Paper No.
CAP21

Effect of DC Interference on the Performance of Sacrificial Anodes Protecting a Pre-Stressed Concrete Cylinder Pipeline

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ABSTRACT

The protection level of a four-meter diameter Pre-stressed Concrete Cylinder water Pipeline of the Great Man-Made River was achieved by retrofitting vertical sacrificial anodes along its entire length. The sacrificial CP system was favored over impressed current CP system to avoid the risk of overprotection which can cause detrimental hydrogen embrittlement of the PCCP pre-stressing steel wire. A preexisting foreign oil pipeline protected by an impressed current CP system was intersecting with the PCCP pipeline. Interference testing and Close Interval Potential Survey (CIPS) performed at the pipeline crossing on both lines suggested that the sacrificial magnesium anodes may have rather enhanced the stray current pick up through the low resistance path. That effect presumably exacerbated the severity of interference with the adjacent PCCP pipeline at the stray current pick-up and discharge regions.

This work describes and evaluates the adverse interaction effect on the protection level of PCCP at the pipeline crossing and discusses possible interpretations of CIPS anomalies and likely mitigation measures.

Keywords: Cathodic Protection; Stray Current; PCCP; CIPS

INTRODUCTION

The Great Man-Made River is composed of four meter diameter Pre-stressed Concrete Cylinder Pipelines (PCCP) extending for hundreds of kilometers across Libya. The pipelines are intended to convey massive amounts of potable water by gravity from the well fields in the Sahara desert to the densely populated coastal regions on the Mediterranean Sea. The underground transmission pipeline has an average soil cover of three meters and passes through various corrosive soil environments. At several locations along its route, the pipeline crosses foreign oil and gas steel pipelines. A pre-stressed concrete cylinder pipe is a pressure pipe made up of a steel cylinder with inner and outer concrete cores and a pre-stressing wire helically wrapped around the outer core.[1] The high strength steel wrapping wire is covered with a nineteen millimeter thick mortar layer and followed by a layer of coal tar epoxy for corrosion protection purposes. [2] (Figure 1 (A)).

Due to its national significant nature as the main source of potable water, the PCCP pipeline owner adopted a conservative corrosion protection approach requiring the provision of cathodic protection systems for the entire pipeline. That proactive measure aimed to maintain the continuity of water supply and prevent pre-stressing wire corrosion which can result in wire break followed by pipe distress and ultimately sudden catastrophic failure of the pressurized large pipes. Pre-stressed steel is known to be susceptible to hydrogen embrittlement and therefore distributed Sacrificial Anode CP system was chosen over the impressed system. A protection criterion of a hundred millivolt - shift or decay was considered sufficient for preventing corrosion according to the relevant NACE standards. However, protection may not be achieved with that criterion if corrosion has already initiated as was found in some cases and therefore only partial protection will be attained instead.

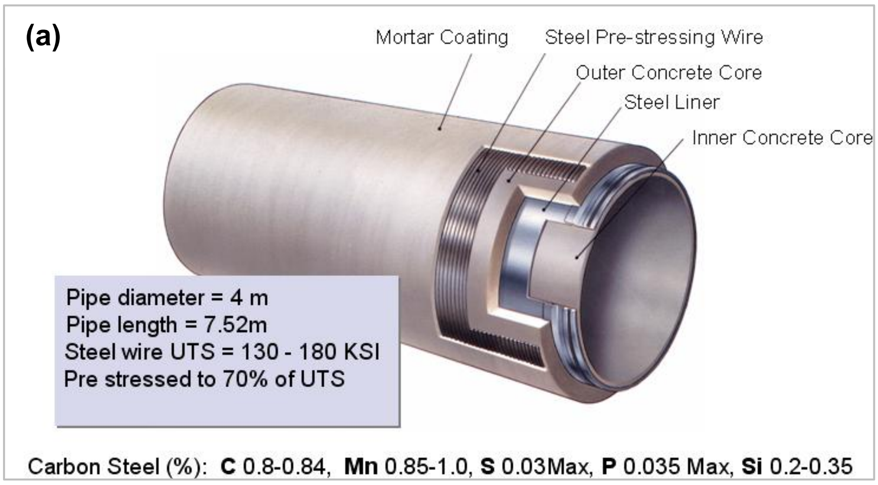
This paper discusses a case where a section of the PCCP pipeline comes into crossing with three 42 inch (106 cm) diameter oil pipelines transporting crude oil from a tank farm to a loading terminal. Interference testing conducted and measures taken to resolve the problem were described. Possible explanations for the persistence of the interference issue in spite of the actions taken were discussed along with recommended actions to troubleshoot and mitigate the adverse effects.

CATHODIC PROTECTION SYSTEMS

The PCCP is protected at the utility crossing region by vertical high potential magnesium anode groundbeds positioned on each side of the PCCP pipeline at 5.5 m interval from the pipe centerline with anode to anode spacing of 13.5 m. Each vertical magnesium anode is made up of six -one meter long segments connected together with a stainless steel stranded wire with a total active length of 6 m and weight of 20.75 kg. The top of each vertical anode is positioned at a depth of three meters. The anodes on each side of the pipeline are connected through insulated stranded copper cables having a cross-sectional area of $16mm^2$ to a header cable having a cross-sectional area of $300mm^2$. The header cable on each side of the PCCP pipeline is connected from its both ends to the pipe through the manhole chambers located at 600 m intervals along the pipeline (Figure 1 (b)). Inside the chambers the cables passes through junction boxes to allow subsequent measurements of IR-free pipe potentials by installing current interrupters and current measurement on a shunt.[3] The cable is then connected by means of a welded stud or a brazed pin to a steel flange. The total current outputs of the magnesium anode groundbeds measured in the junction boxes located in the upstream and in the downstream of the utility crossing region are 16.1 A and 8.1 A.

On the other hand, the oil company is protecting their loading pipelines between the tank farm and loading terminal by means of a "blanket system". All metallic facilities are electrically bonded together and receiving cathodic protection currents from about twenty transformer rectifier units through shallow and deep well groundbeds.[4] The transformer-rectifier units operating outputs range from 24 to 74 A. The three pipelines were constructed about fifty years ago and the high current demand may indicate deterioration of the pipe coating.

The area of utility crossing along the PCCP pipeline is kept clear from any sacrificial anode installations as required by the utility owner to avoid drilling within the foreign utility right of way and prevent any damage to the underground structures. The foreign utilities at the crossing include, in addition to the three oil pipelines, an asphalt road, two underground power cables and a PVC pipeline. The former requirements left the crowded area of crossing which is about 100 m wide along the PCCP with no sacrificial anodes installed.



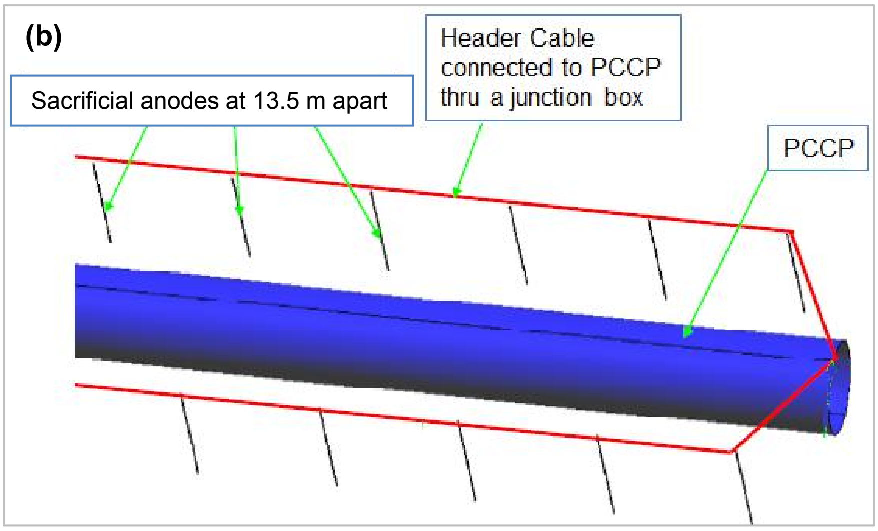


Figure 1: (a) PCCP pipe construction details (coal tar epoxy on top of mortar is not shown), (b) Sacrificial anode distribution and connection details

EXPERIMENTAL PROCEDURE

Before the installation of sacrificial magnesium anodes, measurement of natural PCCP to soil potentials with respect to saturated copper-copper sulfate reference electrode was carried out. The potential values were measured with the reference electrode placed on the ground level along the PCCP pipeline at 1 m intervals (Close Interval Potential Survey) or (CIPS).[5] As will be shown in the results section, the as- found or natural potential survey at the crossing showed a potential dip of about 250 mV in the positive direction. Therefore, the pipeline operator agreed with the utility owner to install a resistive electrical bond between the PCCP and the foreign steel pipelines. The resistive bond value was 0.5 ohms. There was no information found on the values and direction of current passing through the resistive bond between the PCCP pipeline and the oil pipelines.

Following the installation of the sacrificial anode CP system about a year later, CIPS on the PCCP pipeline was carried out with the sacrificial anodes being interrupted with synchronous current interrupters installed. The switching cycle used was (4 seconds ON and 1 second OFF). It appeared that the positive potential dip at the crossing point had occurred to both ON and Instant OFF values on the PCCP which is indicative of possible further stray current discharge. As a result the PCCP pipeline owner decided to have the resistive bond completely removed and to add four more sacrificial magnesium anodes (with two on each side of the PCCP) within the foreign utility right of way as close as possible to the suspected discharge region. The four additional anodes had the same original anode configurations but were installed at 15 m deep borehole as opposed to the rest of anodes for the purpose of counteracting the stray current discharge effect. Installation of the additional anodes was made about two years after the original installation. Subsequently, interference testing had to be conducted as described in the sections to follow in order to examine the mitigating effect of the corrective measures taken (i.e. installation of additional anodes and removal of resistive bond).

INTERFERENCE TESTING

Due to the high operating levels of some of the CP transformer-rectifier units and the system design (blanket scheme) providing protection to the oil pipelines, commonly known interference testing procedures were not possible.[6-9] Therefore, it was decided to conduct an alternative interference test procedure in conjunction with the utility owner personnel as follows:

1. Synchronized interruption of the foreign pipelines cathodic protection Transformer-Rectifier (T/R) units in groups and conduct potential measurements to check for any potential swing over the PCCP pipeline in the area of pipeline crossing for each CP system group.

2. Switch off all the foreign pipelines cathodic protection T/R units and conduct potential measurements over the PCCP pipeline in the area of pipeline crossing

3. With all the foreign CP system T/R units switched off, the units were re-energized one at a time while recording the pipe to soil potential for both the PCCP pipeline and the oil pipelines at the crossing region.

Synchronized interruption of the PCCP sacrificial anode CP system and conduct pipe to soil potential measurements over the oil pipelines. This step was conducted only for completeness as the PCCP pipeline had been the interfered with and not the interfering structure.

The PCCP pipeline owner adopted a conservative criterion to make a judgment as to whether there is an anodic interference. The criterion requires that if the difference in the pipe potentials is zero or the potential is shifted in the positive direction by a value of less than 20 mV, when the foreign CP system is switching from OFF to ON then there is no interaction and no mitigation is required. The switching cycle of the foreign CP system units used in the interference testing was (5 seconds ON and 1 second OFF).

Soil Resistivity was measured at the pipeline crossing region using the Wenner method (four-pin method) at depths of about 5 m and 10 m to assist in the interpretation of the interaction details. The former depth represents the soil regions at the PCCP spring line depth whereas the latter represents the soil regions at the PCCP invert level.

As part of the regular PCCP potential monitoring, three sets of switched ON and OFF CIP surveys were conducted over the subsequent six years. Afterwards, the PCCP pipeline had been in operation for 10 years till the present time without significant monitoring performed. It is worth noting that there was no information readily available on any changes in the operating levels by the foreign utility owner.

RESULTS AND DISCUSSION

INTERFERENCE EFFECT ON FOREIGN PIPELINES

The effect of the magnesium anodes of the PCCP pipeline on the three oil pipelines was minimal. Positive potential swings of 12 mV, 20 mV and 24 mV were recorded were recorded on the loading lines 1, 2 and 3, respectively, at the crossing with the PCCP when the sacrificial CP system of the latter was switched from OFF to ON. However, the effect of stray current from the impressed CP system of the oil pipelines on its own structures (that it is intended to protect) looks more pronounced at the crossing regions. The current picked up by the PCCP away from the crossing is again discharged back to the oil pipelines at the crossing and thereby raising the potential in the negative direction by about 300 mV on each of the three loading lines. That effect may not be of any particular concern to the oil pipeline owner given the ON-potential values observed were in the order of -1600 mV vs. CSE. The interference effect of protection current redistribution followed by current concentration to a point at the crossing was not detectable by switching the “interfered with” CP system (e.g. PCCP CP system).

INTERFERENCE EFFECT ON PCCP PIPELINE

Figure 2 shows the natural (pre-installation) potential of the PCCP pipeline section at the crossing region with a potential dip of about 250 mV in the positive direction over the crossing. The polarized potential survey immediately after the energization of the original sacrificial anode CP system is shown on Figure 2 with the potential dip still present.

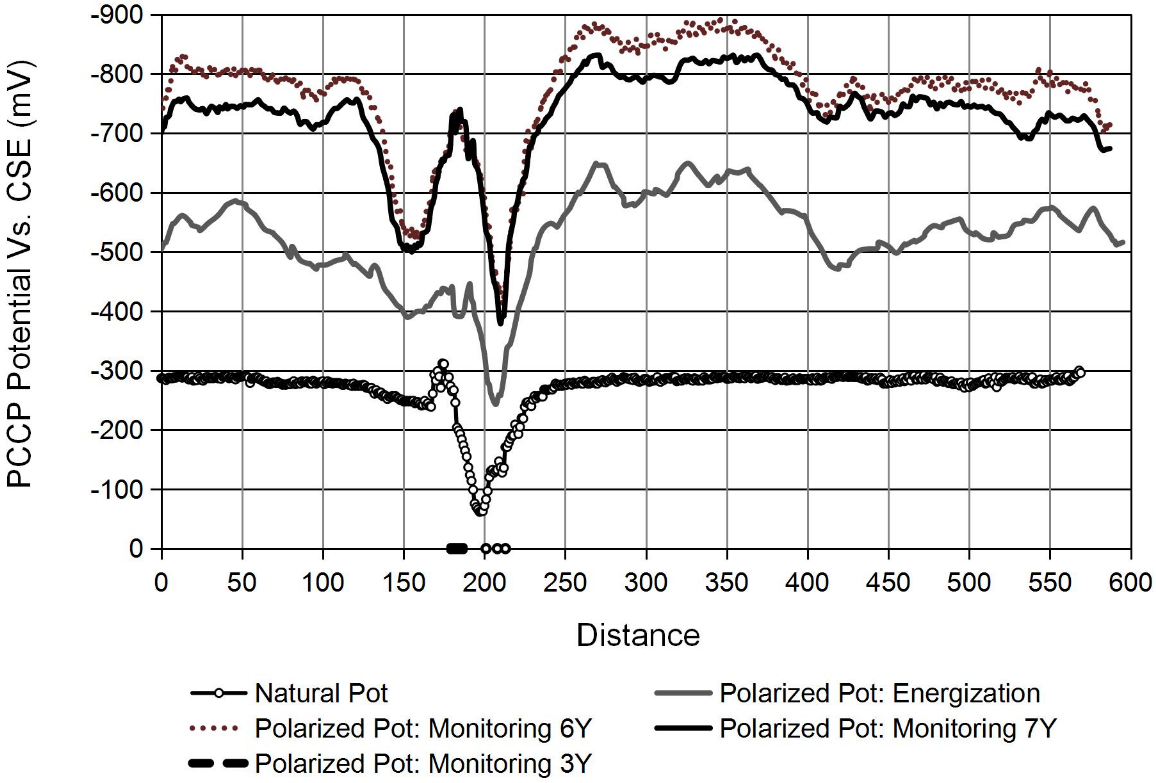


Figure 2: Natural and polarized PCCP to soil potentials measured by CIPS over and on both sides of crossing. The labels 3Y, 6Y and 7Y indicate number of years after original CP system Energization. The graphs indicated with those labels are for measurements taken with the additional anodes installed. All measurements were taken with all foreign T/R units ON. The white circles and black dash on the X-axis indicate the locations of pipelines and road crossings, respectively.

The polarized potential graphs labeled (3Y, 6Y and 7Y) represent the status after installing the additional 4 anodes and removing the resistive bond between the PCCP and the foreign pipeline 3, 6 and 7 years after original energization. It appeared that even after taking that remedial measure, the potential dip was still present and rather magnified to a value of about +300 mV. It also appeared that there is a new positive potential dip of about 150 mV had emerged on the potential graphs 3Y, 6Y and 7Y about 50 m in the upstream direction of the original dip. That unwanted effect seems to be resulting from the fact that the interconnected magnesium anodes running alongside the PCCP pipeline acted as a medium that stimulated the stray current to be picked up away from the crossing and be discharged at the crossing.[10] The current discharge at the crossing region may be occurring from both the anodes and the PCCP as exhibited by the potential dips.

Previous experience with sacrificial protection of other PCCP pipeline sections showed that the most negative potential shift (cathodic polarization) is attained at the energization stage. Figure 2 showed that an average negative shift of about 200 mV was achieved at the energization and then the PCCP continued to polarize to a make an average total negative shift of about 400 mV after 7 years.

That further shift may be attributed to a polarization effect from the foreign impressed CP system. Stray current picked up away from the crossing seems to discharge from magnesium anodes to the PCCP at the crossing before it discharges again back to the loading lines. The latter was thought to be manifested by the obvious negative shift in polarized potential from distance 250m to 400m in Figure 2. Further, changing the impressed CP system operating outputs for any of the many T/R units (Table 1) across the foreign “blanket” CP is something beyond the control of the PCCP pipeline operator. The high operating output values and any possible adjustments to the foreign system can change the overall polarization of the PCCP pipe at the affected regions.

Table 1: Grouping of the foreign CP system T/R Units

Group	Impressed CP System T/R Units	Output currents / A	Location	Comments
1	18	42	Shore Valve	Shallow Groundbed
	19	67		
	20	63		
	21	52		
	25	36		
2	2	40	Tank Farm	Shallow Groundbed
	13	50		
	11	61		
3	12	66	Tank Farm	Deep Well
	4	42		Deep Well
	3	46		Shallow Groundbed
4	1	24	Tank Farm	
	15	62		
	9	58		
	7	66		
5	6	64	Tank Farm	
	10	70		
	5	52		
	14	74		

Table 2 showed that there is an interference effect on the PCCP manifested by a potential swing of more positive than 20 mV at the crossing resulting mostly from T/R groups 4 and 5 on the three loading lines and from T/R group 1 on loading line no. 2. The most observed swing was observed on loading line 2 when interrupting any T/R group. The combined interference effect is shown on Table 2 as the algebraic difference in PCCP potentials when all T/R units switched ON and then completely switched OFF. The latter showed more positive swing values than the collective potential swing resulting from the sum of all positive swings for a given loading line when interrupting each group. For example for loading line no. 2, the sum of all potential swings when interrupting each group in the 5 scenarios is + 159 mV whereas the combined positive swing when switching the entire foreign system ON and then completely OFF is + 221 mV. Therefore, it can be said that the instantaneous interruption of the foreign CP system when carrying out an interference testing may not show the exact magnitude of the interference effect even if all the foreign T/R units were interrupted together in a synchronized fashion.

Table 2: Interference testing effect on PCCP pipeline

Reference Electrode Location	PCCP Potential measured when own sacrificial system operational and foreign system switching / mV (CSE)			Group switching
	ON	OFF	Difference	
Loading Line 1	-441	-460	19	1 (All other groups ON)
Loading Line 2	-338	-365	27	
Loading Line 3	-389	-406	17	
Loading Line 1	-426	-439	13	2 (All other groups ON)
Loading Line 2	-333	-349	16	
Loading Line 3	-386	-398	12	
Loading Line 1	-412	-419	7	3 (All other groups ON)
Loading Line 2	-328	-341	13	
Loading Line 3	-369	-373	4	
Loading Line 1	-447	-473	26	4 (All other groups ON)
Loading Line 2	-342	-384	42	
Loading Line 3	-388	-411	23	
Loading Line 1	-441	-480	39	5 (All other groups ON)
Loading Line 2	-345	-406	61	
Loading Line 3	-394	-432	38	
Loading Line 1	-407	N/A	151	All T/R Units ON
	N/A	-558		All T/R Units OFF
Loading Line 2	-333	N/A	221	All T/R Units ON
	N/A	-554		All T/R Units OFF
Loading Line 3	-384	N/A	153	All T/R Units ON
	N/A	-537		All T/R Units OFF

In spite of the observed interference, the described case has been dominating for about 17 years since the original sacrificial CP system was energized. During this operation period, there was no PCCP pipe burst recorded or pre-stressing wire break reported by acoustic monitoring at the crossing region. The PCCP pipeline owner considered that observation as a good sign for the effectiveness of the 100 mV potential shift protection criterion, regardless of the amount of potential swing resulting from interference. As a precautionary measure, the pipeline operator is currently considering to have diodes installed at each sacrificial anode cable to prevent stray current from flowing from the soil to the anodes especially at the suspected pick-up regions.

CONCLUSIONS

1. There was no evidence of corrosion-induced wire breaks resulting from the interference for the PCCP sections that achieved the 100 mV protection criterion.

2. The instantaneous interruption of the foreign CP system (in a synchronized fashion) when carrying out the interference testing did not show the full magnitude of the interference effect (potential shift)

3. PCCP pipelines entirely protected by sacrificial anodes may be subjected to stray current pick-up and discharge at various regions along the pipeline through the anodes that can behave as if they were bare metals exposed at large coating defects.

ACKNOWLEDGMENTS

The authors would like to thank the Great Man-Made River Authority (GMRA) for their kind assistance and sponsorship of the participation in the CORCON 2017 conference. The opinions, findings, views and conclusions are those of the authors and they do not necessarily represent the Great Man-Made River Authority.

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