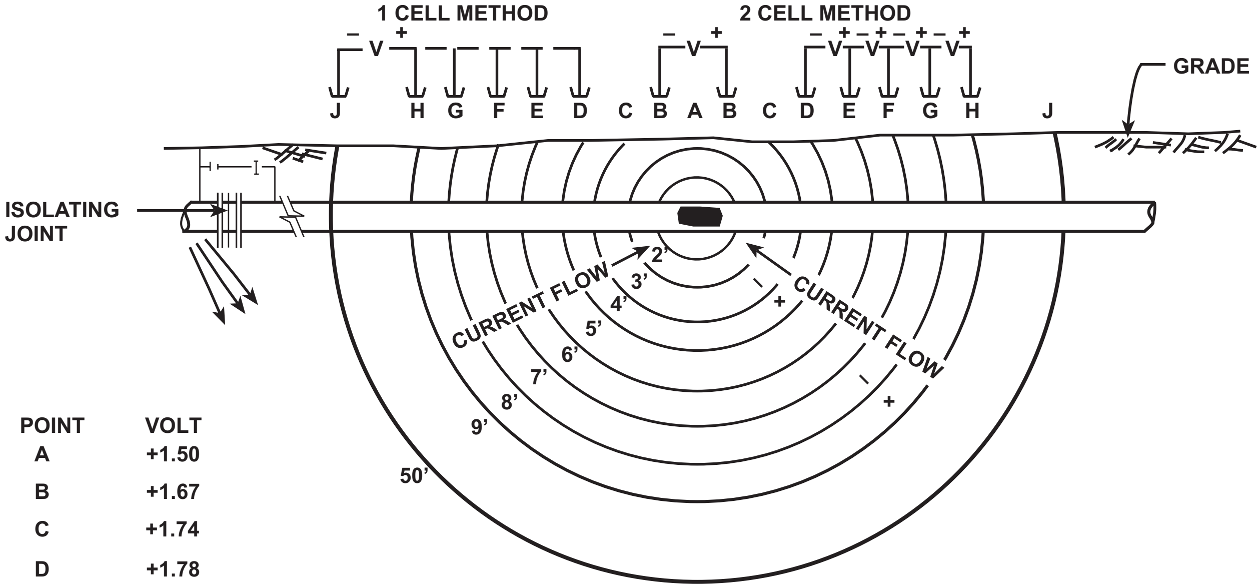
Surface potential surveys used to locate holidays or anodes can be conducted using either the one electrode or two electrode method. Both surveys are commonly referred to as a "cell to cell" surveys and both surveys use two identical reference electrodes. In the one electrode survey, one reference electrode remains stationary while the other electrode is moved during testing. During the two electrode survey, both reference electrodes are moved. When two reference electrodes are both moved, it is important to retain the same separation between electrodes as well as the same polarity configuration. In this case the polarity sign of the potential difference measured will change once both electrodes are past either the coating fault or anode. The use of these two methods is illustrated in the following examples.

Example #1 - Measuring Holiday Gradients

Referring to Figure 8-16, the two methods of surface potentials can be used to measure the holiday voltage gradients caused by a test current applied at the isolating flange which changes the pipe-to-soil potential by 2.0 volts.

First, using the one electrode method, the positive or stationary electrode is place at point J. The moving or negative electrode is placed at point H. The measured potential difference at this point is +0.08 volt. Subsequent testing consists of moving the negative electrode to points G through A and measuring the potential at these various points with respect to the reference left in place at point J. These readings will become more positive. In this example, the potential difference between points J and A is +0.50 volt. As the negative electrode is moved past point A through points B through H and the potential differences are measured, the readings become less positive. Plotting both sets of potential measurements on a graph will indicate the location of the holiday. The location of the holiday will coincide with that of the most positive potential measurement.

The second method, the two electrode method, involves moving both the positive and negative electrodes. A test current is applied at the isolating joint as previously illustrated in Figure 8-16. A potential difference of +0.06 volt is measured when the positive electrode is placed at point H and the negative electrode at point G. The positive electrode is placed at point G and the negative electrode at point F for the second reading. The positive electrode is then placed at point F and the negative electrode at point E for the third reading. All subsequent readings must follow this same pattern. The sixth reading will be the highest positive reading (+0.170 volt), which is measured with the positive electrode at point A and the negative electrode at point B. The seventh reading taken between points A and B, with the positive electrode at point A and the



POINT	VOLT
A	+1.50
B	+1.67
C	+1.74
D	+1.78
E	+1.82
F	+1.84
G	+1.86
H	+1.92
J	+2.00

SURFACE POTENTIAL SURVEY
MEASURING ANODE VOLTAGE GRADIENTS

FIGURE 8-16

negative electrode at point B, will be a negative reading (-0.170 volt).

The change in the potential measurement from positive to negative indicates a closure of current around the coating holiday. A potential reading of zero would be obtained if the positive and negative electrodes were placed at point B on either side of point A directly over the holiday. The most positive and most negative readings will be located on each side of the holiday and the zero reading directly above its center.

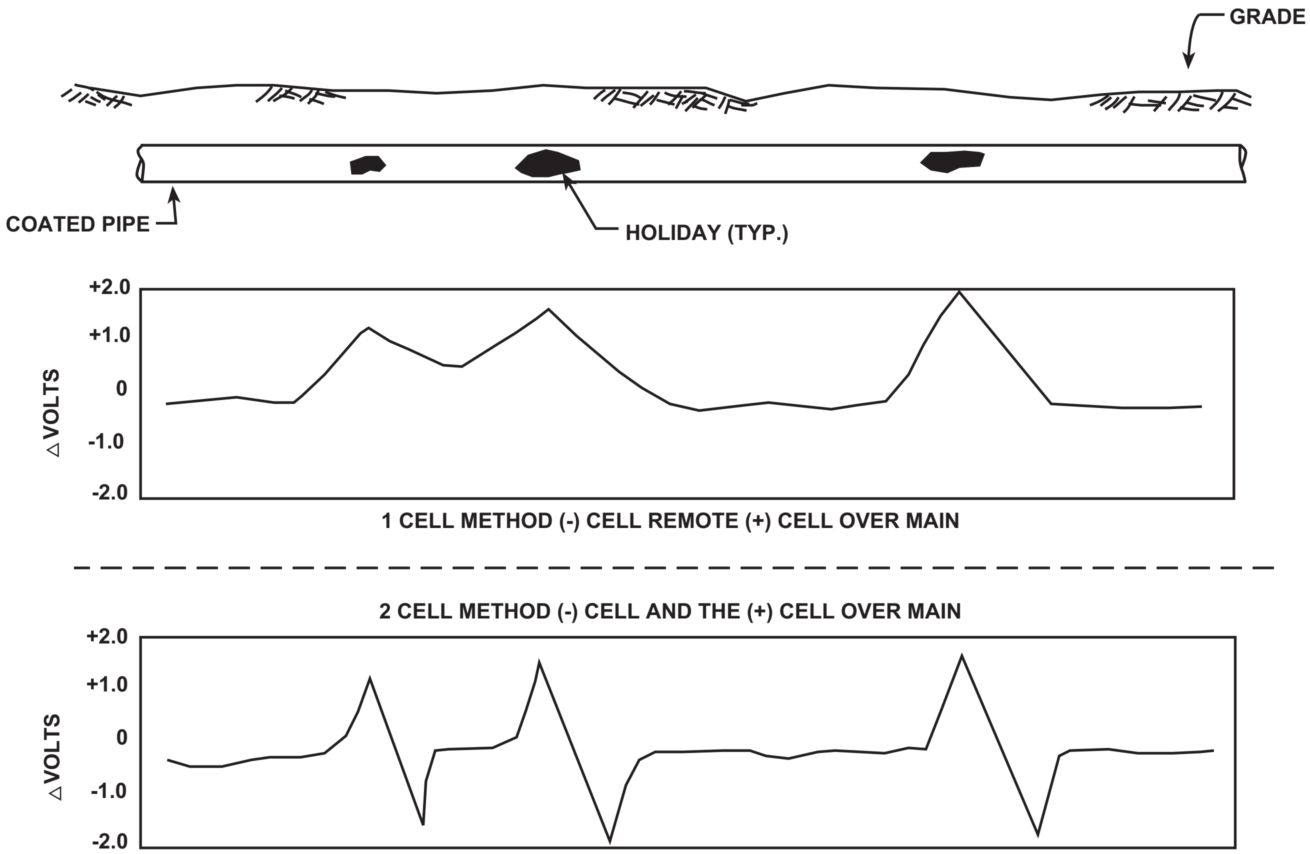
Figure 8-17 illustrates the two graphs obtained when plotting the data from the examples discussed above. The top graph represents the readings from the one electrode method. Using this method, if one holiday exists on a pipeline, a definite peak will show on the plot. However, if there are two or more holidays located close together, the resulting graph will not show two or more definitive peaks. Rather, the graph will indicate a holiday that is approximately 5 to 10 feet long. A base line is defined by the absence of significant peaks on the graph. The magnitude of peaks on the graph will be proportional to the size of the holiday.

The lower graph represents the data obtained using the two electrode method. As opposed to the single electrode method, the two electrode method will show definite peaks for multiple holidays that are located in close proximity to each other.

Example #2 - Locating Anodes

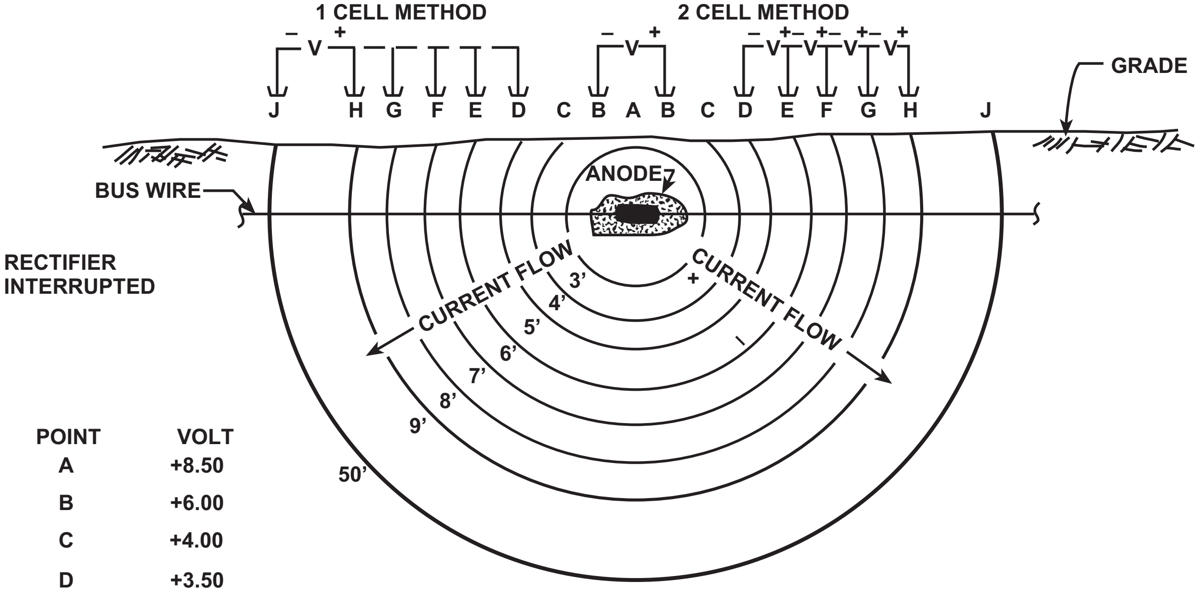
Figure 8-18 illustrates the typical voltage gradients created around an operating anode buried in the earth. These gradients follow the same pattern as those found at a coating fault except that the direction of the gradient field is reversed. Using the one electrode method, the stationary or negative electrode is placed between 50 and 100 feet away from the anode string. The moving or positive electrode is placed above the anode string and then moved along its length. Positive potential peaks will be observed over each anode. If the anode output is interrupted, the potential changes will be related to the pattern of current discharge of the anodes into the earth. A potential change of +1.30 volts is measured between the negative and positive electrodes located at points J and H respectively. When moving the positive electrode over points G through A and measuring the potentials with respect to point J, the readings will become more positive. The measured potential in this example between points J and A is +8.30 volts. Moving the positive electrode over points B through H and again measuring the potential difference with respect to point J, the readings will become less positive.

As stated earlier, when using the two electrode method, both the positive and negative



SURFACE POTENTIAL SURVEY
MEASURING HOLIDAY VOLTAGE GRADIENTS

FIGURE 8-17



POINT	VOLT
A	+8.50
B	+6.00
C	+4.00
D	+3.50
E	+3.00
F	+2.50
G	+2.00
H	+1.50
J	+0.20

SURFACE POTENTIAL SURVEY
MEASURING ANODE VOLTAGE GRADIENTS

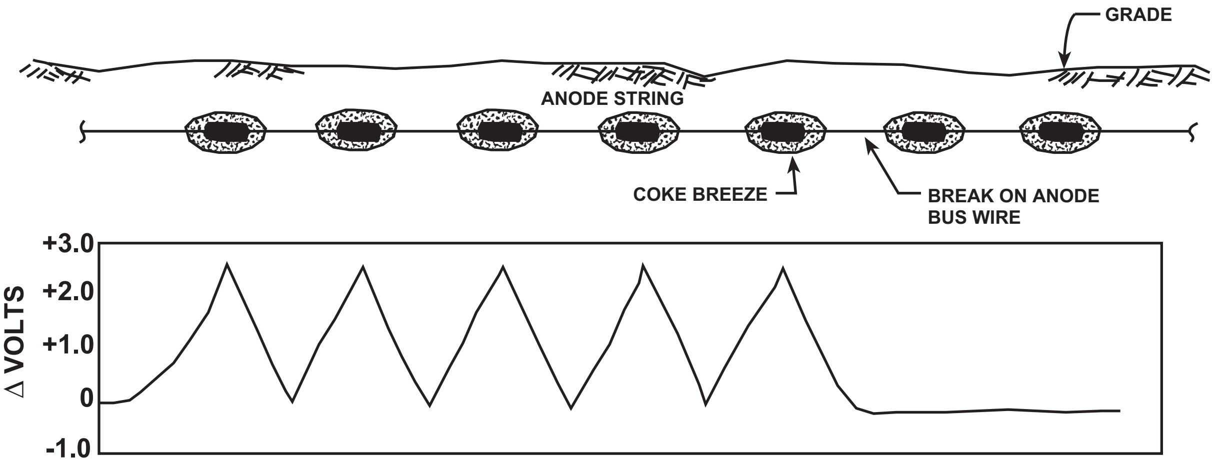
FIGURE 8-18

electrodes must be moved with each reading. With the anode output interrupted and the positive electrode at point G and the negative electrode at point H, the potential difference is +0.50 volt. Refer again to Figure 8-18. Subsequent readings must follow the same pattern as that discussed in Example # 1. A positive potential of +2.50 volts is measured at the sixth location with the positive electrode at point A and the negative electrode at point B. The seventh reading between points A and B with the positive electrode on B and the negative electrode on A will give reading of -2.50 volts. If the positive and negative electrodes are placed at both points B, on either side of point A directly over the anode, the measured potential difference will be zero. The area between the most positive and the most negative readings will be over the anode. A zero potential difference will be over the anode. Figure 8-19 shows the data plotted for both types of survey. The spacing between each anode can be determined from the graph. The top graph represents the data from the one electrode method. The high positive readings or peaks occur directly over the anodes. This type of survey can be helpful when trying to locate a break in an anode string since it can identify the last operating anode. The data obtained using the two electrode method is shown in the bottom graph of Figure 8-19.

The one electrode and the two electrode surveys are useful in locating individual galvanic anodes directly connected to a pipeline. By interrupting the test current across an isolating joint, the galvanic anodes will appear as large holidays on the pipeline.

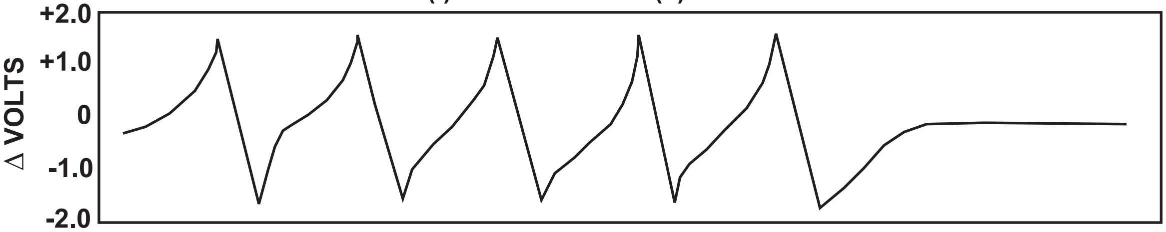
There are times when a break in an anode cable is excavated but it is not known whether this is the first break in the cable from the rectifier and that there is power to this point. One way to determine that there are not other breaks in the cable between this point and the rectifier is to measure the potential-to-earth of the cable at this point to a standard reference electrode and compare this value to the operating voltage output of the rectifier. These two values should be similar. Proper safety precautions should be taken when connecting to the anode cable in the ditch and a high output rectifier should be adjusted to a lower setting for this testing.

Another type of potential survey that uses two reference electrodes is known as a side drain survey that is often used to delineate possible areas of active corrosion, particularly on bare or poorly coated pipe. For this survey the first electrode is placed directly above the pipe, in contact with the soil. The second electrode is placed in contact with the soil at a 90-degree angle to the pipe at a distance approximately equal to 2½ times the pipe depth. During testing, the electrode placed directly above the pipe should be connected to the positive terminal of the voltmeter and the other electrode to the negative terminal. Positive side-drain readings indicate that current is being



1 CELL METHOD (-) CELL REMOTE (+) CELL OVER ANODE STRING

2 CELL METHOD (-) CELL AND THE (+) CELL OVER ANODE STRING



SURFACE POTENTIAL SURVEY
MEASURING ANODE VOLTAGE GRADIENTS

FIGURE 8-19

discharged from the pipe at this point, making it an anodic area. Negative side-drain readings normally indicate that current is flowing towards or onto the pipe at this point, making it a cathodic area. The side-drain measurements should be continued at no more than 5-foot intervals. Tests must be made on both sides of the pipe, until the extent of the possible problem section has been determined. However, under certain conditions a relatively strong localized anodic cell could exist on the bottom of the pipe with the top of the pipe serving as a cathode and negative side-drain readings could be measured while severe corrosion is actually occurring on the bottom of the pipe at this location.

Testing for Pipelines in Contact with Casings

Two types of contacts are typically considered when evaluating whether a pipeline is in contact with its casing. These two types are known as either an electrolytic couple or a metallic contact. An electrolytic couple refers to a situation where the annular space between the pipeline and the casing is filled with water or some combination of electrolyte that provides a low resistant path between the carrier pipe and the casing. A metallic contact refers to the situation where the carrier pipe is in direct metallic contact with the casing. There is also the case where both of these situations are present at the same time.

A low resistant electrolytic couple or metallic contact between the carrier pipe and the casing will affect the operation of a cathodic protection system. The casing is typically a large bare section of steel pipe that will act as a large coating holiday that may divert current away from any local coating holidays on the carrier pipe. In the case of an electrolytic couple, the return path for the cathodic protection current will be through the low resistant electrolyte in the annular space between the two structures. In the case of a metallic contact, the return path for the cathodic protection current will be through the point of metallic contact. Therefore, piping with coating faults near a "shorted" casing may not receive the proper current density required for protection. A "shorted" casing will also diminish the amount of current attenuation from a protection system since the current will be drawn to this rather large coating fault.

Any areas of bare metal found at coating faults on the carrier pipe inside of a casing filled with electrolyte will require protection against corrosion. In this instance, cathodic protection current must pass from the earth to the casing, through the electrolyte, and then on to the pipe. This series of resistances causes a voltage drop that may result in less than adequate protection.

Identifying possible "shorted" casings is usually accomplished through a comparison of the "on/off" structure-to-earth potentials of both the carrier pipe and the casing. Usually there is a significant potential difference between the carrier pipe and the isolated casing when the carrier pipe is well coated and the casing is bare. These potential differences become less when the carrier pipe is poorly coated and the surrounding soil is of low resistivity. When both the carrier pipe and the casing exhibit the same potential values there is a strong indication that some type of "short" is present.

Another indication of a "shorted" casing is a significant change in the amount of current flow measured on the pipeline at a point on the far side of the casing from the cathodic protection system. If the carrier pipe has a fairly uniform coating, the amount of current measured along the pipeline should gradually decrease as the distance from the cathodic protection system becomes greater. However, since a "shorted" casing has the same effect as a large coating fault, there should be a significant decrease in the amount of current measured on the far side of the casing. This difference in the amount of line current measured on both sides of the casing would be approximately equal to the amount of protective current going to the "shorted" casing. This measurement of line current should be made with the test current interrupted.

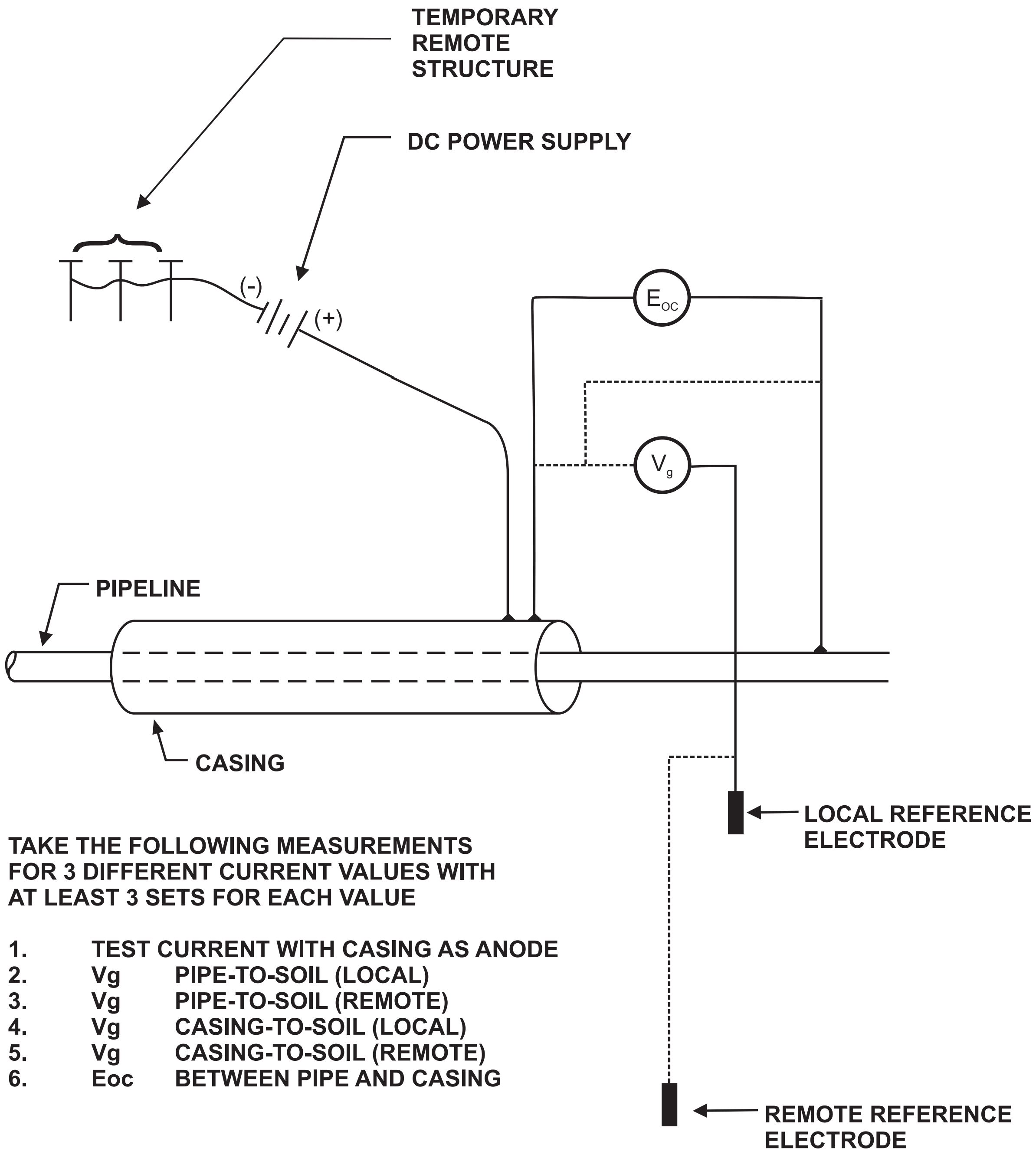
One field test that can be performed to determine whether a casing is "shorted" to the carrier pipe involves using the casing as a temporary anode bed. In this instance the casing is deliberately depolarized as current is discharged from the casing into the earth and then on to the carrier pipe. The indication that the casing is isolated from the carrier pipe is given by casing potential readings becoming less negative with increasing amounts of test current. The carrier pipe potential readings can vary in either direction, however if the two structures are not in metallic contact, the potentials measured on the carrier pipe will probably become more negative with increasing amounts of test current. Figure 8-20 depicts this particular testing arrangement.

CONCLUSIONS

The establishment of a cathodic protection maintenance program is vital if the system is to operate as intended. A system that is not properly maintained will undoubtedly experience premature failure.

Any system malfunctions detected during periodic surveys or maintenance operations should be repaired as soon as possible. A system that is malfunctioning or not operating for an extended period of time may be detrimental to the protected structure.

This Chapter has presented some troubleshooting techniques that can help corrosion



TAKE THE FOLLOWING MEASUREMENTS
FOR 3 DIFFERENT CURRENT VALUES WITH
AT LEAST 3 SETS FOR EACH VALUE

1. TEST CURRENT WITH CASING AS ANODE
2. Vg PIPE-TO-SOIL (LOCAL)
3. Vg PIPE-TO-SOIL (REMOTE)
4. Vg CASING-TO-SOIL (LOCAL)
5. Vg CASING-TO-SOIL (REMOTE)
6. Eoc BETWEEN PIPE AND CASING

DETERMINATION OF TYPE OF CASING “SHORT”

FIGURE 8-20

personnel to determine where the problem may be in a cathodic protection system that is not functioning properly. The use of these techniques and the implementation of subsequent repairs will result in reducing the down time of the cathodic protection system to a minimum.