A field study of line currents and corrosion rate measurements in a pipeline critically interfered with AC and DC stray currents

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Abstract

Based on individual field trials, this paper discusses the following points:

I. The possibility of detecting corrosion due to DC interference by logging the DC parameters of a coupon in distinct time periods corresponding rush hour and silent periods, and the corrosion rate described as a function of the anodic DC charge in pure DC interference cases.

II. The possibility of detecting corrosion due to AC interference by logging AC and DC parameters and correlating corrosion rate with critical combinations of these parameters.

III. The combined mechanism of AC and DC stray current corrosion showing both critical alkalization and anodic dissolution at threshold AC/DC parameters, and the possibility of diagnosing this combined action.

IV. The possibility of detecting the primary DC-interference source using synchronized line currents and potentials, and the possible recommendations for mitigating the corrosion risk in such cases.

Introduction

A distribution pipeline grit system (66 km, operating pressure 19 bar) positioned in proximity of Copenhagen, Denmark, was investigated for potential corrosion risks due to electrical interference. A complex system of high voltage power lines was a major AC interference source, whereas two DC traction systems (north line and south line) were sources of DC interference (see sketch).

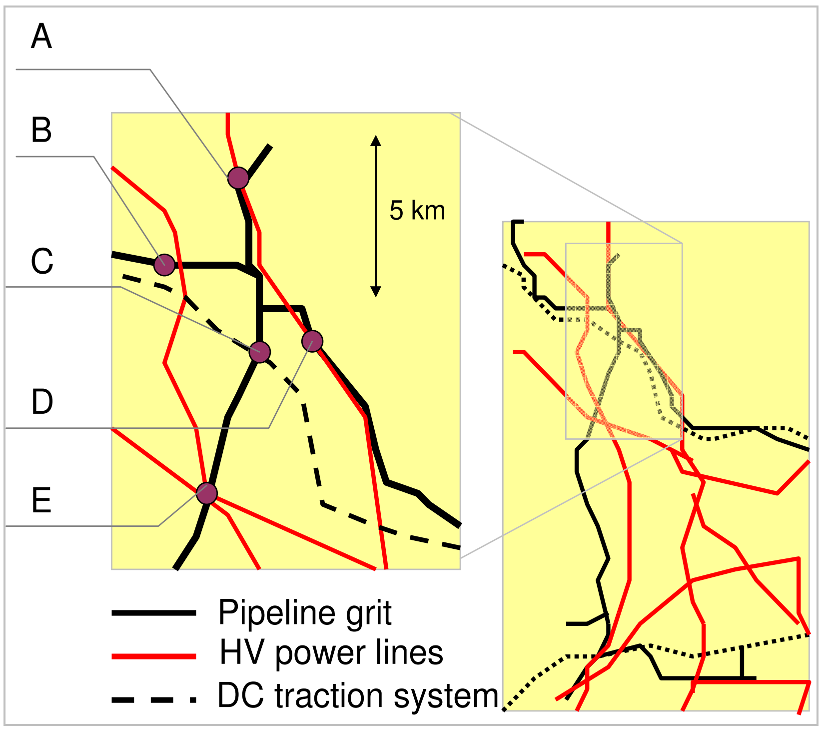


Figure 1. A sketch of the gas grit system and relative position to high-voltage power lines and DC tractions systems.

ER coupons positioned along the line indicated high corrosion rates due to the interference. Particularly, coupons placed in railway crossings showed high corrosion rates.

Due to the complex interference pattern with severe risk of both AC and DC interference, various field trials have been made at different sites in order to characterize the relative importance of the DC, the AC, and the combined DC and AC.

Trials were performed at

a. A site with a DC traction system as the primary interference source (no AC interference),
b. A site with overhead high voltage AC power lines as the primary interference source (no DC interference),
c. A site with both AC and DC interference – sketch in figure 1.

Instrumentation

The instrumentations used for quantifying and characterizing corrosion due to electrical interference include the coupon datalogger ICL-02 (MetriCorr) and the microvolt scale voltmeter from DONG (the DONGLog) – see figure 2.

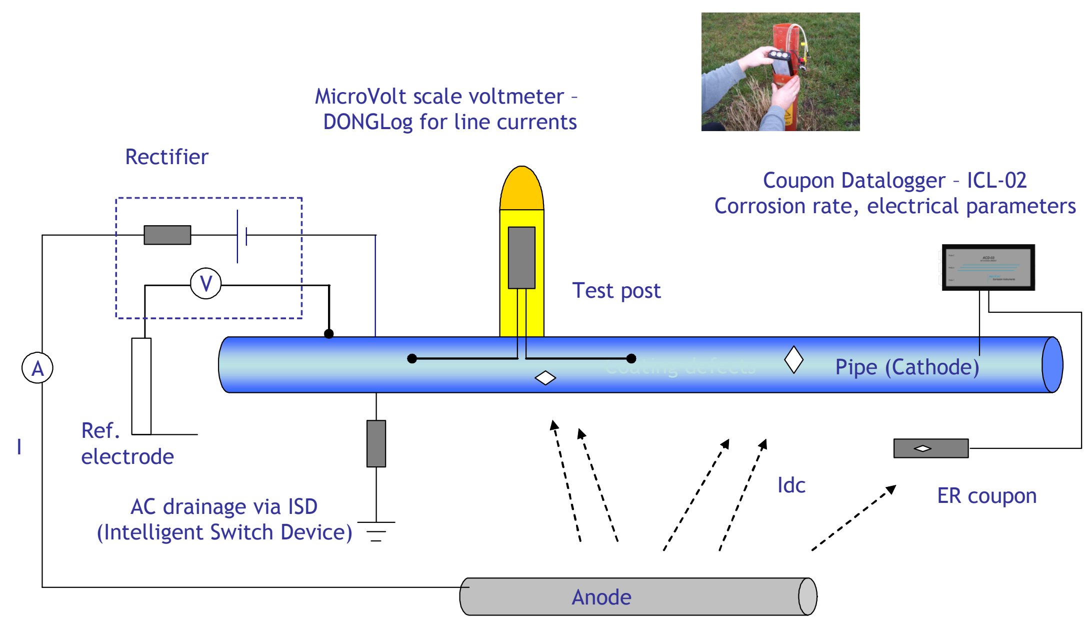


Figure 2. Instrumentations used for detecting and characterizing corrosion due to electrical interference.

The ICL-02 coupon datalogger is positioned in a test post and connected in between the coupons and the pipeline. A reference electrode is connected to the logger for voltage measurements. The logger measures characteristic quantities of the pipeline and the connected coupons:

- Pipeline AC voltage at the test position,
- Pipeline DC potential at the test position,
- AC current flow through connected coupons,
- DC current flow through connected coupons,
- Spread resistance of the connected coupons,
- Accumulated corrosion and corrosion rate on coupons (if coupons are of the ER type coupon).

The DONGLog line current datalogger is a two channel datalogger, one channel offering 0.1 μV resolution for accurate line current measurements, the other channel mV – V scale for potential measurements. The datalogger is capable of measuring up to 25 datasets per second with effective AC filtering capability, e.g. for effective off-potential measurements.

Field Trials – Case Stories

Detection and mitigation of DC interference corrosion

At one location, intensified measurements of the corrosion rate was established and the datalogger was programmed to acquire DC potential and –current every 5 seconds in 5 different 20 minutes periods throughout the day (02:00h, 07:00h, 11:00h, 15:00h and 19:00h).

For each of these 20-minute periods, the DC potential and –current can be plotted against time (figure 3). From the plot (in practice in a spreadsheet) the maximum, minimum, and average values as well as RMS and standard deviation were determined. In the same spreadsheet, the positive (anodic) and negative (cathodic) current measurements can be identified and directed to separate columns in the sheet, and based on this procedure, the anodic charge and the cathodic charge for each period of 20 minutes can be calculated.

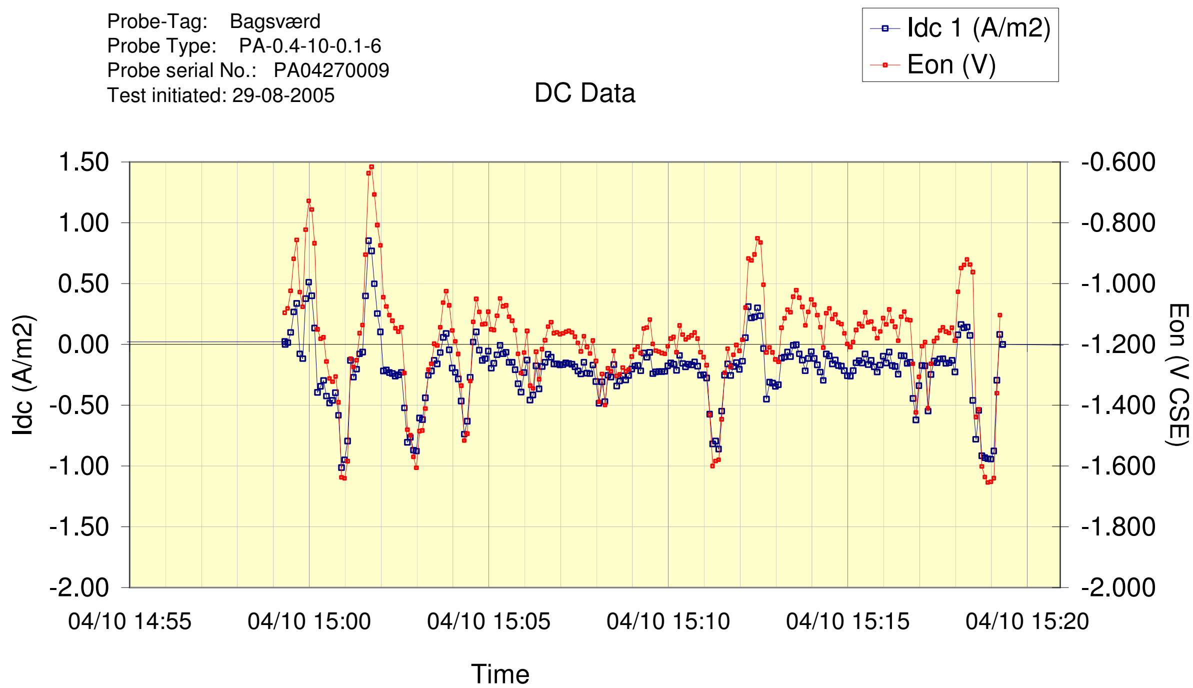


Figure 3. Example of a DC potential and –current plot throughout one period of 20 minutes around 15:00h.

From figure 3 is observed that both anodic and cathodic currents are present throughout this period. The DC potential fluctuates over a wide range both more positive and more negative relative to the -850 mV CSE cathodic protection criterion.

A full scale experiment with the pipeline rectifier was initiated[1]. The initial rectifier output current (around 50 mA) was gradually decreased once a week, and the corrosion rate and the intense 20 minutes DC current and potential measurements were realized at these mentioned 5 periods a day. Figure 4 shows the rectifier current output (dotted line) throughout a 5 week test period. Initial value 50 mA was decreased to 25 mA after a week, 10 mA after another week, then stepwise back to the 50 mA. The maximum, minimum and mean potential resulting from the 5 daily intense measurements are shown in the figure as well.

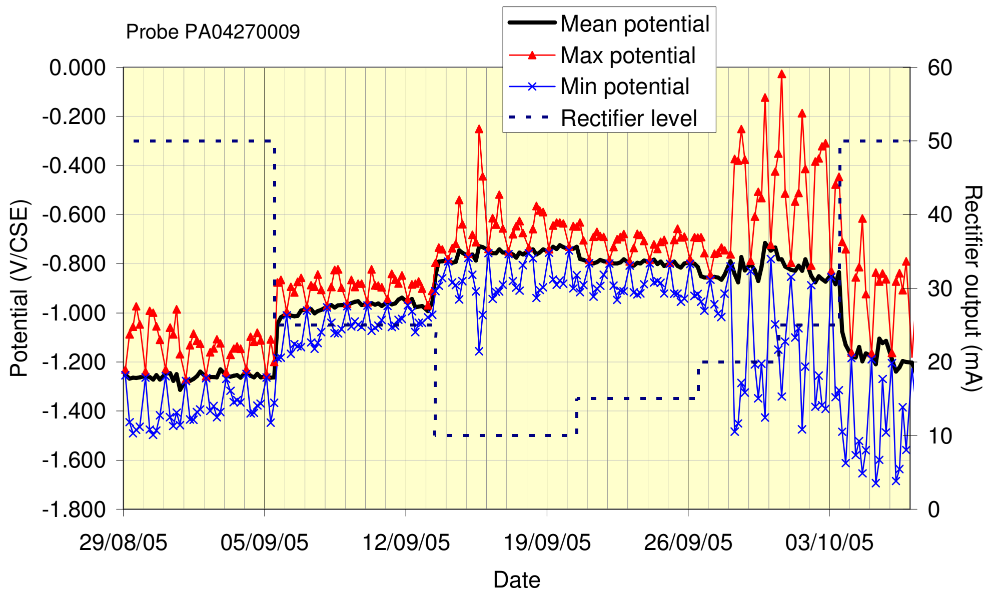


Figure 4. Rectifier output and max/min/mean potential detected during experiment with different rectifier output under DC stray current conditions.

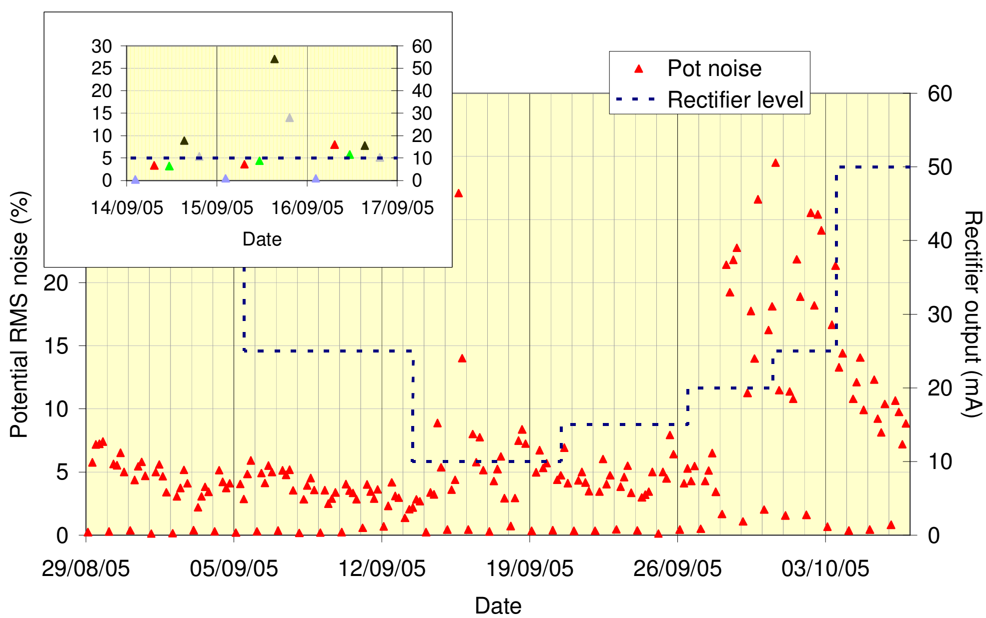
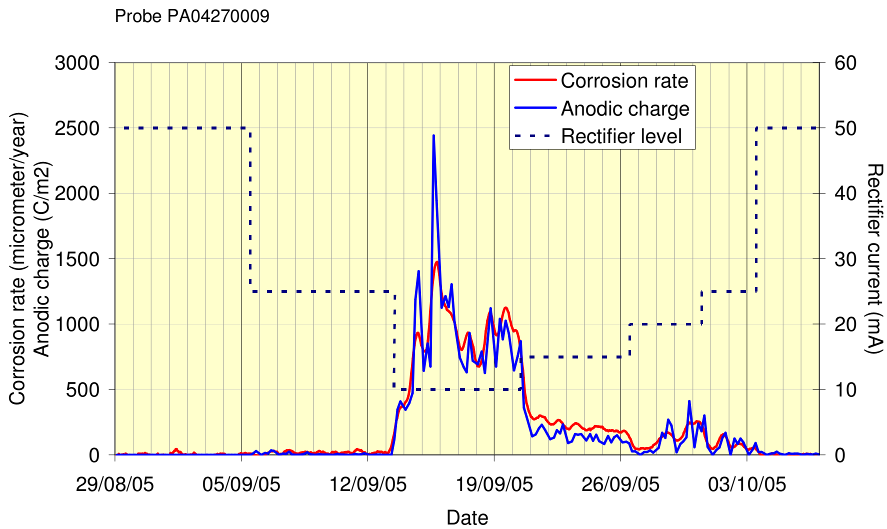


Figure 5. Potential RMS noise throughout the experimental period. The small graph illustrates the noise measured in the 5 daily periods for three following days, just to illustrate the low noise at night and increasing noise during daytime with traffic etc. Apparently, the noise is highest (in these periods) during the afternoon (black indications).

Figure 6 illustrates the resulting charge calculations. The lower figure is the cathodic charge released whereas the upper figure illustrates the anodic charge release. In the upper figure, the corrosion rate measured on an ER coupon is illustrated as well, showing a very good correlation with the anodic charge release.



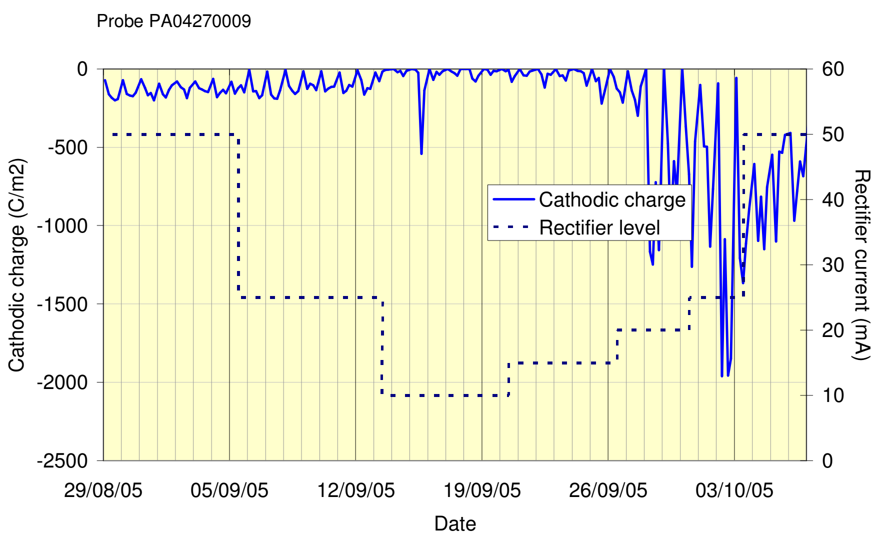


Figure 6. Comparison between the release of cathodic charge (lower) anodic charge and corrosion rate (upper).

Detection and mitigation of AC interference corrosion

This field trial has been presented at previous CeoCor conferences[2,3], however, illustrating well the AC corrosion mechanism and the impact of excessive CP. The trial results are shown in figure 7. The trial involved a pipeline with a constant 15 V AC combined with different levels of rectifier output. At first, the DC on-potential was adjusted to -1150 mV CSE (lower left). This caused corrosion to occur (upper left). Lower right graph shows the density of the DC current through the coupon. When corrosion rate increased above 500 micron/yr, the DC potential was adjusted to -850 mV CSE, and the corrosion stops. The AC current density decreases as well – although the AC voltage was 15 V constantly, indicating an increase in spread resistance.

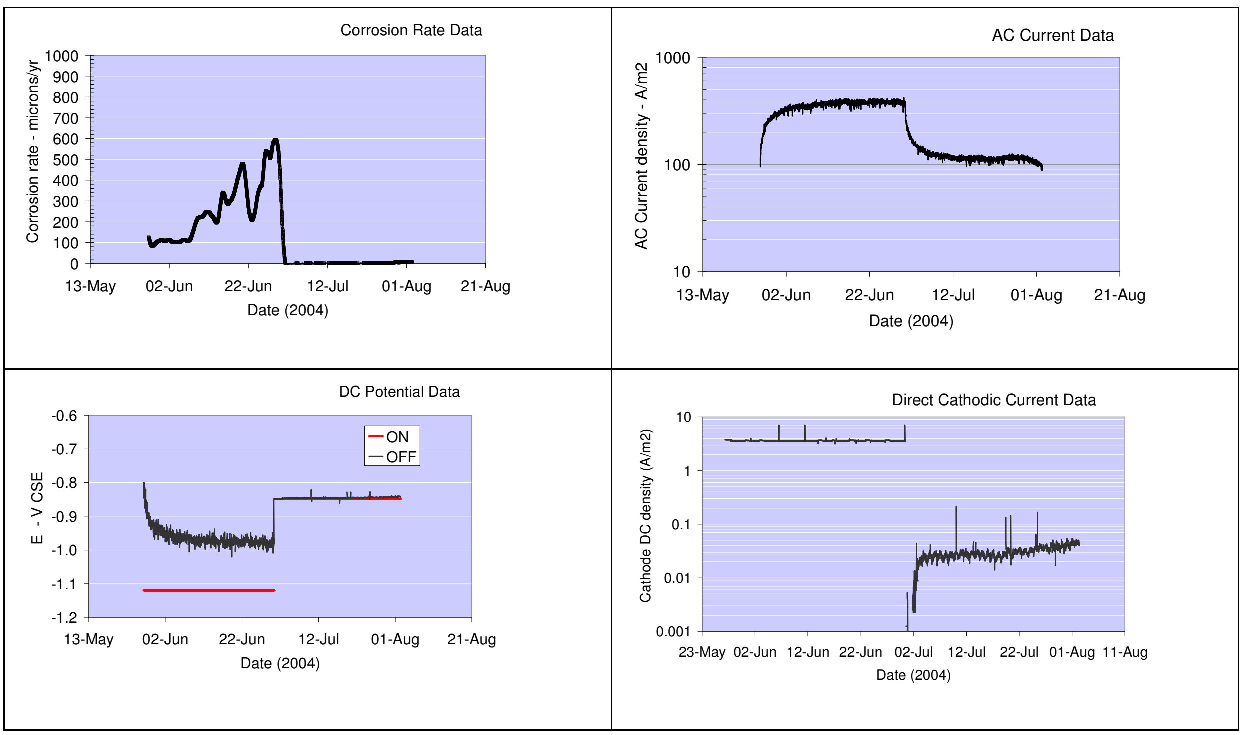


Figure 7. Example of elimination of the corrosion when cathodic protection level is lowered. Upper left: Corrosion rate throughout time. Lower left: DC-on potential, upper right: AC current density, lower right: DC current density.

The above observations illustrate the role of alkalization caused by excessive CP which in combination with a certain level of AC causes AC-influenced corrosion. This has been discussed in further details in previous papers[2,3].

Detection and mitigation of combined AC and DC interference corrosion

Returning at this point to the complex pipeline grit illustrated in figure 1, where both AC and DC interference is present. Figure 8 is an illustration of the ICL-02 data – the pipeline AC voltage and the ER coupon AC current density picked up during a period of a week at the test post positioned in point C, figure 1. Evidently, the AC voltage peaks at 12-13 V at the highest from midnight and about 6 hours ahead, corresponding high current transmission during the night hours. The density of the AC current flowing through the coupon follows the AC voltage as these quantities are connected through the spread resistance.

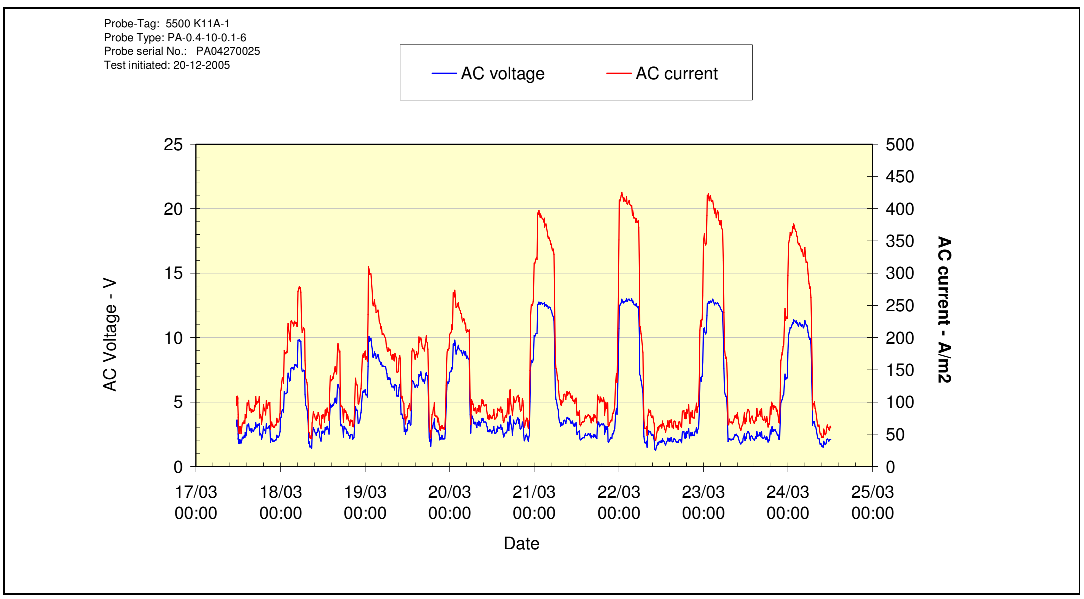


Figure 8. The pipeline AC voltage and AC current density flowing through a coupon positioned at point C (railway crossing) of the pipeline sketched in figure 1.

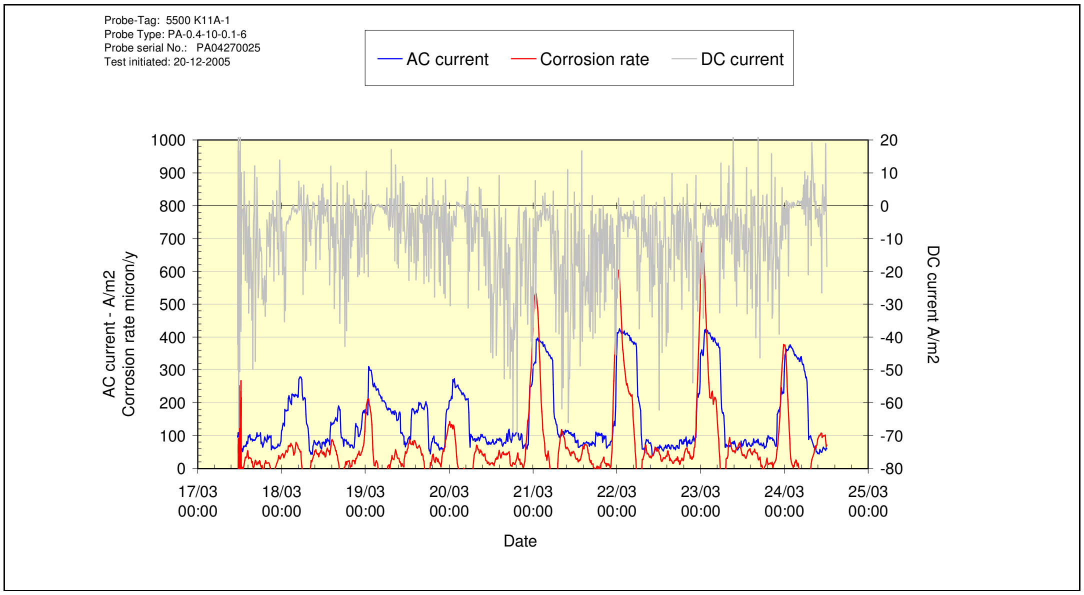


Figure 9. The AC and DC current density flowing through a coupon positioned at point C (railway crossing) of the pipeline sketched in figure 1, and the resulting corrosion rate.

Figure 9 shows the AC and DC current density flowing through the coupon throughout the period of interest, as well as the corrosion rate measured on the coupon. Large fluctuations are observed in the DC current due to the activity of the traction systems. At 01:00 o'clock, night time, this DC interference ceases and rests until around 06:00 o'clock (morning).

The corrosion rate due to the above AC / DC interference pattern increases at midnight along with the increase in AC current density, but ceases along with the silence of the DC noise one or two hours later.

Figures 10 and 11 show some results of the line current survey. Figure 10 is the potential measured by the DONGLog datalogger 25 times per second in a 20 minute period around 15:00 hour in the afternoon. The curves are all in the same phase. Figure 11 shows the corresponding line currents, which are – for the actual test post configurations and definitions of the CP manual of the pipeline – 180 degrees out of phase with the measured potentials. Similar trials performed at 02:00, 08:00 and 12:00 hour showed the same trend.

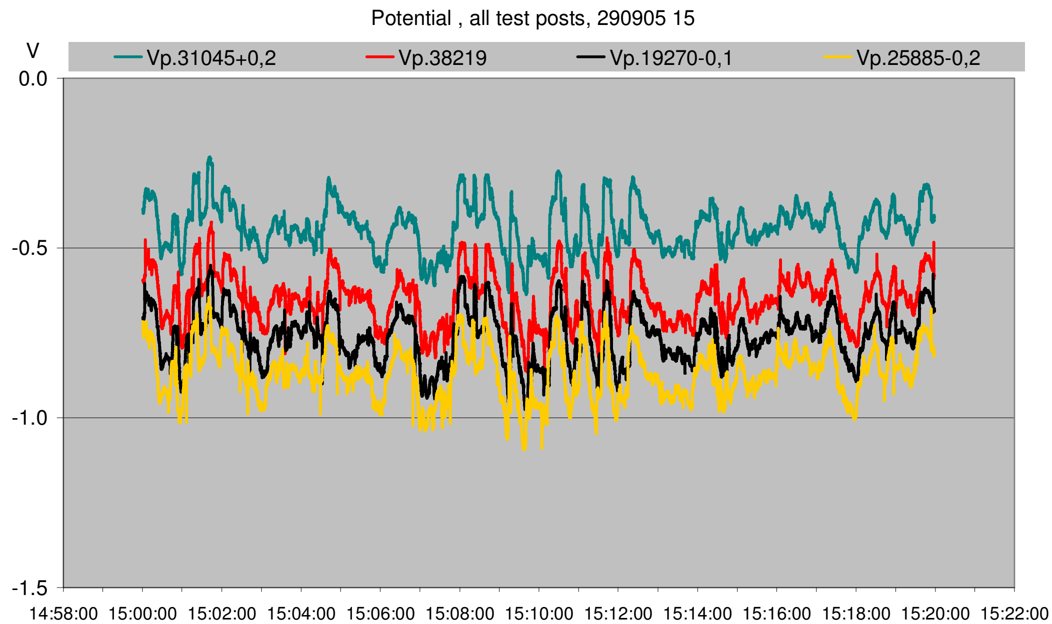


Figure10. Example of the potential measurement survey performed simultaneously in various test post around the post where high corrosion was found.

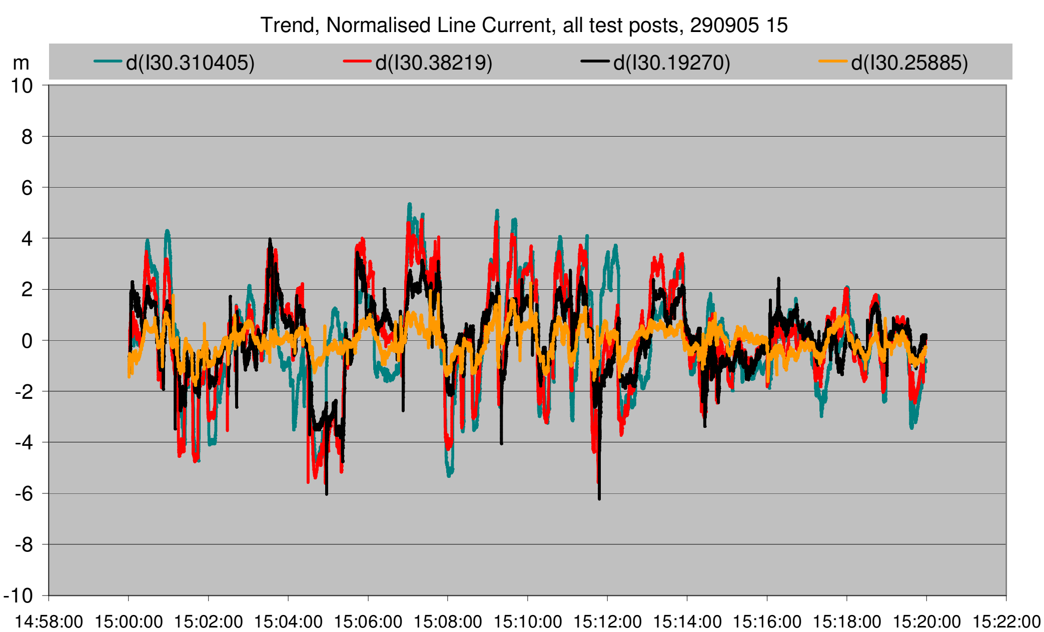


Figure11. Example of the line current measurement survey performed simultaneously in various test post around the post where high corrosion was found.

Discussion

The corrosion caused by the pure DC interference seemed in this case to be in nice correlation with the anodic charge released due to the interference pattern, and the corrosion could me entirely mitigated by dosing an adequately high CP.

In general, this correlation may not exist in any DC interference case, and examples have actually been observed (within this research group) where no corrosion occurred during anodic charge release. One would anticipate that the actual chemical environment as well as the specific interference pattern (perhaps being characterized by the quantities indicated in figure 12) will determine the degree to which a correlation between corrosion and released charge exist. Further studies on this are desirable.

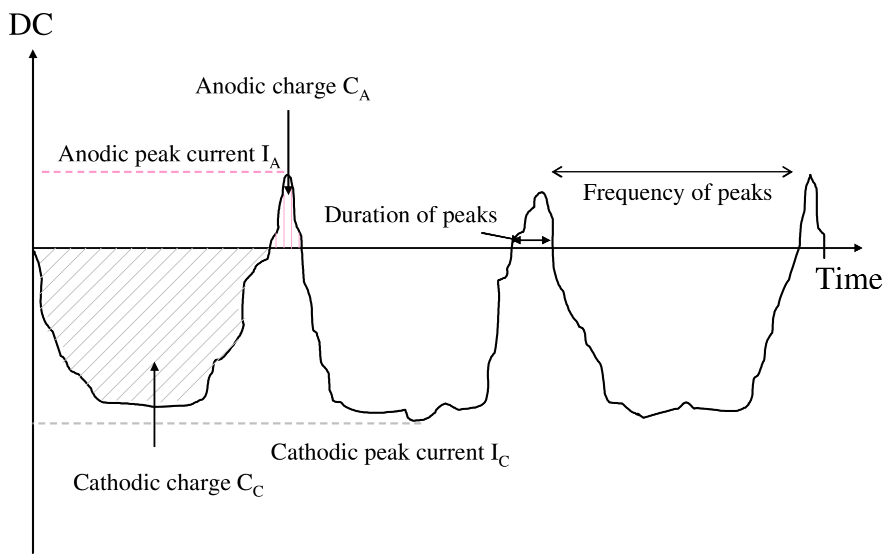


Figure 12. Schematic illustrations of suggested characteristic parameters of a DC interference pattern.

The corrosion caused by the pure AC interference is believed to depend on an alkalization of the environment close to the coating defect due to excessive DC, combined with the potential vibration caused by the AC – as stated and discussed in previous papers[1-3]. Numerous examples both from laboratory work and from field trials have shown this behavior. The AC corrosion phenomenon can be controlled / reduced by decreasing the CP level to an adequate minimum dose.

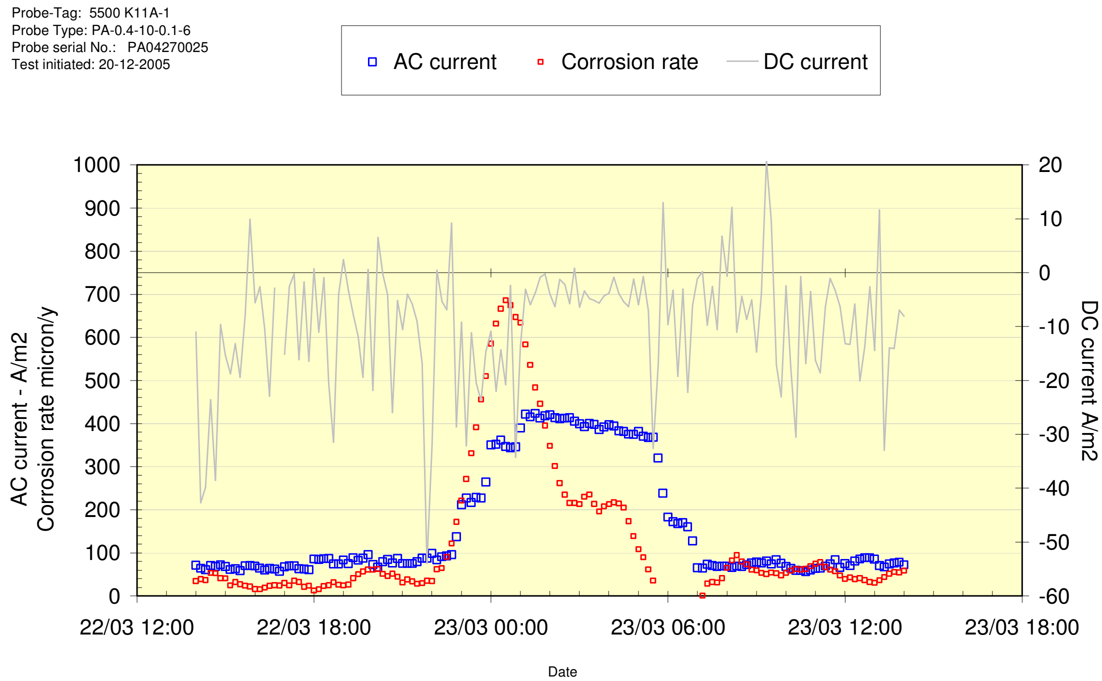


Figure 13. Close up of the AC and DC currents and the corrosion rate found during March 22^{nd} and 23^{rd}.

In the case of the mixed AC / DC interference condition, a careful study shows the remarkable and reproducible result that the cathodic charge released during DC interference will be sufficient to produce alkalization around the artificial coating defect of the applied coupon, and thus produce corrosion when adequate AC interference is added. Figure 13 is a close up of the AC and DC currents found during March 22^{nd} and 23^{rd} along with the corresponding corrosion rate. It is observed that the when the AC increases just before midnight, the corrosion sets in. When the DC interference is decaying along with the resting traffic at night, the corrosion decays as well, since alkalization caused by the DC interference cannot be maintained. Note that the corrosion rate has been assessed as a rolling average trend over 2 hours, leaving the time stamp (defined as being in the middle of the trend assessment period) a little bit ahead.

It seems that in the above combined AC / DC interference case, the corrosion could be avoided or reduced significantly if:

- The AC transmission was avoided or initiated some two hours later at night until after traffic had stopped,
- The AC was drained more effectively from the pipeline
- The DC noise pattern is reduced – i.e. the exact source of the DC interference could be located and disengaged.

The pipeline is very effectively mitigated from AC by proper grounding through AC discharge devices (Intelligent Switch Devices, ISD's), and further lowering of the AC would be quite a costly affair. Turning off the transmission of power is of course not an option. The corrosion will probably not be controllable by adjusting the CP level in a traditional manner, since lowering the CP to avoid AC influenced corrosion may produce corrosion due to the daily DC interference pattern. Hence, the best option seems in this case to be tracking the DC interference source and minimize it.

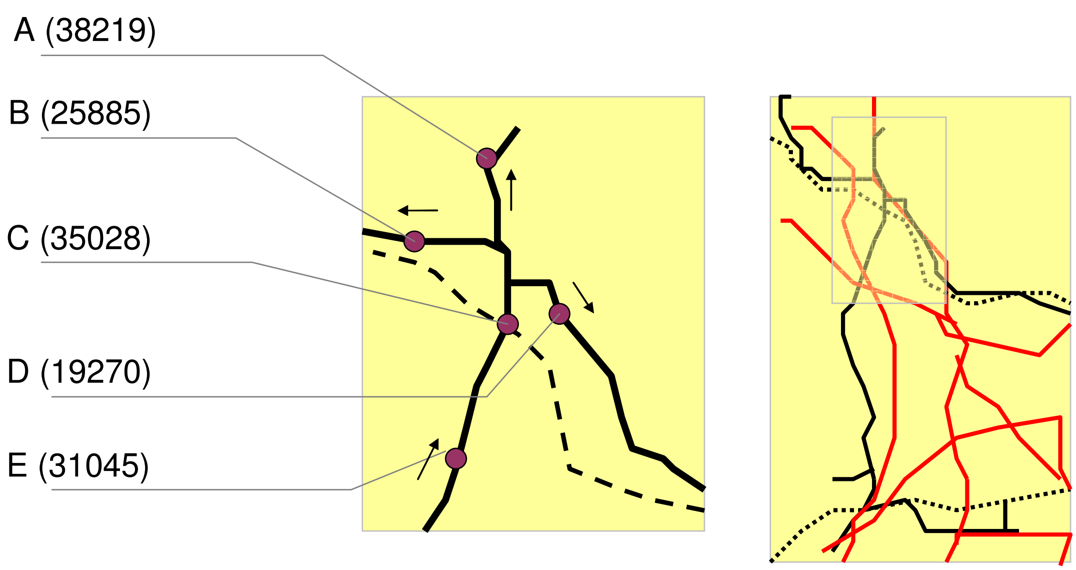


Figure 14. Determined directions of the line current when anodic potential displacement occurs.

From the line current survey, the directions of the line currents when an anodic shift in potential occurs can be determined – figure 14. In the present case, it seems that the origin of the DC interference was not – as somewhat expected – the crossing of the traction system in point C (where corrosion is found and the interference first registered), but further south of this point. Further such studies have shown that the southern traction system had been the course of corrosion risk and measures are undertaken to minimize the interference and hence the corrosion risk in such combined AC / DC interfered pipeline section.

Conclusions

- Field trials have been performed on pipelines interfered with pure DC, pure AC, and combined AC and DC.

- In the pure DC interference case investigated, the DC stray current corrosion correlated with the anodic charge released during the interference, and the corrosion could be controlled by maintaining adequate high dosage CP.

- In the pure AC interference case, the corrosion could be controlled by maintaining adequately low dosage of CP as expected and presented previously.

- In the mixed AC/DC interference case, the DC resulted from traction systems being active during daytime and silent at night, whereas the AC resulted from power transmission taking place exclusively during night time. The corrosion took place in a 2 hour overlap period from midnight and forth, and is believed to result from alkalization caused by the DC stray currents combined with the AC.

- Tracking of the DC interfering source was made by synchronized line current measurements / potential measurements made at 4 different test posts.

Acknowledgements

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References

1) AC / DC interference corrosion in pipelines, summary report, The Danish Gas Technological Centre, 2006.

2) L.V. Nielsen, B. Baumgarten, P. Cohn, Investigating DC and AC stray current corrosion – a report from the Danish activities, Proc. CeoCor 2005 (Malmö).

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