

Some Aspects of Cathodic Protection

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PRINCIPLES OF CATHODIC PROTECTION

Many regard cathodic protection as a mysterious subject involving good amount of black magic though the basic principles of cathodic protection are really very simple. As already discussed by Prof. Arceivala, corrosion is an electrochemical process, with current flowing between two areas having difference in potential. These areas may either be closed to each other or further apart depending on number of variables either in the surface condition or in the environment to which the particular material is exposed. The metal goes into solution at areas having more negative potential, called 'anode', while the cathodic reaction, i.e., neutralisation of positive ion, takes place at areas having less negative potential. The factor which controls the intensity of corrosion, is the current flowing between anodic and cathodic areas. Taking the value of potential at anode and cathode to be E_A and E_C respectively and the resistance of electrolyte as R_e (the resistance of short circuited metal path of the system being negligible) the flow of current may be represented by the equation

$$I_m = \frac{E_A - E_C}{R_e}$$

In actual practice the current flow does not remain as I_m but rapidly decreases soon after the anode and cathode are short circuited. As R_e remains constant the fall in current is apparently due to decrease in $E_A - E_C$. This decrease in potential difference between anode and cathode is an inherent property of the corrosion cell and occurs due to what is known as "polarisation" whereby the potential of anode and cathode moves towards each other. The equilibrium potential and current occur at the intersection of anodic and cathodic polarisation curves.

Considering the corrosion process discussed above, it can be reasoned that if there could be some procedure whereby ~~potential of anode~~ ^{cathodic} areas on a corroding structure could be ~~brought~~ ^{open circuit} to the potential of ~~cathodic~~ ^{cathodic} areas, corrosion should stop. Following this reasoning, if an electrical circuit is established using a separate structure (anode) contacting the environment and the corroding structure, and if direct current is allowed to flow from this anode through the environment to the structure to be protected and thence back to the anode by way of metallic conductor, the whole structure will be converted into a cathode thus completely arresting corrosion (Fig. 1). This is what happens during cathodic protection and is manifested in the change in potential towards more negative side, ~~in a, anodic side.~~

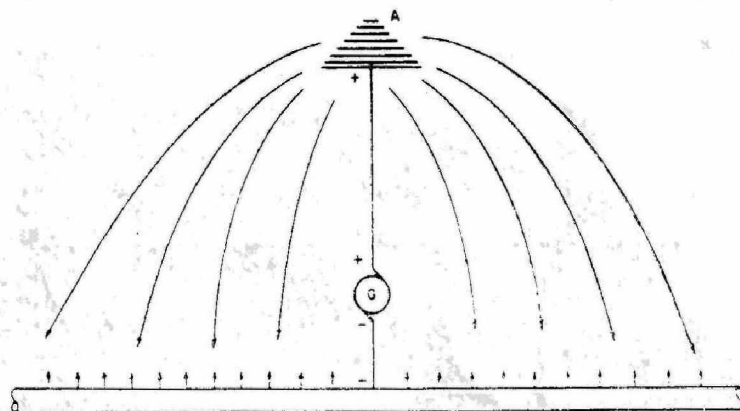


Fig. 1

CRITERIA OF CATHODIC PROTECTION

Although the basic idea of cathodic protection as described is simple the application of cathodic protection to practical structure may at times become somewhat more involved. One of the particular problems associated with any cathodic protection installation is knowing when all anodes on a structure being protected have actually been converted to cathodes, i.e., what potential should be considered to give complete protection. In many instances the structure being worked on is essentially inaccessible for direct observation or test. As a result, various criteria have been developed for knowing whether full protection has been obtained or not. Although in this paper the subject has not been explored in detail, it will suffice to indicate that one of the more popular criteria used for this purpose consists of polarising the structure being protected to a potential which depends on the type of metal being protected. For iron a potential of -0.85 V against Cu/CuSO_4 electrode is commonly used.

TYPE OF CATHODIC SYSTEMS

There are two general types of cathodic protection systems in common usage. One of these is called the "Galvanic anode" system. In using this method, anodes of alloys based on magnesium, zinc, and aluminium are connected to the structure to be protected by means of an insulated electrical conductor. These anodes (buried or immersed in the same conducting electrolyte as the structure to be protected) discharge cathodic protection current which flows to the protected structure. The current flows because of the greater electrochemical activity of the anode metal in comparison to the metal of the protected structure. The other general type of cathodic protection system is termed as 'impressed current' system. When using this method of protection, anodes contacting earth or electrolyte surrounding the protected structure are made of relatively inert materials, e.g., graphite, iron-silicon alloys, etc., which will corrode at a low rate. The driving potential necessary to force these anodes to discharge current to the protected structure is supplied by some external source of direct current power.

Different factors that need consideration in practical application of cathodic protection system have been discussed below:

(a) *Current Requirements*

Before a cathodic protection design can be initiated, it must be known how much pro-

tection current will be required to provide a satisfactory degree of protection. The amount of current required to provide complete cathodic protection varies over an extremely wide range but in general depends mainly on —

1. Surface area of the pipe.
2. Electrical resistance of the coating and area of exposed metal (holidays in the coating).
3. Distribution of cathodic protection current.
4. Polarisation characteristics of the metal being protected in the particular environment.
5. Bacterial activity.
6. Interference.

Although corrosion engineers experienced in this field may be able to estimate the current requirement with a reasonable degree of accuracy, it is always desirable to conduct current drainage (requirement) test specially where the structures are already present. In case of areas where new lines are laid for the first time, preliminary design is made on the basis of estimated current requirement, followed by final alterations as and when required during actual installation. This is an important point which should be kept in view.

Current drainage tests are usually made by applying a test current to the structure to be protected and adjusting the current output of the temporary direct current power source (installed for test purposes) until the desired degree of protection is obtained. The amount of current determined in this manner is helpful for design purposes. The actual current required will however depend on the type of anode system and anode bed used. The flow of current is maximum at a point nearest to the drainage point and then decreases with increase in the distance from the bed (Fig. 2). Use of suitable design can bring down the amount of excess current

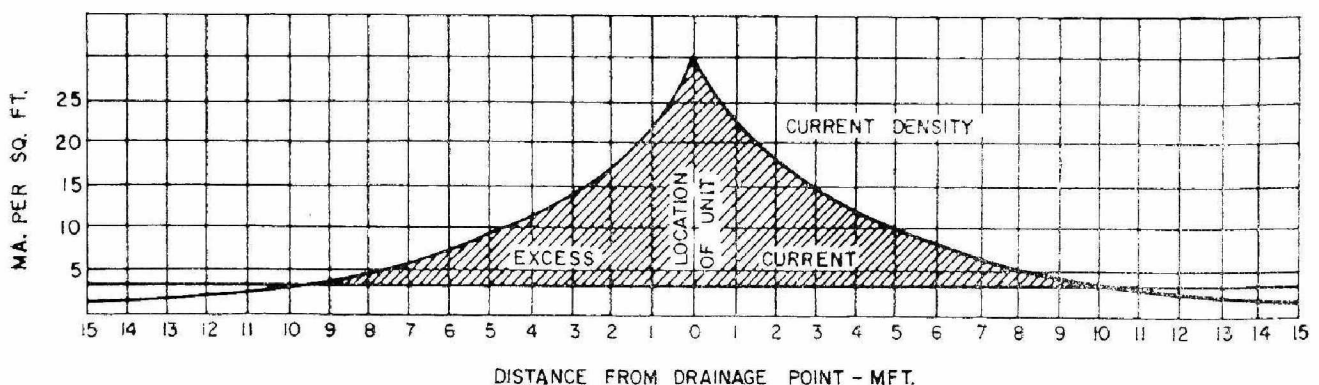


Fig. 2

but the loss is quite high in impressed current system due to the necessity of using higher supply voltages. In case of sacrificial anode, however, the loss is much less. The current requirement also varies with the type of coating given on the pipe. If the coating resistance is high the current required will be very low as the available bare area needing protection is low. An idea about the relationship between resistance of the coating and the current required will be obtained from the data given in Table 1. In designing the current requirement it is also necessary to evaluate the possibility of the current requirement increasing with time specially in case of structures having insulating electrical coatings which generally deteriorate with time. Reserve

capacity in the cathodic protection system should be allowed for this depending on the expected rate of deterioration of a particular coating being used.

TABLE 1.

Range of Current Required for Protection of 10 Miles of 36-inch diameter pipe

Effective coating resistance in Ohms for one average square foot	Current required in amperes
Bare pipe ¹	500
10,000	14.91
25,000	5.964
50,000	2.982
100,000	1.491
500,000	0.2982
1,000,000	0.1491
5,000,000	0.0298
Perfect Coating	0.00058

¹ Bare pipe assumed to require a minimum of 1 milliamp per sq. ft.

(b) *Environmental characteristics*

The design engineer will have to have adequate data regarding characteristics of the environment, e.g., soil, water, etc. The electrical resistivity of the environment is normally of prime concern. Where the resistivity of the environment is low, it means that corrosion activity on the structure to be protected may be relatively high but it also means that the amount of current which can be discharged by an anode of any specific size will be greater per unit of applied DC voltage than would be the case with the same size anode in a higher resistivity environment. Knowing the soil resistivity, it is possible to design the most economical protective system. The soil resistivity profile is therefore taken along the pipeline in a way similar to that of potential survey by using more commonly the four-pin method.

The resistivity of the soil is important from the point of view of its corrosivity as soil resistivity is, to some extent, dependent on the acids, alkalies and salts dissolved in the soil water. From the broad correlation observed, the popular figures used to relate soil resistivity to its corrosivity are given in Table 2.

Table 2. Relationship of Soil Conductivity and Corrosivity

Soil resistivity in ohm-cm	Corrosivity.
0 — 1,000	Probably severe
1,000 — 10,000	Moderate to severe
10,000 — 100,000	Mild if aerated
More than 100,000	Probably not corrosive

The potential difference between a buried pipe and the soil is also of considerable importance, either in determining the corrosivity or in evaluating the extent of cathodic protection being applied. The pipe-to-soil potentials are measured commonly at different specified distances along the pipeline against Cu/CuSO_4 electrode. Generally soil resistivity and the potential are measured at the same points, so that comparison of soil resistance and pipe-to-soil potential profiles indicate the conditions of corrosion. The potential measurements are made by connecting an instrument (corrosion voltmeter or electronic voltmeter) between the pipe itself and a special electrode placed in contact with the soil surface near the pipe.

(c) *Current Sources*

Selection of the type of protection system will depend on number of factors. Where the current needs for a cathodic protection system are small, (small diameter pipes with good protective coatings) galvanic anode system may be used if the resistivity of the soil is such that sufficient current may be obtained from such anodes with a reasonable or economical amount of material lost. Where current requirements are relatively high or where environmental conditions otherwise favour its usage, impressed current installations may be the better choice. Occasionally a combination of the two systems may be used. In case of impressed system, either deep anode, distributed anode or single anode beds may be used. The selection of a particular design depends on number of factors, e.g., interference effect, variation in soil resistance with depth, type of coating, etc.

(d) *Anode materials*

Many of the items of material and equipment which are used for installing cathodic protection installations are highly specialised. Most of the equipment for impressed current system are easily available in India except insoluble anodes. While graphite is to be imported iron-silicon anodes can be made indigenously by iron foundaries. However, the manufacture of these anodes has not reached the desired stage of getting 1st grade material. Of the galvanic anodes zinc and aluminium can be made comparatively more easily. However, there are yet no firms who deal exclusively with the production of such materials. Where galvanic anodes are buried in soil environment, they are usually installed with a special chemical backfill surrounding the anode. This may be a mixture of materials, such as, bentonite, clay and gypsum which will have the effect of providing a uniform resistivity environment directly surrounding and contacting the anodes. The advantage of having such a material is to promote uniform corrosion of the anode, to isolate it from the surrounding soil which may contain chemicals causing it to go passive (cease to discharge useful amounts of current) and to promote satisfactory anode efficiency.

Anode materials for impressed current systems include graphite and high silicon cast iron. Both of these materials will corrode at a relatively low rate provided current density is below a certain limit. Scrap steel can also be used but corrodes rather rapidly so that relatively frequent replacements are to be made. Suitable backfill is also used with these anodes.

For use in sea water, lead alloy anodes are quite popular and these corrode at a very slow rate. Also for use in sea water and/or other specialized applications, anodes having a platinum surface may be used very effectively. Platinum is consumed at an extremely low

rate and a thin platinum layer deposited over a suitable underlying metal (such as titanium and tantalum) will give long life even with high amounts of current discharge.

(e) *Rectifiers*

Rectifiers, the common power source used in impressed current systems, may be obtained in a great variety of d-c ratings. They may be used with a variety of input, single or multi-phase A.C. supply lines. Such rectifiers are provided with a means of adjusting the direct current output so that the voltage applied to the anode system may be suitable to supply the desired amount of protective current. In addition to commercially used manually adjusted rectifiers, automatic rectifiers, e.g., constant current or constant potential rectifiers, can also be used in order to maintain a set level of protective current or potential. However such rectifiers are not easily available in India.

(f) *Insulated wiring*

Insulated copper wiring used in cathodic protection installations is critical on the positive (current discharge) side of an impressed current power source. Such conductors when buried or submerged are at a positive potential with respect to the environment and will discharge current at pin holes, scraps or other damage to the insulation. Copper which is a relatively corrosion free material, will corrode very rapidly when discharging direct current resulting in the failures of the protective system if the insulation damage is allowed to occur. The insulation used, therefore, should be compatible and durable with respect to the environment, specially in environments containing large amounts of chlorides.

(g) *Life Requirement*

When designing a cathodic protection installation the life expectancy of the installation is based upon the probable life requirement of the structure to be protected. If the expected economic life of the protected structure is short the power supply installation is designed so that anode life will not be substantially greater than the structure life. On the other hand, if the structure being protected has (or is expected to have) a long life, the anodes are replaced at certain specified intervals; commonly used period being 10-15 yrs.

INTERFERENCE EFFECTS ON OTHER STRUCTURES

While it is always possible to instal a cathodic protection system for a structure, the adjacent (foreign) structure, which is not protected, may be adversely affected if proper care is not taken. It is caused by the fact that current discharged from an anode (usually associated with an impressed current installation) while flowing through the environment to the structure being protected may be collected by an adjacent unprotected structure in proximity to the anode. The current picked up by this structure is finally discharged to environment again where the foreign structure more closely approaches the facility being protected. Alternately, the current collected by the structure to be protected may cause interference due to the presence of a foreign structure near-by. These are known as "anodic" and "cathodic" interference of which, the former is more dangerous. The best means of avoiding this effect is to so locate the anode systems that they will not be likely to cause current flow into the foreign structure. This cannot always be avoided but there are techniques whereby the effect of the stray current may be minimised.

ADVANTAGES AND LIMITATIONS

The prime advantage of cathodic protection is that when properly designed and installed, it will prevent or greatly minimize the corrosion. Anodes associated with the protection systems have to be replaced periodically (with the length of time being a function of the design) but when these replacements have to be made they can be accomplished with no need whatsoever for discontinuing the normal function of the structure being protected. This of course assumes prompt replacement, when required, such that there is small time lapse between the failure and restoration of cathodic protection.

There are limitations to cathodic protection applications. Chief among these is that there must be a suitable path for the cathodic protection current to flow between the anodes used and the structure to be protected. If a structure to which protection is being applied is only partially immersed in soil or electrolyte, the cathodic protection current can only reach that portion of the structure which is buried or immersed. In such case the portion of the structure which is not in contact with an electrolyte will receive no corrosion protection. If cathodic protection is applied to the external surfaces of a hollow structure, the inside surface of that same structure will not be protected and vice versa.

If a structure to be cathodically protected is bare, the amount of current required to afford adequate protection may be very high and may impose substantial design difficulties in applying a suitable system. If, however, the same structure is coated with a suitable electrically insulating material (such as coal-tar or asphalt enamels, epoxy coatings, etc.) the cathodic protection system will supply protective current only to those metal surfaces which are exposed to the environment at any cuts, scraps, pin holes or other defects in the insulating coating. This means that a coated structure can be cathodically protected, effectively, with very much less electrical energy compared to bare structures. For this reason, the combination of suitable coatings and cathodic protection is nominally considered the best method of affording corrosion control except in those instances where a coating may be impractical.

Bare pipes, specially the old installations, have also been successfully protected cathodically. The protection of bare pipes, however, requires careful design. Different anode beds have been tried for bare pipe lines and deep-anode beds and distributed anode beds have been found to be the best.

ECONOMIC CONSIDERATIONS

Whether or not a cathodic protection system should be considered in any specific instance is largely a matter of economics. It would not, for example, be reasonable to install an expensive cathodic protection installation on a facility which is to be scrapped sooner or later. There are many instances where corrosion, if it is allowed to continue, will cause interruption of service on a facility which may result in considerable loss. In any case, the value of such outage time and product loss, is to be balanced against the cost of installing cathodic protection. There are many instances where such comparisons greatly favour the installation of cathodic protection. Such comparisons are easy to make when working with facilities where corrosion failures have already occurred and the cost of such failures is known. When working with new installations where it is decided to apply cathodic protection from the start, the com-

parison must then be made with respect to the hypothetical cost of failures should they occur. This can often be done by reference to actual corrosion failure experience with similar installations in the vicinity or in areas of similar environmental characteristics.

In making cost studies, cathodic protection costs must include not only the original investment required for making the installations but must also include the cost of maintaining the system, making periodic replacements of anodes and other elements of the system as required, and (in the case of impressed current systems) the cost of power for operating the system. It should be emphasized that maintenance is a highly important factor associated with cathodic protection and if adequate maintenance is not rendered the cathodic protection system may become ineffective and a costly venture.