Detection of coating damage on buried pipelines using an electrochemical method

By

Andrew Gordon CEng IMechE, RISE KIMAB AB, Box 7047, 164 07 Kista, Sweden
Bror Sederholm, Rise KIMAB AB, RISE KIMAB AB, Box 7047, 164 07 Kista, Sweden

Abstract

This paper presents a summary of project results from a research project (called Pipestatus) into dig-free methods of assessing the condition of buried water and district heating pipelines in built-up areas. An electrochemical method of measuring potential gradients (similar to DCVG) has been tested in the field on district heating systems and shown to be useful in locating coating damages on the buried pipelines. After excavation of the suspected coating damages it was shown that the method had successfully located areas of damage and that the underlying steel had corroded due to contact with the surrounding soil.

It is recommended that the method undergo further research and testing in order to quantify its accuracy further and to investigate the size of defects that can be detected using this method.

Introduction

Stable access to clean water, wastewater and district heating is a necessity for a sustainable and attractive city. District heating in Sweden was first installed in 1948, and was expanded during the 1950's. Today it accounts for approximately 50% of all heating (domestic and industrial) in Sweden (1). Carbon steel is the preferred material for the pipelines, with a protective barrier coating such as a polyurethane insulation layer and a polyethylene external barrier. The pipes are often laid directly in the soil, sometimes with backfill material. The use of tunnels and culverts is also used but not in the majority of cases. The use of cathodic protection is not common to these systems due to the presence of grounding systems and connections to other buried structures. District heating systems have an estimated 7000 km of buried pipework in Sweden with an annual cost of repair/replacement of ca. 300 million euros (3). Dig-free methods and new technical solutions have long been asked for by owners of piping systems in Sweden as well as globally.

The risk for external corrosion of the buried pipelines exists where the coatings/insulation is damaged and exposed to the surrounding environment and has resulted in some catastrophic failures causing leaks and in some cases casualties (2). Therefore work is required to establish efficient methods of detecting coating damage at an early stage in order to prevent corrosion and subsequent leaks.

In the Pipestatus project five new dig-free methods for status assessment of piping systems were evaluated for efficiency of localizing coating damages on buried steel pipelines. These methods included camera inspection, radar surveys, resistivity measurements of the soil, acoustic emission, and electrochemical measurements (3).

Existing methods of detection and localizing coating damages on buried pipelines are often used in the gas distribution industry. Where pipelines are cathodically protected large potential gradients can be detected at coating damages using methods such as DCVG. Due to the lack of cathodic protection systems and the presence of grounding systems on district heating pipelines a modified method was devised for this study.

This paper presents the electrochemical method and reports the results of tests carried out on district heating pipelines. It was found that this method could be effective for finding coating damages and areas of potential corrosion damage. The method, similar to DCVG, is new in the district heating and water distribution sector in Sweden and could potentially provide large cost savings by reducing the number of excavations required to locate and maintain coating damages.

All potential measurements reported in this paper are vs a $Cu/CuSO_4$ reference electrode.

Investigation

4 different district heating pipelines located in the south of Sweden were investigated in this work:

1. Tornavägen in Lund, 100m
2. Pomonavägen in Ängelholm 340m
3. Nyhemsleden in Ängelholm. 220m.
4. Trastvägen in Lund, 165 m.

OCP and polarized potential measurements

Initially, open circuit potential measurements (OCP) were carried out along the length of the pipeline. This was done by connecting a reference electrode ($Cu/CuSO_4$) to the pipeline at a suitable location such as a valve connection, see Figure 1. The electrode was placed on the soil surface directly above the pipeline for each measurement carried out with 10 m intervals. The measurements were then

repeated whilst a DC current was supplied to the pipeline. The potentials were measured using a high-impedance (>10^7 ohm) voltmeter connected to the reference electrode and pipeline.
From experience it is known that typical OCP values of pipelines buried ca. 2m under the soil surface are normally around -650 mV (vs $Cu/CuSO_4$). For uncoated copper items the OCP is typically ca. -150 mV in the same conditions. A mixed OCP in cases where steel pipelines are in contact with copper earthing equipment the OCP is typically ca. -350 mV in similar conditions.

Figure 1 – connection point to pipeline 4: valves in a manhole.

Potential gradient measurements

Copper-coated steel electrodes were placed in the soil and DC current was passed to the pipes being examined via a transformer rectifier (T/R) connected either to a petrol-powered generator or directly connected to the electricity grid, see Figure 2. The current supplied at each test location is shown in Table 1.
The potential gradients along the length of the pipeline were measured using two reference electrodes with a spacing of 10 m placed directly above the buried pipeline. The measurements were carried out both with and without the applied DC current from the T/R. After each measurement the electrodes were moved 10 m along the length of the pipeline, thus creating a map of the potential gradients along the pipeline.

Table 1 – DC current applied at the four test locations.

Pipeline	Location	Current (A)	Voltage (V)	Number of anodes
1	Tornavägen	2,20	67	3
2	Pomonavägen	0,77	67	3
3	Nyhemsleden	1,30	67	3
4	Trastvägen	0,15	80	4

Figure 2 – Equipment for applying DC current to the pipelines: a) T/R, b) anode, c) generator

Results

OCP and polarized potential measurements

The results of the OCP measurements on pipelines 1 - 3 showed that they probably had electrical contact with copper earthing systems: the OCP values ca -400 mV, see Table 2 to Table 4, and Figure 3 to Figure 5. Therefore, it was not possible to determine the presence of any possible coating damages at these locations.

For pipeline 4 the OCP was between -446 mV and -489 mV. When current was applied to the pipeline the potential was polarized to between -530 mV and -1165 mV, see Table 5. Two locations had significantly more negative “on potentials”, located at 78 m and 147 m along the length of the pipeline. The “on potentials” were measured as -757 mV and -1165 mV respectively and equates to a polarisation of 295 mV and 702 mV respectively from the OCP measurements, see Figure 6. It was therefore noted that these locations could be possible sites of coating damage.

Table 2 - potential measurements for pipeline 1

Measurement point	**Corrosion potential**	**On-potential**	**Off-potential**
m	mV	mV	mV
0	-405	-1832	-505
2	-420	-1874	509
4	-422	-1844	-502
6	-423	-1790	-510
8	-425	-1447	-506
10	-425	-1488	-511
20	-442	-1026	-504
30	-445	-800	-494
40	-446	-773	-495
50	-446	-735	-498
60	-446	-675	-495
70	-441	-611	-480
80	-431	-570	-470
90	-429	-545	-460
100	-424	-539	450

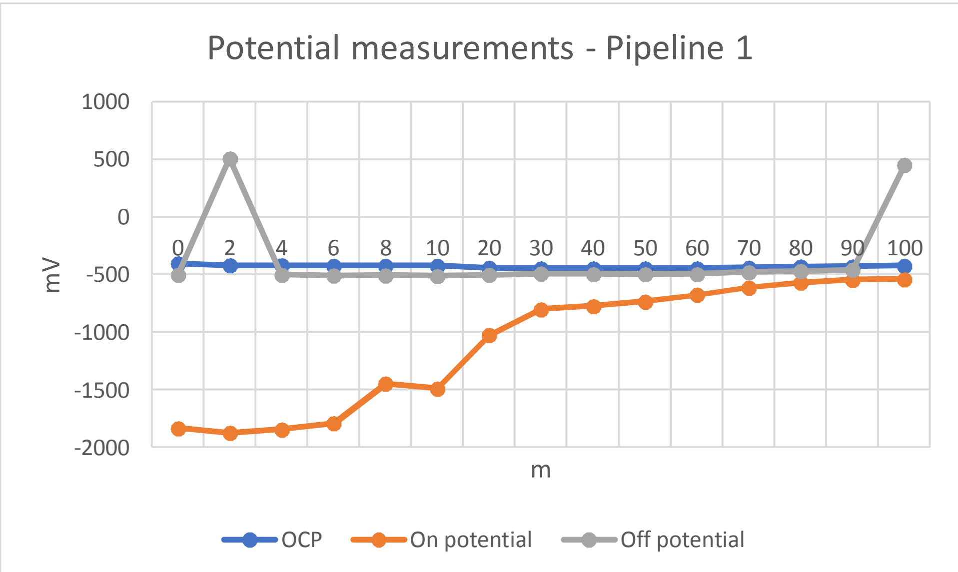

Figure 3 - Results from the potential measurements of pipeline 1.

Table 3 - potential measurements for pipeline 2

Measurement point	Corrosion potential	On-potential	Off-potential
m	mV	mV	mV
0	-435	-880	-500
5	-436	-695	-468
10	-436	-690	-458
20	-437	-610	-439
30	-436	-550	-438
40	-435	-530	-436
50	-437	-532	-436
60	-439	-531	-437
70	-432	-529	-433
80	-435	-528	-436
90	-441	-525	-440
100	-441	-520	-442

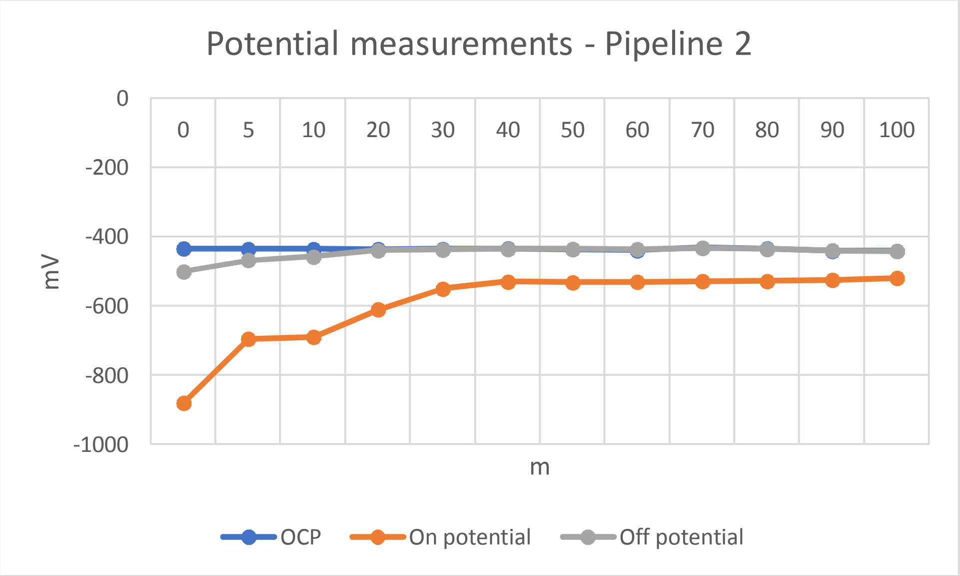

Figure 4 - Results from the potential measurements of pipeline 2.

Table 4 - potential measurements for pipeline 3

Measurement point	Corrosion potential	On-potential	Off-potential
m	mV	mV	mV
0	-375	-472	-375
10	-380	-475	-282
20	-381	-482	-383
30	-384	-493	-386
40	-385	-501	-388
50	-385	-515	-386
60	-385	-520	-386
70	-385	-540	-387
80	-385	-560	-389
90	-384	-560	-387
100	-384	-540	-384
110	-382	-525	-385
120	-383	-520	-386
130	-380	-500	-382
140	-381	-485	-384
150	-380	-484	-383
160	-379	-482	-384
170	-377	-479	-383
180	-372	-477	-381
190	-371	-474	-378
200	-370	-473	-376
210	-370	-472	-375

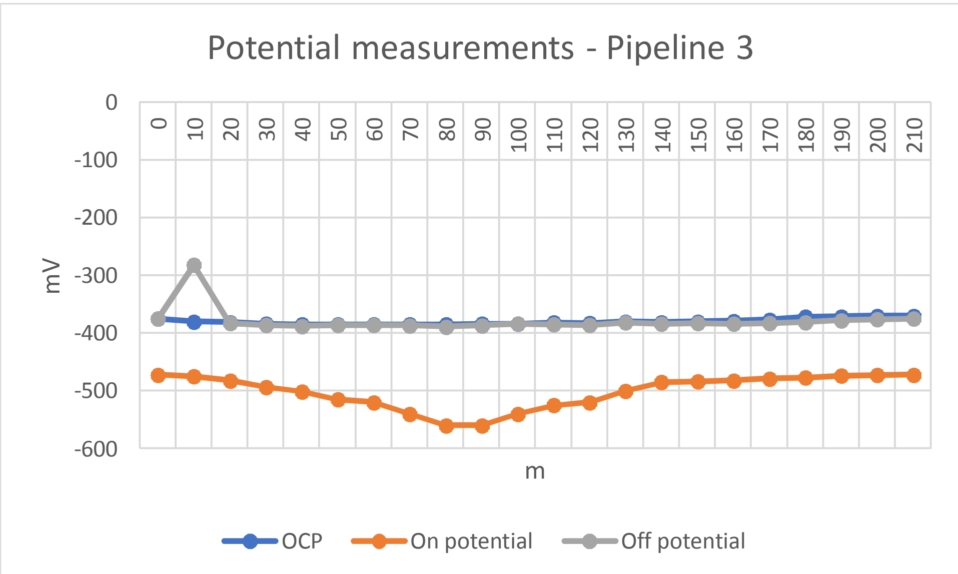

Figure 5 – Results from the potential measurements of pipeline 3.

Table 5 - potential measurements for pipeline 4

Measurement point	Corrosion potential	On-potential	Off-potential
m	mV	mV	mV
0	-473	-530	-490
10	-471	-530	-490
20	-487	-530	-495
30	-489	-545	-500
40	-478	-505	-487
50	-465	-550	-515
60	-464	-564	-517
70	-445	-586	-520
80	-462	-757	-696
90	-459	-599	-515
100	-475	-595	-490
110	-463	-575	-490
120	-446	-570	-520
130	-461	-555	-543
140	-451	-630	-560
150	-463	-1165	-1001
160	-459	-610	-540
165	-455	-645	-550

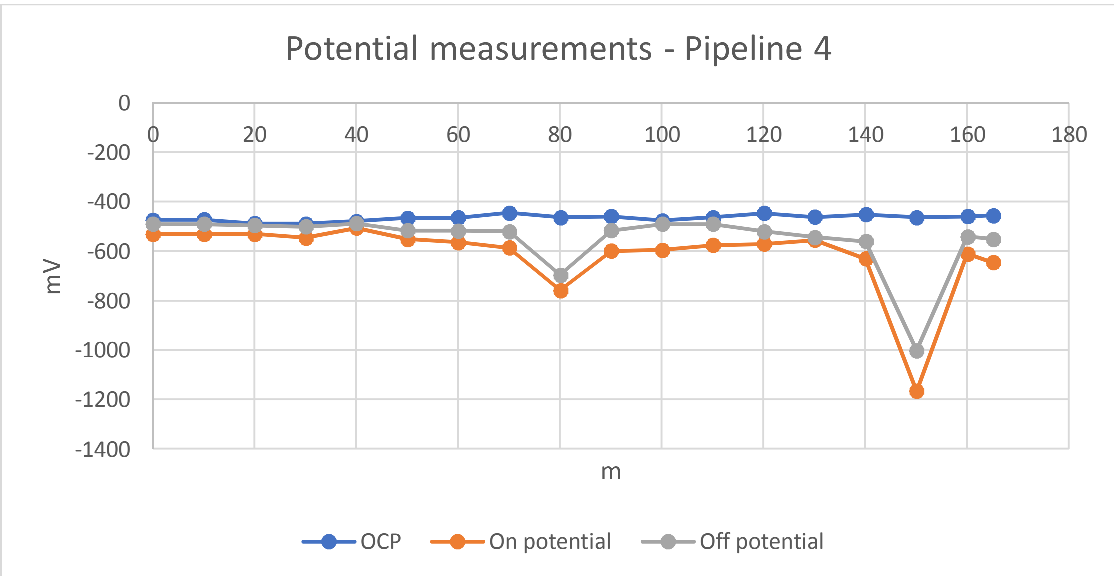

Figure 6 - Results from the potential measurements of pipeline 4 showing the two suspected locations of coating damage

Potential gradient measurements

For pipeline 1 the potential gradient measurements varied largely during the application of the DC current from the anodes. This was most likely due to electrical connection between the pipelines and the copper earthing systems. The copper earthing systems appear the same as a coating damage in the results.

On pipeline 2 measurements were carried out on two different locations along the pipeline. At the first location the anode was placed 15 m away from the pipeline, and at the second location it was placed 500 m away. At the first location (15 m distance) large potential gradients were detected when current was applied to the pipeline which indicated that there was contact with copper earthing equipment. At

the second location (500 m distance) it was not possible to measure any potential gradients or change of the OCP when current was supplied to the pipeline. This indicated that the current supplied was being conducted to nearby structures in the soil that were earthed and in contact with the pipeline.
On pipeline 3 measurements of the potential gradients showed large differences between the reference electrodes when current was supplied to the pipeline. This indicated that the pipeline was in contact with copper earthing equipment. Structures such as lamp posts and substations etc. that have earthing equipment will conduct the current intended for the pipeline during the measurements.
On pipeline 4 the potential gradient measurements showed that when current was supplied the gradients increased significantly at the two locations that were suspected as being coating damages from the OCP and polarized potential measurements (at 78 m and 147 m along the length of the pipeline). See Table 6 and Figure 7 . No other changes in gradients were observed in the measurement data.

Table 6 - potential gradient measurements - Pipeline 4

Measurement point	**Potential gradient when current supplied**	**Potential gradient when no current supplied**
m	mV	mV
0-10	23	22
10-20	14	13
20-30	7	0
30-40	29	0
40-50	24	30
50-60	56	25
60-70	190	20
70-80	685	23
80-90	325	14
90-100	62	2
100-110	37	14
110-120	125	25
120-130	175	0
130-140	275	35
140-150	785	7
150-160	345	6
160-165	45	5

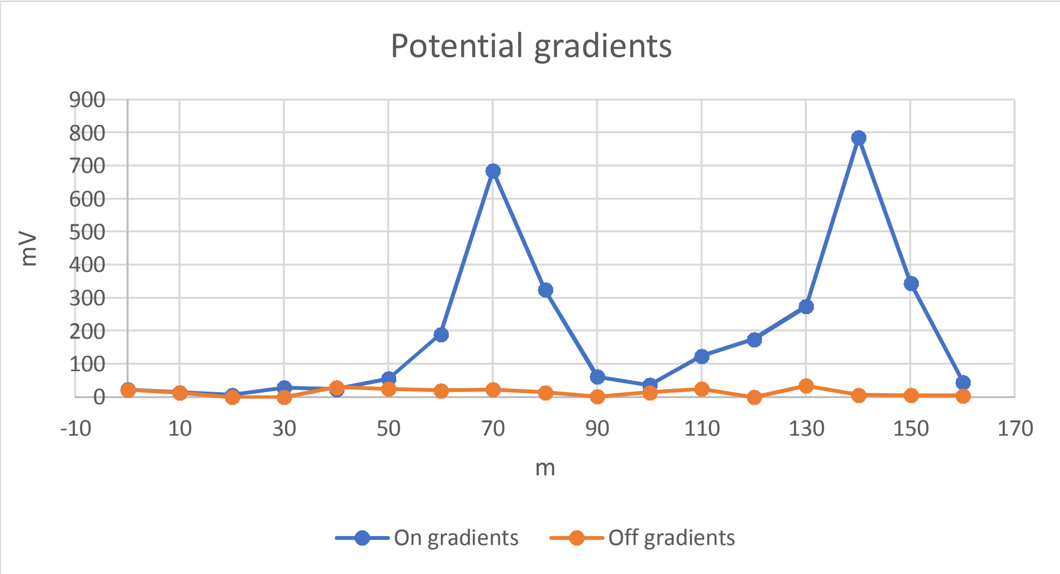

Figure 7 - Results from the potential gradient measurements of pipeline 4 showing the increasing gradients at the two suspected locations of coating damage.

Visual inspection of the suspected damage locations

The two locations suspected of having coating damage on pipeline 4 (78 m and 147 m) were excavated in order to carry out a visual inspection of their condition. At both locations it was found that the pipeline was coated with tape. The tape at both locations had detached and the steel of the pipeline was in direct contact with the surrounding soil and had visible corrosion products on its surface, see Figure 8 and Figure 9.

Figure 8 – Visual appearance of the suspected coating damage after excavation located at 147 m along the length of pipeline 4.

Figure 9 – Visual appearance of the suspected coating damage after excavation located at 78 m along the length of pipeline 4.

Conclusions and recommendations

Suspected coating damages on a buried district heating pipeline have been successfully located by first characterizing the OCP and then polarising the pipeline and measuring the potential gradients along its length. After excavation it was found that the locations were field joints that had been protected with tape which had detached, and the underlying steel had corroded.
This method has probably only been successful in this case because the anodes were placed very close to the pipeline due to practical limitations (presence of asphalt etc.). This meant the pipeline was within the anodic voltage cone and current was forced onto the pipeline instead of onto nearby foreign structures. This implies the method is limited to ca. 10^1 m of the pipe length and must be moved regularly during measurement.
For the other pipelines investigated it was not possible to obtain meaningful polarised potentials or potential gradients using the method due to the presence of earthing systems connected to the pipelines. In order use the method on such pipelines one option would be to remove the connection to the earthing systems if possible prior to the measurements.
The positioning of the electrodes is one parameter that requires further research and testing. It was found that placing the anodes closer to the pipeline gave better results than placing the anodes further away.
The data set obtained in this study is rather small and as such the method requires further research and testing in order to quantify its accuracy and reliability. The size of defects that the method can detect is not known from the work carried out in this study but is an area for future research.

References

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