John Bollinger, Farwest Corrosion Control Company, USA, discusses design considerations in utilising sacrificial magnesium anodes for newly buried pipelines.

CATHODIC COMPLEXITIES

Often customers ask to have a sacrificial magnesium anode cathodic protection (CP) system designed for their new pipeline system. In many cases, however, the customer does not understand the many complexities that can profoundly affect the design and long-term operation of the CP system. Mistakenly, they think that the application of a few magnesium anodes along the length of the pipeline will offer sufficient protection but unfortunately, this is usually not the case.

In designing any CP system for a buried pipeline, there are a number of factors that must be considered. These factors are even more critical when considering a sacrificial anode system, which cannot be adjusted to provide additional CP if needed. Therefore, a robust design approach and careful installation techniques are a must if the CP system is to provide the expected results. Otherwise, the integrity of the pipeline may be at stake for a number of reasons described later.

As mentioned above, there are many design elements to be considered that include pipeline coating type, coating effectiveness or efficiency, electrical isolation of the pipeline, soil resistivity and moisture content, operating temperatures of the pipeline, cathodic interference, induced AC voltages from power lines, lightning strikes, operational issues caused by pigging or similar, and the required service life of the CP system.

Figure 1. Shorted parallel pipeline.

Figure 2. Pipeline electrically shorted to structural steel.

The basis of any CP design requires knowledge, or a competent estimate, of the amount (area) of bare steel that will be exposed to the soil. In a perfect scenario, a pipeline would have a 100% flawless coating. If this were possible, there would be no need for CP as there would be zero contact of the steel with the earth and therefore no possibility of corrosion.

This is an unrealistic expectation due to the inevitable nicks, scratches (called coating holidays) and possibly less than perfectly coated field joints. Therefore, it is up to the CP designer to estimate the coating efficiency for the pipeline in order to calculate the amount of CP current needed to adequately protect the pipeline.

As an example, how does a 99% efficient coating sound? The vast majority of people might agree that a 99% efficient coating would be a relatively good effort. However, consider a requirement or specification to coat a structure that is 10 ft x 10 ft, or 100 ft^2 in total. A 99% efficient coating would mean that 1 ft^2 of the surface area was missed and is now bare. In the author's opinion, a new coating with even 99.9% coverage should be considered unacceptable.

Besides coating efficiency, all coatings have a 'dielectric strength', which varies with coating type. This is the ability of the coating to act as an electrical insulator or barrier between the pipeline and the soil. So even with a perfect or 100% efficient coating, a minute amount of CP current can pass through the coating thereby affecting the CP system's design life.

As it relates to coating efficiency, the new generation of fusion bonded epoxy (FBE) coatings, used on a majority of new pipeline installations, can provide efficiencies well in excess of 99%. Farwest Corrosion Control Company has found, through empirical testing, that FBE coatings provide long-term stability and efficiencies well in excess of 99.9%. This is far superior to some of the old 'coal tar'-type coatings that had a much lower dielectric strength and that would degrade with time. No matter what the coating type, it is important that the entire pipeline is checked for coating imperfections (called holidays) with a high voltage holiday detector. Doing so will help to ensure a minimum number of holidays and much better performance from the designed CP system.

Electrical isolation

As important as an efficient coating is the need for electrical isolation of the pipeline. In a perfect scenario, a pipeline would be a 'stand alone' metallic structure that has no electrical interconnections to other foreign metallic structures. This is typically accomplished by the installation of the appropriate dielectric insulating pipeline fittings, such as isolating flange kits, unions and couplings, which are designed to electrically isolate one section of a pipe from another.

Any physical contact between a subject pipeline and a foreign structure, in this instance another pipeline, will electrically bond or short the two structures together creating many CP related problems for the operators of both pipelines. Therefore, much care and planning to avoid this issue is critical to isolating the pipeline.

There are many situations along the pipeline that can cause electrical isolation issues. These include flanged connections, motor operated valves, pig signals, temperature probes, flowmeters, pipeline taps, casings, bridges and more. Each will require close design and installation attention to ensure that they are properly isolated from the pipeline.

A lesser known isolation problem can occur when a low resistivity product, such as brine water, can bridge a perfectly good isolation flange gasket, thus allowing CP current to cross the previously isolated gasket. The magnitude of the current loss is a function of the resistivity or conductivity of the product and the diameter of the pipeline. As an example, a large diameter pipeline with a low resistivity product can lose the greatest amount of current.

Pipeline pigging can present problems as well. As the pig pushes the sediments, oxides or other contaminants (which can be electrically conductive) through the line and across a dielectric isolation flange, these contaminants can also bridge the isolation gap in the flange. This can again reduce the effectiveness of the isolating fitting, or in some cases, result in a completely shorted flange. The good news is that there are solutions to this problem, such as monolithic isolating fittings and internally coated pipeline spools in conjunction with flange isolation kits.

Pipeline casings must also be electrically isolated in order to achieve an effective and efficient CP system. A shorted casing will serve as a metallic shield to CP current and eliminate any possibility of providing protective current to the pipeline within the casing. Therefore, electrically isolating the pipeline from the casing is important and achieved with the use of casing insulators and casing end seals.

Any compromise to the pipeline's electrical isolation will reduce or nullify the effectiveness of the CP system. When an isolating fitting fails or is bypassed by some parallel metallic circuit (such as a new conduit installation or similar) that touches the isolated section of pipeline, the CP current requirement will increase, which in turn will shorten anode life and/or minimise the CP system's ability to protect the pipeline.

The ratio of anode service life between an isolated pipeline and a shorted pipeline can be as much as 100 to 1. This means that the theoretical service life of a CP system in an isolated condition may be as much as 30 years. However, if the pipeline is shorted to other metallic structures, the additional current loading on the CP system can reduce the actual anode life to less than one year. Therefore, it is extremely important to fully isolate the pipeline and to install enough anode material to survive any increase in CP current demand events.

Cathodic interference

Cathodic interference is caused by 'stray' CP current from foreign cathodically protected pipelines interfering with the subject pipeline. These protected foreign pipelines, which include crossing and parallel pipelines, can cause cathodic interference with a new, well coated pipeline. In this instance, when this stray current finds and then leaves the pipeline, severe damage can occur at any location where a holiday or defect in the coating exists. For this reason, the new, well coated pipeline is very sensitive to the effects of stray current.

In a perfect world, the more distance between these pipelines would be better but unfortunately, this is not usually possible. Therefore, solutions such as anode drain stations, shielding or, as a last resort, resistance bond stations can be installed to control and eliminate the effects of cathodic interference.

Induced voltage issues

Well coated pipelines that are in the vicinity of overhead electrical power transmission lines can be subject to 'induced AC voltages'. This phenomenon can occur when the electromagnetic field from the power lines crosses the pipeline and induces a voltage. Similar to cathodic interference, the AC voltage travels along the pipeline and then leaves the pipeline causing damage where the energy departs.

Depending on the length of parallel transmission line, in respect to the pipeline, as well as the approach and departure angle of the pipeline to the power corridor, the induced voltage can be significant. Depending on the level of induced AC voltage and the actual available power produced, serious corrosion problems can occur.

Figure 3. Over voltage protector across a double isolated, internally lined pipeline spool.

Additionally, well coated pipelines that are in the vicinity of power transmission lines can be seriously damaged if a power cable falls to the ground. The voltage gradients in the soil can produce significantly high voltages on the pipeline. This high voltage is going to seek the path of least resistance and a holiday in the coating is a typical location for the current to discharge. If enough power is available, serious physical damage to the pipeline can occur.

Yet another source of induced voltage is lightning strikes. If a lighting strike occurs near the pipeline, significant voltages can again be generated on the pipeline with the same possibility of serious physical damage.

In any of the high voltage events described above, there is also the possibility of damage to the CP equipment, but more importantly, there can be an electrical shock hazard to personnel contacting the pipeline. It is known that a lightning strike many miles down the pipeline can produce high enough voltages to cause serious injury or death to humans as well as damage to CP power supplies or other equipment connected to the pipeline.

One proven method to reduce the induced voltages on the pipeline is to install numerous magnesium anodes or other grounding devices to serve as 'ground rods'. Besides the improved grounding ability, the anodes can provide needed CP current. Additionally, there are also electronic over voltage protection devices that can be installed on the pipeline to offset these high voltage events. In extreme cases, dedicated low resistance grounding electrodes with associated DC decoupling equipment may be required.

The CP design

It is an essential requirement that any sacrificial magnesium anode system should include more than the minimum anode requirements to obtain adequate CP current over the specified design life of the system. While some may consider the additional anodes to be overly cautious and expensive, it is important to remember that the cost to mobilise labour, equipment and materials in the future will be many times greater versus the cost to install the additional CP anodes during pipeline construction.

Magnesium anodes deteriorate at a rate of approximately 17 lb/A.yr. This means that for every ampere of current discharged, 17 lb of magnesium will be consumed every year. Therefore, a pipeline with a CP requirement of 1.0 A and a specified design life of 10 years will require a minimum of 170 lb of magnesium to reach the specified service life. Magnesium anodes do not deteriorate at a linear rate, however, and near the end of their life, the anodes are not capable of producing the same amount of current as when they were new.

Figure 4. Pipeline electrically shorted to rebar.

Figure 5. Electrical conduit shorted to protected pipeline.

To compensate for this decrease of usable anode material, a design or utilisation factor must be used. This is a matter of how conservative the designer wants to be but in this author's opinion, a minimum 1.3:1 ratio should be used. Theoretically, the original requirement of 170 lb of magnesium would be increased to 221 lb (170 x 1.3). Besides anode weight, the designer must also consider the soil resistivity and physical size of the anodes required to achieve the needed CP design current.

Remember, the above CP design example yields the weight of magnesium required under ideal coating and electrical isolation conditions. However, it is common for an insulator to be bypassed or fail for a variety of reasons and once this occurs, the demand for anode current will increase dramatically and shorten anode life proportionately.

Besides the anodes, a complete CP system design should also include:

- Test stations or monitoring points along the entire pipeline for routine monitoring.
- Proper electrical isolation along the pipeline.
- Over voltage protection (OVP) devices at primary electrical isolation points.

Additional recommendations

During the installation of the pipeline and CP system, it is strongly recommended that an onsite inspector, familiar with the CP design requirements and installation techniques, be hired to oversee all aspects of the installation that relates to CP. This includes anode installation, cable connections, dielectric insulating devices and other protective devices discussed in this article. It is always better to prevent a problem from occurring at the time of pipeline construction than trying to fix the problem down the road, which often means shutting down an operational pipeline.

It is important that any CP system be routinely monitored by a qualified corrosion professional. Doing so will ensure that the CP system provides the required level of protection and maximises the service life of the system. However, if this is not carried out and technical issues occur, such as a compromised dielectric isolator, the anodes can be consumed much sooner than anticipated and protection to the pipeline can be adversely affected.

Conclusion

As discussed, there are many factors that must be considered when designing a sacrificial CP system for buried pipelines. Some of these considerations not only prevent corrosion but can also prevent certain hazardous conditions on the pipeline. Additionally, even seemingly minor issues can greatly affect the ability of a CP system to protect the pipeline.

Therefore, what first may appear as an over-designed CP system may ultimately save the pipeline from damage caused by more than just corrosion. All things considered, the initial extra cost during pipeline design and installation may be many times less costly in the long run.