Ductile Iron Pipe
Research Association

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CORROSION CONTROL

# Stray Current Effects on Ductile Iron Pipe

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Stray currents pertaining to underground pipelines are direct currents flowing through the earth from a source not related to the pipeline being affected. When these stray direct currents accumulate on a metallic pipeline or structure, they can induce electrolytic corrosion of the metal or alloy. Sources of stray current include cathodic protection systems, direct current power trains or street cars, arc-welding equipment, direct current transmission systems, and electrical grounding systems.

To cause corrosion, stray currents must flow onto the pipeline in one area, travel along the pipeline to some other area or areas where they then leave the pipe (with resulting corrosion) to re-enter the earth and complete the circuit to their ultimate destination. The amount of metal lost from corrosion is directly proportional to the amount of current discharged from the affected pipeline.[1]

Fortunately, in most cases, corrosion currents on pipelines are only thousandths of an ampere (milliamps). With galvanic corrosion, current discharge is distributed over wide areas, dramatically decreasing the localized rate of corrosion. Stray current corrosion, on the other hand, is restricted to a few small points of discharge, and, in some cases, penetration can occur in a relatively short time.

Considering the amount of buried iron pipe in service in the United States, stray current corrosion problems for electrically discontinuous gray iron and Ductile Iron Pipe are very infrequent. When encountered, however, there are two main techniques for controlling stray current electrolysis on underground pipelines. One technique involves insulating or shielding the pipeline from the stray current source; the other involves draining the collected current by either electrically bonding the pipeline to the negative side of the stray current source or installing grounding cell(s).[2]

Inquiries to the Ductile Iron Pipe Research Association (DIPRA) show that, of the different sources of stray current previously mentioned, impressed current cathodic protection systems on nearby structures have been the major concern of water utilities. As a result, DIPRA has conducted research for many years on the effects of stray currents from cathodic protection systems on both bare and polyethylene encased iron pipe. The cause, investigation, and mitigation of this source of stray current on iron pipe is the focus of this article.

## Ductile Iron Pipe is Electrically Discontinuous

Ductile Iron Pipe is manufactured in nominal 18- and 20- foot lengths and employs a rubber-gasketed jointing system. Although several types of joints are available for Ductile Iron Pipe, the push-on joint and, to a lesser degree, the mechanical joint are the most prevalent.

These rubber-gasketed joints offer electrical resistance that can vary from a fraction of an ohm to several ohms, which is sufficient for Ductile Iron Pipelines to be considered electrically discontinuous. A Ductile Iron Pipeline thus comprises 18- to 20- foot-long conductors that are electrically independent of each other. Because the joints are electrically discontinuous, the pipeline exhibits increased longitudinal resistance and does not readily attract stray direct current. Any accumulation, which is typically insignificant, is limited to short electrical units.

Joint resistance has been measured at numerous test sites as well as in operating water systems. Table 1 lists 45 joints tested at a DIPRA stray current test site in an operating system in New Braunfels, Texas. In 830 feet of 12-inch-diameter push-on-joint Ductile Iron Pipe, nine joints were found to be shorted. Such shorts sometimes result from metal-to-metal contact between the spigot end and bell socket due to the joint being deflected to its maximum. Due to oxidation of the contact surfaces, however, shorted joints can develop sufficient resistance over time to be considered electrically discontinuous with regard to stray currents.

**FIGURE 1**

**Stray Current Test Site, Kansas City, Missouri**

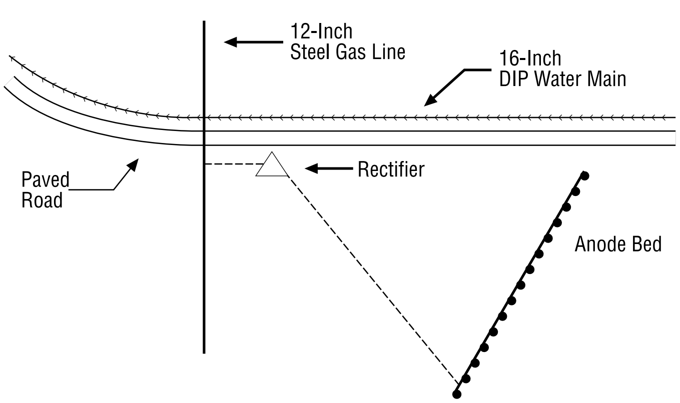



**TABLE 1**

Joint Resistance Measurements
Existing 12-Inch Ductile Iron Pipeline
New Braunfels, Texas

| Joint No. | Reading | Joint No. | Reading |
|---|---|---|---|
| 1 | 14.0 ohms | 24 | 10.0 ohms |
| 2 | Shorted | 25 | 5.4 ohms |
| 3 | Shorted | 26 | 3.4 ohms |
| 4 | Shorted | 27 | 3.7 ohms |
| 5 | Shorted | 28 | 5.0 ohms |
| 6 | 2.5 ohms | 29 | 6.1 ohms |
| 7 | 5.9 ohms | 30 | 2.3 ohms |
| 8 | Shorted | 31 | 3.3 ohms |
| 9 | 2.7 ohms | 32 | 5.1 ohms |
| 10 | 15.0 ohms | 33 | 3.5 ohms |
| 11 | 6.0 ohms | 34 | 3.2 ohms |
| 12 | 20.0 ohms | 35 | 4.0 ohms |
| 13 | 7.2 ohms | 36 | 3.0 ohms |
| 14 | Shorted | 37 | 2.8 ohms |
| 15 | Shorted | 38 | 3.9 ohms |
| 16 | 5.6 ohms | 39 | 3.8 ohms |
| 17 | 4.6 ohms | 40 | 23.0 ohms |
| 18 | 9.3 ohms | 41 | 4.2 ohms |
| 19 | 5.3 ohms | 42 | 14.0 ohms |
| 20 | 5.5 ohms | 43 | 3.2 ohms |
| 21 | 5.7 ohms | 44 | Shorted |
| 22 | 7.1 ohms | 45 | Shorted |
| 23 | 17.0 ohms | | |

The ability of electrically discontinuous Ductile Iron Pipe to deter stray current was demonstrated in an operating system in Kansas City, Missouri, where a 16-inch Ductile Iron Pipeline was installed approximately 100 feet from an impressed current anode bed (Figure 1). A 481-foot section of the pipeline was installed so that researchers could bond all the joints or only every other joint. When current measurements were made on this section of pipeline, it collected more than 5-1/2 times the current when all joints were bonded than when every other joint was bonded (Figure 2, next page).

The effect of joint bonding on stray current accumulation has also been demonstrated in the laboratory. Figure 3, next page, illustrates a stray current environment installed outside the DIPRA laboratory consisting of three sections of 6-inch diameter push-on-joint Ductile Iron Pipe.

**FIGURE 2**

**Effect of Joint Bonding Field Installation Kansas City, Missouri**

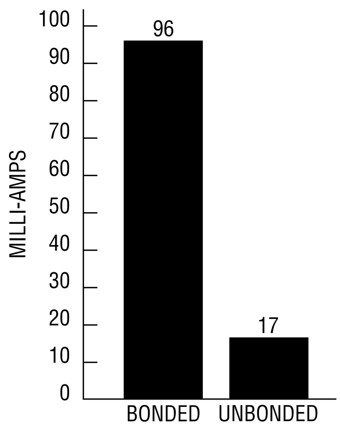



**FIGURE 3**

**DIPRA Stray Current Study**

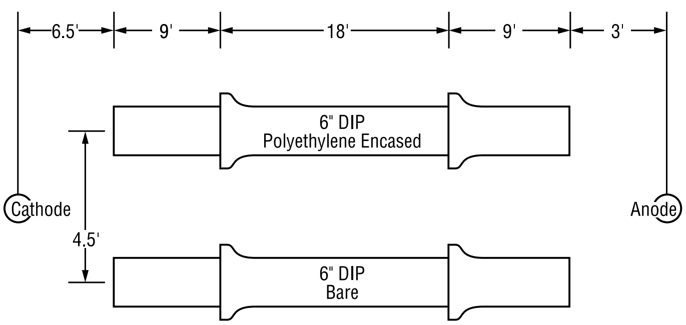
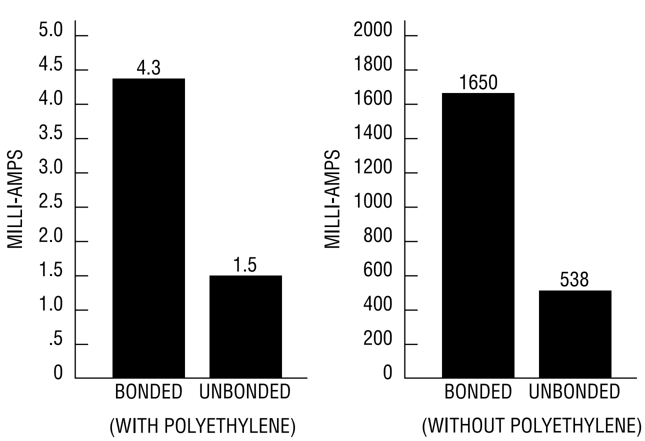



**FIGURE 4**

**Effects of Joint Bonding - Laboratory Installation Rectifier Output: 8 AMPS**




The pipe was installed so that researchers could test combinations of bonded joints, unbonded joints, polyethylene-encased pipe, and bare pipe. It was found that pipe with bonded joints collected three times more current than pipe with unbonded joints (Figure 4). Also, when exposed to the same environment, the bare pipe collected more than 1,100 times the current collected by the pipe encased in 8-mil polyethylene.[3]

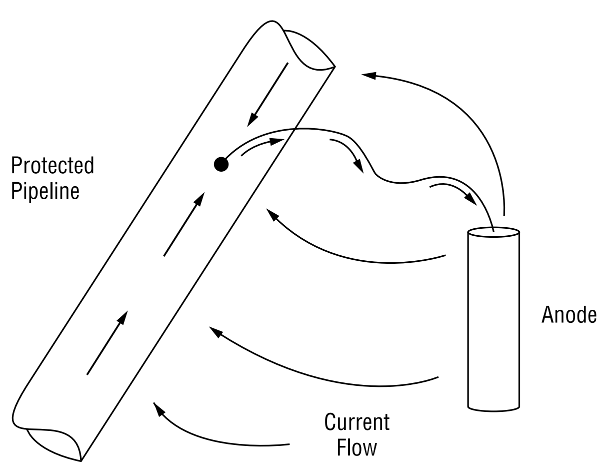
## Cathodic Protection Systems

Cathodic protection, which is a system of corrosion prevention that turns the entire pipeline into the cathode of a corrosion cell, is used extensively on steel pipelines in the oil and gas industries. The two types of cathodic protection systems are galvanic and impressed current.

Galvanic cathodic protection systems utilize galvanic anodes, also called sacrificial anodes, that are electrochemically more active than the structure to be protected. These anodes are installed relatively close to the structure, and current is generated by metallically connecting the structure to the anodes. Current is discharged from the anodes through the electrolyte (soil in most cases) and onto the structure to be protected. This system establishes a dissimilar metallic corrosion cell strong enough to counteract normally existing corrosion currents (Figure 5). Galvanic cathodic protection systems normally consist of highly localized currents, which are low in magnitude. Therefore, they are generally not a concern of stray current for other underground structures.[4]

**FIGURE 5**

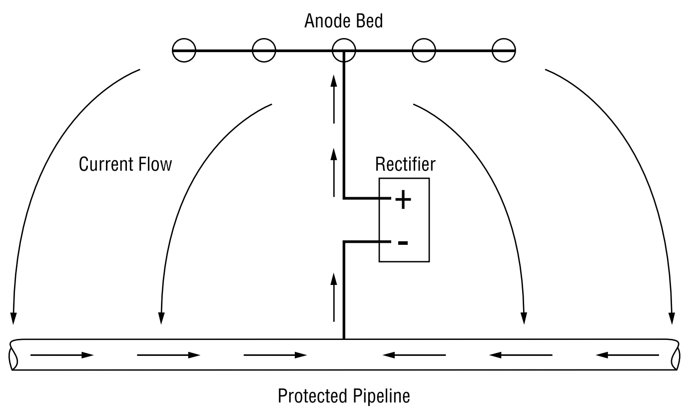
**Galvanic Cathodic Protection System**



Stray current corrosion damage is most commonly associated with impressed current cathodic protection systems utilizing a rectifier and anode bed. The rectifier converts alternating current to direct current, which is then impressed in the cathodic protection circuit through the anode bed. The rectifier's output can be less than 10 volts or more than 100 volts, and less than 10 amperes to several hundred amperes. The impressed current discharge from the ground bed travels through the earth to the pipeline it is designed to protect and returns to the rectifier by a metallic connection (Figure 6). Unlike galvanic cathodic protection systems, one impressed current ground bed normally protects miles of pipeline.

**FIGURE 6**

**Impressed Current Cathodic Protection System**




## Ductile Iron Pipelines in Close Proximity to Impressed Current Anode Beds

Whether an impressed current cathodic protection system might create a problem on a Ductile Iron Pipeline system depends largely on the impressed voltage on the anode bed and its proximity to the Ductile Iron Pipeline. In general, the greater the distance between the anode bed and the Ductile Iron Pipeline, the less the possibility of stray current interference.

If a Ductile Iron Pipeline is in close proximity to an impressed current cathodic protection anode bed, a potential stray current problem might exist. Around the anode bed (the area of influence), the current density in the soil is high, and the positive earth potentials might force the Ductile Iron Pipeline to pick up current at points within the area of influence. For this current to complete its electrical circuit and return to the negative terminal of the rectifier, it must leave the Ductile Iron Pipeline at one or more locations, resulting in stray current corrosion.

**FIGURE 7**

**Stray Current From A Cathodic Protection Installation**

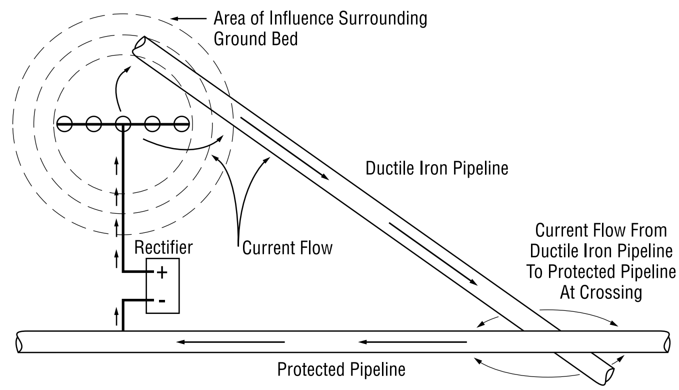
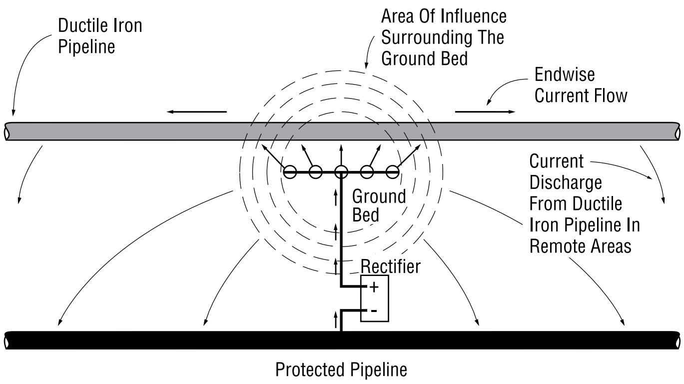



Figure 7 shows a Ductile Iron Pipeline passing close to the impressed current ground bed and then crossing the protected pipeline at a more remote location. Here, if the current density is high enough, current is picked up by the Ductile Iron Pipeline in the vicinity of the anode bed. The current then travels down the Ductile Iron Pipeline, jumping the joints, toward the crossing. It then leaves the Ductile Iron Pipeline and is picked up by the protected pipeline to complete its electrical circuit and return to the negative terminal of the rectifier. At the locations where the current leaves the Ductile Iron Pipeline, usually in the vicinity of the crossing and/or in areas of low soil resistivity, stray current corrosion results.

Figure 8, next page, shows a Ductile Iron Pipeline paralleling a cathodically protected pipeline and passing close to its impressed current anode bed. Again, if the current density is high enough, the Ductile Iron Pipeline may pick up current in the vicinity of the anode bed, after which the current flows along the Ductile Iron Pipeline in both directions and leaves to return to the protected pipeline in more remote areas. This may result in current discharging from the Ductile Iron Pipeline in many areas, usually in low soil resistivity areas, rather than concentrated at the crossing as in the previous example.

**FIGURE 8**



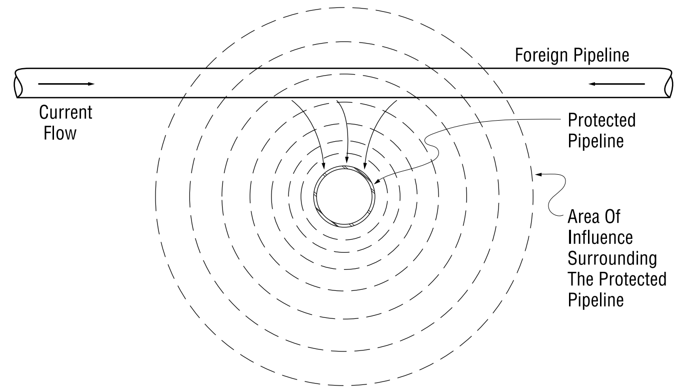

Normally, electrically discontinuous Ductile Iron Pipe will not pick up stray current unless it comes close to an anode bed where the current density is high.

## Pipeline Crossings Remote to Impressed Current Anode Beds

Usually, a stray current problem will not exist where a Ductile Iron Pipeline crosses a cathodically protected pipeline whose anode bed is not in the general vicinity. A potential gradient area surrounds a cathodically protected pipeline due to current flowing to the pipeline from remote earth. This current causes the soil adjacent to the pipeline to become more negative with respect to remote earth. The intensity of the area of influence around a protected pipeline is a function of the amount of current flowing to the pipeline per unit area. If a foreign pipeline crosses a cathodically protected pipeline and passes through this potential gradient, it tends to become positive with respect to adjacent earth. Theoretically, the voltage difference between pipe and earth can force the foreign pipeline to pick up cathodic protection current in remote sections and discharge it to the protected pipeline at the crossing, causing stray current corrosion on the foreign pipeline (Figure 9). Because the intensity of the potential gradient around the protected pipeline is small – negligible for well-coated pipelines – and because Ductile Iron Pipelines are electrically discontinuous, stray current corrosion is rarely a problem for Ductile Iron Pipe systems crossing cathodically protected pipelines if the impressed current anode bed is remote. At these locations, the Ductile Iron Pipeline can be encased with polyethylene per ANSI/AWWA C105/A21.5 for a 20-foot perpendicular distance on each side of the crossing for precautionary purposes.

**FIGURE 9**

**Foreign pipeline Passing Through Potential Gradients Around Cathodically Protected Bare pipeline**



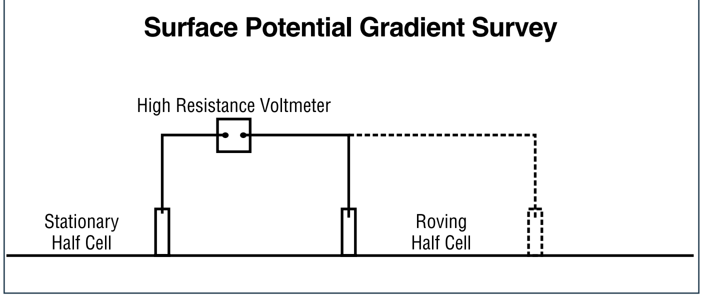

## Investigation of the Pipeline Route Prior to Installation

It is important to inspect the pipeline route during the design phase for possible stray current sources. If stray current problems are suspected, mitigation measures can be designed into the system, the pipeline can be rerouted, or the anode bed can be relocated.

If, during the visual inspection, an impressed current cathodic protection rectified anode bed is encountered in the general vicinity of the proposed pipeline, one method of investigating the possibility of potential stray current problems is to measure the potential difference in the soil along the proposed pipeline route in the area of the anode bed. This can be done by conducting a surface potential gradient survey using two matched half cell electrodes (usually copper-copper sulfate half cells) in conjunction with a high resistance voltmeter. When the half cells are spaced several feet apart in contact with the earth and in series with the high resistance voltmeter, earth current can be detected by recording any potential difference. The potential gradient in the soil, which is linearly proportional to the current density, can then be evaluated by dividing the recorded potential difference by the distance separating the two matched half cells.

When conducting a surface potential gradient survey, one half cell can be designated as "stationary" and placed directly above the proposed pipe alignment while the other half cell is designated as "roving" (Figure 10, next page). Potential difference readings are then recorded

**FIGURE 10**




as the roving half cell is moved in intervals along the proposed route. A graph of potential vs. distance along the proposed pipeline can then be constructed. Normally, depending on the geometry of the ground bed, cathodically protected pipeline, and foreign pipeline locations, the highest current density will be found closest to the anode bed. Usually, the higher the current density, the greater the possibility of encountering a stray current corrosion problem on the proposed pipeline.

The installation of a Ductile Iron Pipeline typically will not appreciably change the potential profile. This allows the engineer to make recommendations based on the surface potential gradient survey conducted prior to pipeline installation. Figure 11 and Figure 12 are surface potential gradient survey graphs of stray current test sites located in New Braunfels, Texas, and in San Antonio, Texas, respectively, which compare the current density profile before and after installation of the Ductile Iron Pipeline. As can be seen, there is very little difference in the current densities of the two profiles regarding their slope and their boundaries – a fact evidenced in numerous other installations and test sites.

**FIGURE 11**

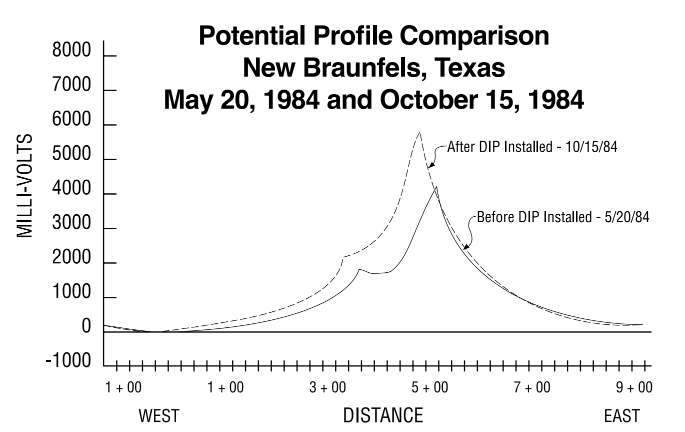
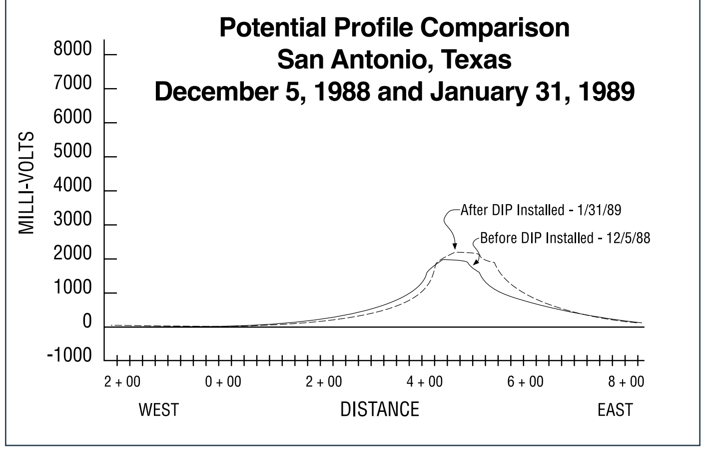



**FIGURE 12**




pipeline installations can vary by geometry, soil resistivity, water table, pipe sizes, pipeline coating, rectifier output, etc. Yet by knowing the potential gradient prior to installation, the engineer can predict – using conservative values – whether the proposed pipeline will be subjected to stray current corrosion.

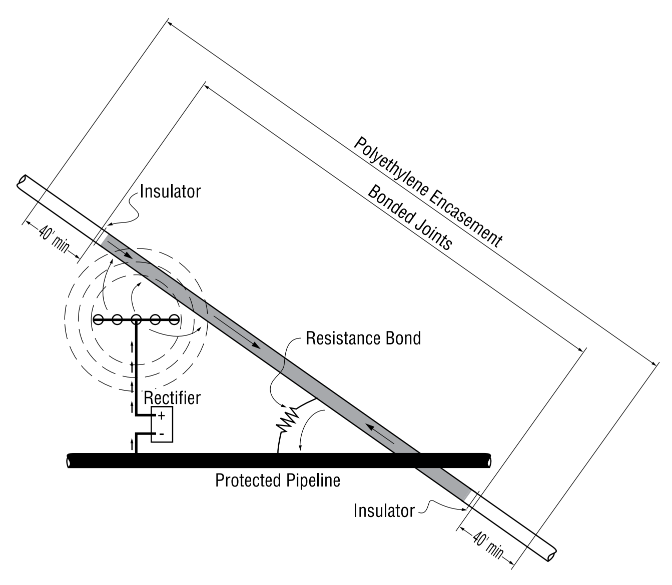
### Mitigation of Stray Current

Electrical currents in the earth follow paths of least resistance. Therefore, the greater the electrical resistance a foreign pipeline has, the less it is susceptible to stray currents. Ductile Iron Pipelines offer electrical resistance at a minimum of every 18 to 20 feet due to their rubber-gasketed joint systems. This in itself is a big deterrent to stray current accumulation. The effect of joint electrical discontinuity can be greatly enhanced by encasing the pipe in loose dielectric polyethylene encasement in accordance with ANSI/AWWA C105/A21.5.

The electrical discontinuity of Ductile Iron Pipelines and the shielding effect of polyethylene are effective deterrents to stray current accumulation and are all that is required in the vast majority of stray current environments. This would include any crossing of cathodically protected pipelines and/or where the Ductile Iron Pipeline parallels a cathodically protected pipeline. At these locations the potential gradient is created by the protective current flowing to the protected pipeline and is normally small.

There are isolated incidents where electrical discontinuous joints and polyethylene encasement would not be adequate to protect the pipe, e.g., the Ductile Iron Pipeline passing through, or very close to, an impressed current cathodic protection anode bed. When this is encountered, consideration should be given to rerouting the pipeline or relocating the anode bed. If neither of these options is feasible, the potential area of high density stray current should be defined (this can be accomplished by conducting a surface potential gradient survey), the Ductile Iron Pipe in this area should be electrically bonded together and electrically isolated from adjacent pipe, polyethylene encasement should be installed in accordance with ANSI/AWWA C105/A21.5 through the defined area and extended for a minimum of 40 feet on either side of said area, and appropriate test leads and "current drain" should be installed. A typical installation is shown in Figure 13.

**FIGURE 13**




In the defined area, the Ductile Iron Pipe will probably collect stray current. This area needs to be electrically isolated from adjacent piping that will not be collecting stray current. One method of achieving this is installing insulating couplings. Bonding of joints in this area ensures that corrosion will not occur at the joints.

Polyethylene encasement of the pipe in the defined area dramatically reduces the amount of collected stray current. This helps to contain the area of influence and reduces the power consumption of the cathodic protection system. The polyethylene encasement extending on either side of the said area shields the pipe from collecting stray current. Test leads for monitoring are normally installed on each side of the insulators and in the location of the crossing, if one exists. By having test leads on each side of the insulators, their effective electrical isolation can be ascertained. The test leads on the insides of the insulators can also be used to check whether the bonded section is, in effect, electrically continuous.

The collected current then will need to be effectively drained back to the cathodic protection system. This can be accomplished by installing a resistance bond from the affected area of the Ductile Iron Pipeline to the protected pipeline or to the negative terminal of the rectifier. Resistance can then be regulated to achieve a desired potential on the Ductile Iron Pipeline and reduce the current consumption from the cathodic protection system. Another method of draining the collected current is the design and installation of grounding cells. These grounding cells normally consist of anodes located in areas of current discharge.

## Conclusions

DIPRA has conducted numerous investigations in major operating water systems where Ductile Iron Pipelines crossed cathodically protected gas and petroleum pipelines. These investigations involved rectifiers and anodes located in the immediate vicinity (within several hundred feet of the crossing), as well as those located at remote distances.

When the anode beds were remote to the crossings, all investigations indicated that the amount of influence on the Ductile Iron Pipe was negligible and would not be considered detrimental to the expected life of the system. In installations where the anode bed was located in the immediate vicinity, the findings were influenced by factors such as rectifier output, soil resistivity, diameter of the respective pipelines, condition of the coating on the protected line, etc. Despite these variables, several observations confirmed the findings of laboratory tests. The most significant was the efficacy of rubber-gasketed joints and polyethylene encasement in deterring stray current from Ductile Iron Pipelines.

Throughout the United States, thousands of Ductile Iron and gray iron pipelines cross cathodically protected pipelines. Yet very few actual failures from stray current interference have been reported.

This is additional strong evidence that stray current corrosion will seldom be a significant problem for electrically discontinuous Ductile Iron Pipelines. The bonding of joints and the use of galvanic anodes or drainage bonds may well be a solution to stray current interference in high current density areas, but these systems must be carefully maintained and monitored. If the anode grounding cell becomes depleted or the drainage connection broken, the bonded Ductile Iron Pipeline will be more vulnerable to stray current damage than if the pipe had been installed without joint bonds. Therefore, such measures should be taken only where stray current interference is inevitable. In most cases, passive protective measures such as polyethylene encasement are more desirable.

## References

1. A. W. Peabody, *Control of Pipeline Corrosion*, National Association of Corrosion Engineers, Houston, Texas.

2. E. F. Wagner, “Loose Plastic Film Wrap as Cast-Iron Pipe Protection,” Presented September 17, 1963, at AWWA North-Central Section Meeting, Reprinted in *Journal* AWWA, Vol. 56, No. 3, pp. 361-368, (March 1964).

3. T. F. Stroud, “Corrosion Control Measures for Ductile Iron Pipe,” National Association of Corrosion Engineers, 1989 Conference.

4. W. Harry Smith, “Corrosion Management in Water Supply Systems,” Van Nostrand Reinhold, 1989.

# For more information contact DIPRA or any of its member companies.

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