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Investigating water pipelines using IR-free potential measurements under stray current interference conditions

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ABSTRACT

A large diameter water transfer pipeline coated partly with bitumen fibreglass (47km) and partly with sintered polyethylene (56km) was fitted with ICCP. The pipeline crosses a heavy-haul DC electrified rail and other pipelines. Significant DC stray current interference was identified during construction. The sources of interference could not be switched off or interrupted. A number of techniques were utilised to determine whether the pipeline was adequately protected in terms of BS EN 13509 Section 4. These included the use of coupons, intensive measurement, potential recordings, integrated CIPS / DCVG and physical inspection of selected locations. This paper presents the methodologies undertaken and the correlation between the results of the various techniques.

Introduction

South Africa is a country with scarce water resources. The water supplies are seasonal and geographically disparate. Power generation, mining and primary industry are concentrated in relatively small areas which do not necessarily coincide with water resources. As a result, South Africa has an extensive high pressure water pipeline network totalling several thousand kilometres, the majority of which is steel, lined and coated.

South Africa also has an extensive heavy-haul rail network which is powered primarily by a 3kV DC traction system. This network consists of approximately 20 000km of track, 80% of which is electrified. Of that 80%, a further 80% is DC. This combination of rails and pipelines, combined with several thousand kilometres of steel oil and gas pipelines, has given rise to a complex electrical interference scenario which is unparalleled in its complexity and intensity.

Prior to the recent adoption of ISO 15589 and EN 50162 as the governing standards for cathodic protection and stray current interference in South Africa, a local code of practice, SANS 10121, was in place. This code set out the criteria for cathodic protection and stray current interference mitigation, and entrenched the South African Electrolytic Corrosion Committee (SAECC), an industry forum for the mitigation of stray current interference, which has been in existence for some 50 years. This committee is still active and fulfills the recommendation of section 4 of EN 50162

SANS 10121 had as its protection criterion the ubiquitous −0.85V $CuCuSO_4$, in the early years as an "ON" potential and latterly incorporating the concept of polarised potential. A value of −2.5V $Cu/CuSO_4$ was set as the maximum negative "ON" potential. These parameters had been successfully applied for many years in an industry where bitumen fibreglass coatings were predominant.

On the stray current mitigation front, an industry norm had become common practice (born out by practical experience rather than scientific investigation) that metal loss would not be expected if the pipeline was cathodically protected for at least 95% of the time. Some basic research was conducted by the CSIR which validated this approach. It is interesting to note that recent standards such as AS2832-1 2004 incorporate similar values.

In the late 1990's there was a dearth of pipeline construction in South Africa. The first major project for many years was a large diameter steel water pipeline totalling some 103km. The first 47km of this pipeline was coated with bitumen-fibreglass. Although SANS 10121 was the ruling code at the time of construction, evaluation of the status of the pipeline in terms of the newer standards was required. The pipeline crossed a heavy-haul rail line and 2 fuel lines and was known to be affected by stray current interference from the DC rail system

Accordingly, a suite of tests was undertaken based on EN 13509 in order to determine whether the cathodic protection system was functional.

This paper presents the results of these tests conducted on the bitumen-fibreglass coated section of the pipeline. The purpose of this paper is not to comment on the adequacy of the cathodic protection, but to present the test methods used and examine the correlation between the results of these tests.

The section of pipeline under consideration was equipped with 5 ICCP stations with conventional remote shallow horizontal groundbeds. The rectifiers were installed with feedback control and operated in constant pipeline potential mode.

CP test stations were installed at nominal 1km intervals. These test stations incorporated a coupon and soil tube for potential measurement using a portable reference electrode. The coupon could be switched independently of the pipeline.

Measurement Techniques.

SANS 10121, the cathodic protection code of practice in force at the time of the installation contract, required only that the potential of the pipeline be maintained more negative than −0.85V $Cu/CuSO_4$ (−0.95V in the presence of SRB). The industry norm of 95% protection on a time basis was also adopted.

Accordingly, the pipeline was initially evaluated using 24-hr recordings of "ON" potential at test points. As the South African rail system is no longer schedule driven, the accepted practice of using the "dead" time around midnight as a reference period has not been found to be effective for eliminating the effect of stray current interference.

In terms of Section 2.2 of EN 13509, there are 3 recommended techniques for evaluating the true potential of a protected structure under the influence of remote, fluctuating stray current interference. These are detailed in the standard in sections 4.4.2.2, 4.4.2.3 and 4.4.2.4 and may be summarised as:

- Special "OFF" potential measurements
- Intensive measurement technique
- External coupons.

It was not considered feasible to undertake the special "OFF" potential measurements, so evaluation was conducted using intensive measurement and coupon "OFF" potentials.

It is inherent in the intensive measurement technique that potentials are measured at known defects in the pipeline coating. Accordingly, a hybrid close interval survey (CIS) was undertaken in accordance with NACE SP0207-2007 section 8 using longitudinal gradient measurement. The primary purpose of this survey was to locate coating defects. A secondary result was to determine whether the data from test posts was representative of the intervening pipeline, which would permit the application of the principle of monitoring "ON" potentials inherent in the special "OFF" potential measurement technique detailed in section 4.4.2.2 of EN 13509.

The effect of stray currents on the pipeline was compensated by the use of synchronised static data loggers during the CIS. There was no point in measuring pipeline "OFF" potentials during the CIS as it was not possible to interrupt all sources of current on the pipeline and it has been extensively shown that "INSTANT OFF" potentials can in fact be anodic when the stray current mitigation system is interrupted.

Locations identified during the hybrid CIS were later pinpointed by conventional DCVG and the IR-free potential determined from pipeline and lateral gradient potential measurement. It is interesting to note that whilst these locations coincided with sites determined using AC attenuation and voltage gradient surveys (PCM), there were many indications of coating defects from the PCM survey which did not have corresponding indications in the hybrid CIS.

Coupon "OFF" potentials were measured at the test stations installed during pipeline construction. Some coupons gave anomalous results and certain coupon test facilities had been damaged, so a full suite of coupon potentials was not obtained.

Survey Results

24-hr Potential Recordings at Test Points

Potential recordings were taken using data loggers with 10 MΩ input impedance sampling at 30s intervals and portable reference electrodes at surface. The maximum, minimum and average potential from each data logger has been extracted and plotted against chainage. (Fig 1) The results indicate that the pipeline is fully protected in terms of the

−0.95V Cu/$CuSO_4$ “ON” criterion over a period of 24 hours, as per SANS 10121.

The effect of stray current interference as the pipeline approaches the railway line can clearly be seen in the increasing negative potentials after approximately Ch 32 km

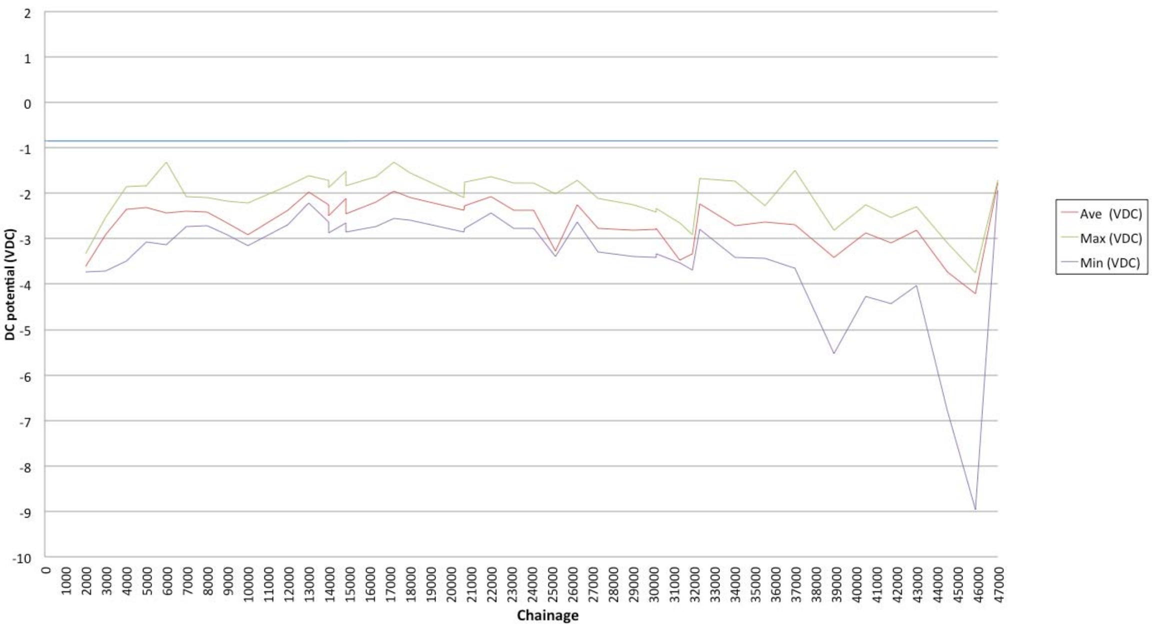


Fig 1: Average, Minimum & Maximum Potentials over 24 hours

The % time more negative than −1.0V is plotted in Fig 2. This confirms that the stray current positive excursions are being contained by the rectifiers.

The potential recording in Figure 3 was taken at Ch 6010 m adjacent to the bend at Ch 5560 m

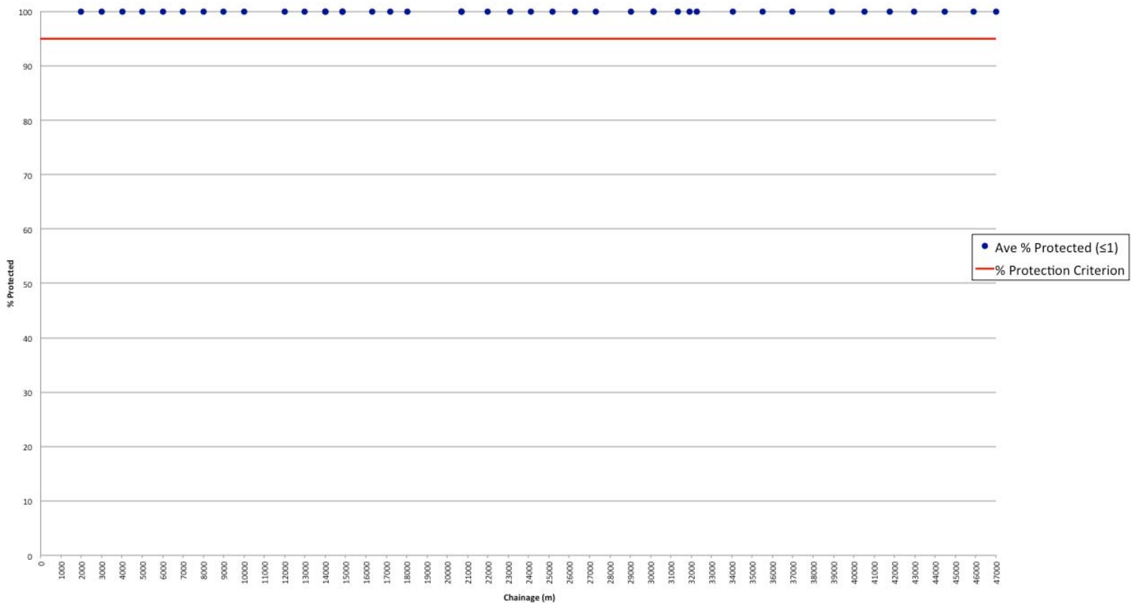


Fig 2: % Time ≤1VCSE Average Potentials over 24 hours

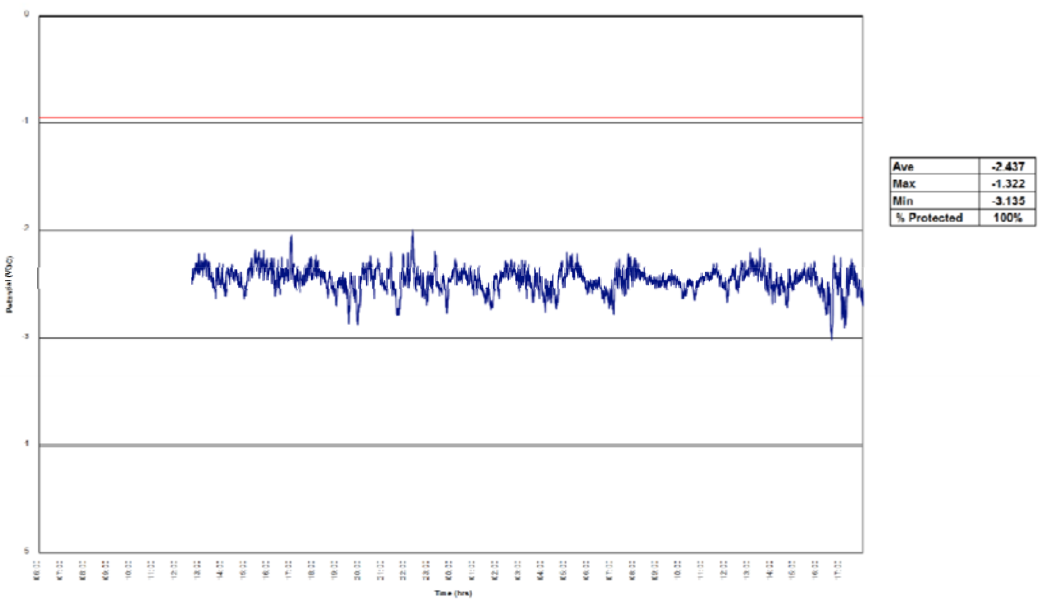


Fig 3: The graph illustrates full protection in terms of the −0.95V $Cu/CuSO_4$ "ON" potential and % time protected criteria

Hybrid Close Interval Potential Survey

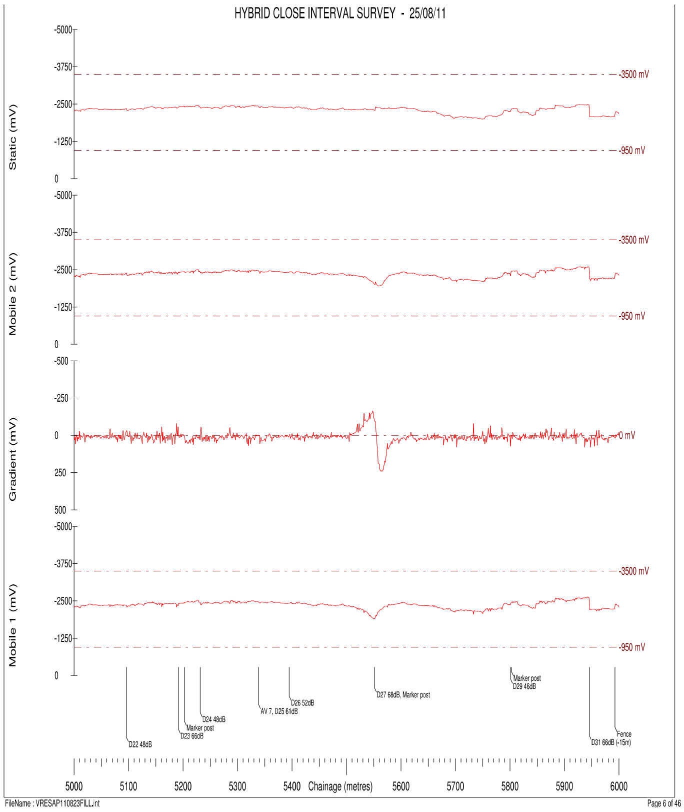
The graph on the following page illustrates the coating defect at Ch 5560 m together with the associated PCM indication D27. Note the lack of HCIS indications for PCM indications D22 to D26.

Intensive Measurement

The target range for IR-free potentials is -0.95 to -1.2 VCSE.

Table 1 Defect Locations from HCIS and IR-Free Values (EN 13509)

Ref.	Location	IR-Free Potential (VCSE)	Excavation/ Comment
D2	~Ch 5 550,	-.94	Bend, cracks in coating. PCM D27
D2	~Ch 5 550	-.95	
D2	~Ch 5 550	-.92	
D3&4	~Ch 14 680, 160m before AV27	-1.4	No evidence of coating defect on exposure
D5	~Ch 14 800, AV 27	-1.19	
1	~Ch 25 150, 77m before AV46	-1.13	Lifting lugs on bend, calcareous deposits
2	~Ch 26 300, 49m before AV48	-.62	Lifting lugs on bend, calcareous deposits
3	~Ch 40 800, FT11	-1.06	
4	~Ch 45 400, 61m before AV84	-1.04	
5A	~Ch 46 400, 24m before AV87	1.28	AV87 leaking, chamber flooded
5B	~Ch 46 400, 12m after AV87	-1.33	AV87 leaking, chamber flooded
5C	~Ch 46 400, 26m after AV87	-1.32	AV87 leaking, chamber flooded
5D	~Ch 46 400, 59m after AV87	-1.38	AV87 leaking, chamber flooded



Coupon "OFF" Potentials

Table 2 below summarises the pipe/soil potentials taken at test posts, using coupons where available. All potentials referenced to a portable copper / copper sulphate electrode placed in the tube incorporated into the test post foundation.

Table 2 – Coupon Potentials at Test Posts

Test Post No.	Coupon ON	Coupon OFF	Pipe ON
2004	-3.56	-1.11	
2996	-2.60	-1.27	
4007	-2.77	-1.26	-2.82
4996	-2.25	-1.22	
6010	-2.52	-1.11	
7000	-2.18	-1.23	
8000	-2.22	-1.15	
8984	-2.47	-1.09	
10006	-2.72	-1.04	
12004	-1.82	-1.20	
12997	-1.80	-0.99	-1.77
14016	-2.23	-1.21	-2.25
14847	-1.83	-0.98	-1.82
20270	-2.26	-1.03	-2.24
22076	-1.87	-0.55	-1.90
25171	-2.99	-1.06	-2.98
26278	-2.58	-1.18	-2.56
27100	-2.65	-1.19	-2.70
28200	-2.95	-1.17	-2.91
29045	-2.41	-1.12	-2.45
30163	-2.28	-1.17	-2.32
30989	-2.39	-1.35	-2.28
31935	-2.88	-1.15	-2.87
34035	-2.62	-1.24	-2.63
36065	-2.31	-1.15	-2.29
36965	-3.18	-0.92	-3.17
37680	-3.05	-1.17	-2.99
38920	-2.98	-1.19	-3.00
39933	-2.59	-1.21	-2.60
40686	-2.05	-0.43	-2.05
41753	-3.07	-1.19	-3.06
42987	-3.96	-1.31	-3.95
45900	-2.19	-0.77	-2.19

Physical Inspection

The photograph below shows the excavation and bitumen damage on the bend at Ch 5560m

Conclusions

- The hybrid CIS survey technique provided accurate location of significant coating defects on the pipeline.
- The results of conventional "ON" potential recordings at test points correlated with both coupon "OFF" potentials and intensive measurement IR-free calculations in demonstrating that full cathodic protection had been achieved on the pipeline.
- The condition of the steel at significant coating defects was evaluated by excavation and physical examination which validated the IR-free results.
- The evaluation exercise underpins the principle inherent in NACE SP 0502 that pipeline condition should never be assumed based on a single monitoring technique, and that a minimum of 2 and preferably 3 techniques should be used to evaluate a corrosion situation by indirect inspection.

References

SANS 10121: Cathodic Protection Of Buried And Submerged Structures

SANS 15589 (ISO 15589) Cathodic protection of pipeline transportation systems -- Part 1: On-land pipelines

SANS 50162 (EN 50162) Cathodic protection of pipeline transportation systems -- Part 1: On-land pipelines

SANS 53509 (EN 13509) Cathodic protection measurement techniques

NACE SP 0207 Performing Close-Interval Potential Surveys And Dc Surface Potential Gradient Surveys On Buried Or Submerged Metallic Pipelines

NACE SP 0502 External Corrosion Direct Assessment (ECDA) Process