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On-site measurements of AC induced corrosion: Effect of AC and DC parameters

- A report from the Danish activities

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Abstract

Field research activities at AC corrosion monitoring stations along the Danish gas grit system have given successful on-line and real time measurements of AC induced corrosion risk using ER coupons and related instrumentation combined with logging of the electrical data of the coupons.

Studies have given further evidence for the alkalisation mechanisms, and it has been indicated in the field and further proven by laboratory soil box experiments that AC corrosion stops at low CP dosage and accelerates at high dosage of CP.

Field investigations at a site with alternating ground water level have shown that corrosion stops when the water disappears from the coupon's sphere, and therefore the presence of the groundwater seems crucial. Measurements in pure pore water have on the other hand shown that AC corrosion does not occur in pure water phase and therefore that the soil particles are necessary requisites in the build up of the hydroxyl accumulation at the coupon surface. Soil texture – grain size distribution - is of less importance.

The base (OH⁻) neutralising capacity of the soil has been investigated and apparently has no effect on whether or not AC corrosion develops – perhaps rather on the incubation period.

Investigations in laboratory soil boxes have shown that the spread resistance is a function of the OH⁻ concentration and decreases with increasing DC current (CP) dosage. By obtaining polarisation data, the high pH general corrosion domain has been identified as a result of the OH⁻ production by the CP.

Further activities will include establishment of yet a significant amount of field test stations with the purpose of generating complete evidence that AC corrosion risk will be minimised if the CP is kept low. The effect of DC stray currents on corrosion will be investigated under decreased CP conditions. These field measurements will be sustained by controlled soil box experiments.

Intelligent pigging of the Gastra F-E pipeline has been scheduled with the purpose of evaluating if the critical AC corrosion conditions found at coupons have actually developed attacks in the pipe.

Introduction

Research in Denmark on AC corrosion has been going on for several years. Both transmission and distribution companies are nowadays joining in a coordinated effort to establish mechanistic/qualitative- as well as quantitative information that can be used for monitoring and mitigation strategies. Devices for mitigation and on-line monitoring have been developed and employed. The activities cover both field studies involving various measurements performed using (ER and traditional) coupons connected to the pipe, soil chemical and physical analysis, and modelling laboratory experiments performed in soil boxes.¹⁻⁶

Regarding mechanistic studies, the activities joins up behind collecting evidence for the alkalisation theory that has emerged and evolved since (as far as these authors are aware of) first presented by Stalder et al.^{7,8} Hydroxyl ions produced from the electrolysis by cathodic protection current accumulates in the near surroundings of the coating defect (figure 1) and the combined action of potential vibration caused by the AC and adequately high pH induces corrosion with high penetration rate despite (or even enhanced by) cathodic protection measures.

At elevated pH, it is suggested that the potential vibration in between the immunity and passivity region of the Pourbaix diagram (figure 2) may cause corrosion due to different time constants associated with iron dissolution (fast) and subsequent formation of passive film (slower), so that iron dissolution would be the net result of a 50 Hz vibration. At even higher pH (14) the formation of dissolved HFeO_2^- may stabilize corrosion at a very high penetration rate.

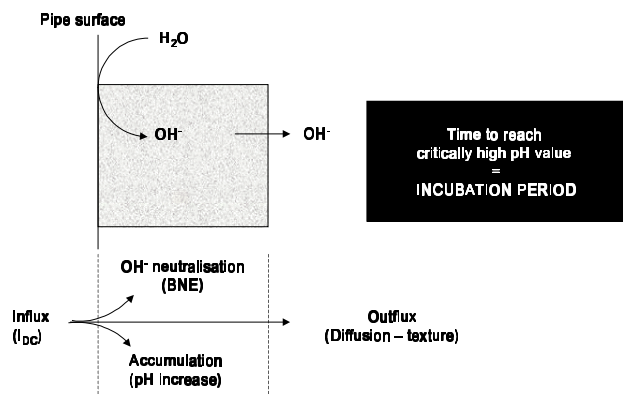


Figure 1. Mass balance schematics for OH^- ions produced by CP at a coating defect.

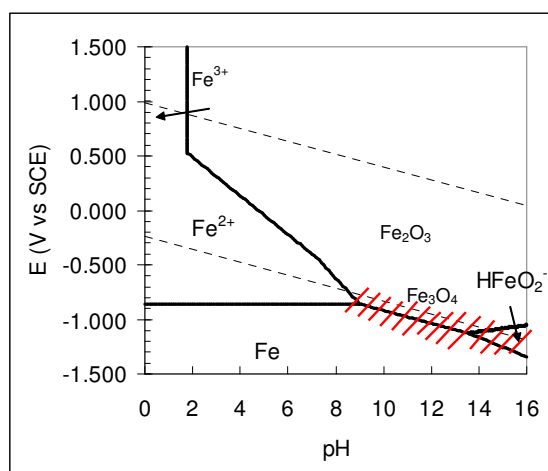


Figure 2. Pourbaix diagram showing unsafe region with respect to AC corrosion.

The electrical equivalent diagram of an AC infected pipeline with CP may be sketched as in figure 3.¹ The electrochemical conditions as well as the CP rectifier produce electromotive forces. E_{01} and E_{02} are equilibrium potentials of the electrochemical processes that are active at a coating defect (e.g. ferrous corrosion and hydroxyl production). VB1 and VB2 are diode-like components and represent activation kinetics of involved processes. Warburg impedance components (W) are coupled to indicate influence of diffusion limitation. R_s (spread resistance)

denotes the ohmic resistance from pipe to remote earth, and C is the interfacial capacitance. The ac generator refers to the AC induced on the pipe by paralleling high-voltage power line.

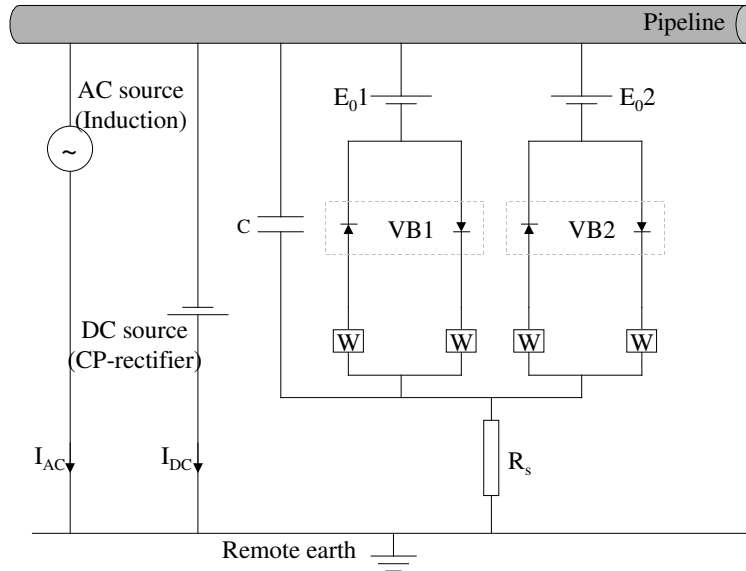


Figure 3. Equivalent diagram for ac corrosion.

It is well recognized that small rather than large coating defects are susceptible to ac corrosion since the spread resistance (in $\Omega \cdot m^2$) associated with the defects increases with increasing area¹:

$$R_s = K \cdot \rho_s \cdot d \quad (\Omega \cdot m^2) \quad (1)$$

where K is a constant depending on the geometry of the defect, d is a measure of the extension of the defect, and ρ_s is the specific resistivity of the local soil environment right in the coating defect. Since the spread resistance directly determines the magnitude of the AC current flowing out of a coating defect at some DC voltage, and since the ac current both influences the amount of potential vibration and (probably for the same cause) dc kinetics, the spread resistance is a key parameter – which is also well recognized throughout the society.

This paper gives examples of results from the Danish studies primarily in relation to above identified mechanistic issues.

Experimental

Today 20-25 test stations throughout Denmark are part of the research and monitoring of AC corrosion (figure 4). These stations have received special attention regarding soil analysis, and ER coupons (figure 5) have been installed parallel to traditional coupons (which are also installed in numerous other locations). Currently, 40-50 other stations are under installation according to activity plans described in annex 1. ER coupons have as a standard element a $2 \times 20 \text{ mm} = 0.4 \text{ cm}^2$ size to simulate a small coating defect. Some elements have $3.3 \times 33 \text{ mm} = 1 \text{ cm}^2$ size. Functionality of the instrumentation has been described elsewhere.^{5,6}

Coupons are connected via 10Ω resistors to the pipeline. Spotwise measurements of the electrical parameters as well as the accumulated thickness reduction of the coupons can then be collected.

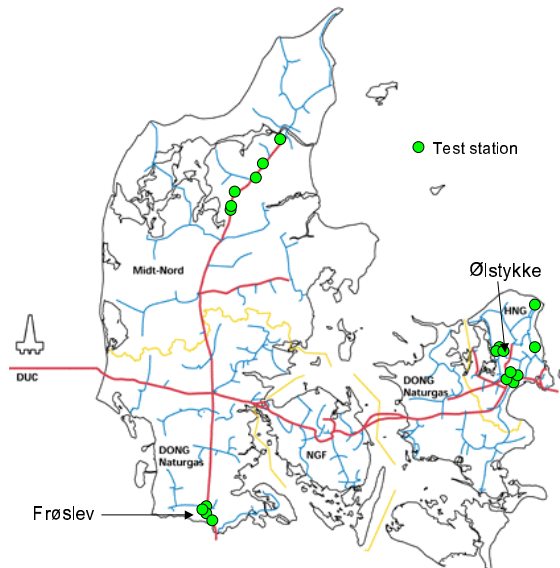


Figure 4. Test stations for AC corrosion monitoring and research activities.



Figure 5. ER coupon for corrosion rate measurements.

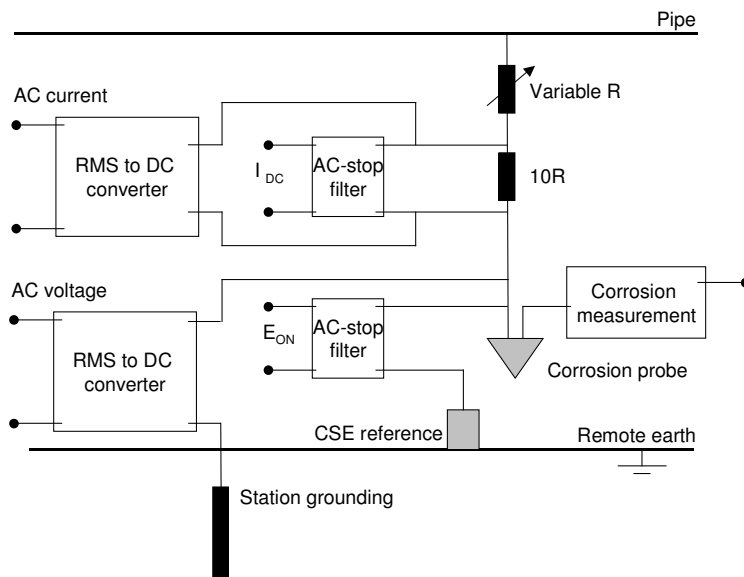


Figure 6. Configurations at the part of the test stations that are selected for intensive measurements.

During intensive measurements, an instrumental setup allowing for recording of AC and DC parameters as well as real time corrosion measurements is established (figure 6).

The soil analysis includes the parameters shown in table 1. Texture of the selected soil types is visualised in figure 7.

Besides these parameters, a procedure has been initiated by which soil is sampled from different depths (0 cm = ground level to position of the coupon), dried, and analysed for the conductivity according to standard procedures. A well-defined portion of dried soil whereto is added a well-defined portion of distilled water (ratio w/w = 2:5), shaken for 24 hours, and the conductivity measured in the solution. Figure 8 shows an example of conductivity-depth curve for a few locations.

Table 1 – Soil characterisation.

Chemical Parameter	pH (H ₂ O)	pH (CaCl ₂)	BNE* cmol/kg	CaCO ₃ %	C %	Na+ cmol/kg	K+ cmol/kg	Mg ²⁺ cmol/kg	Ca ²⁺ cmol/kg
Frøs - 0.9	7.2	6.3	1.5	0	0.22	0.51	0.04	0.05	1.42
Ølst. MR	8.1	7.3	2.0	2	1.2	1.40	0.00	0.50	31.70
Texture	<2µm	2-20µm	20- 63µm	63- 125µm	125- 250µm	250- 500µm	500µm- 1mm	1-2 mm	>2mm
Frøs - 0.9	2	1	1	2	17	33	34	10	5
Ølst. MR	6	4	8	18	22	13	9	13	13

*Base neutralising effect stating the quantity of hydroxyl needed to rise pH to 10. 5 different samples of the soil is shaken in different concentrations of NaOH solution for 24h, pH is measured to establish titration curve.

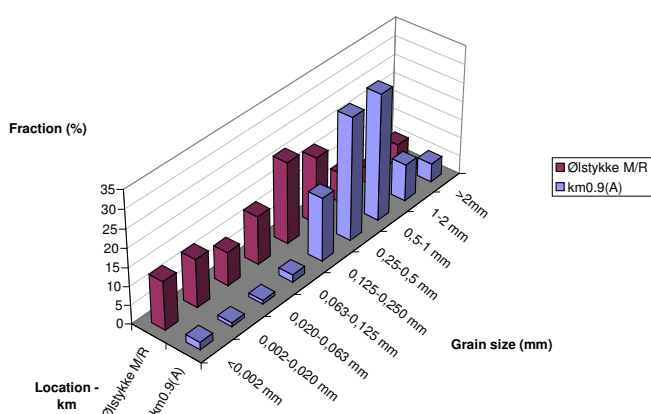


Figure 7. Texture graph of the data from table 1 (Frøslev and Ølstykke).

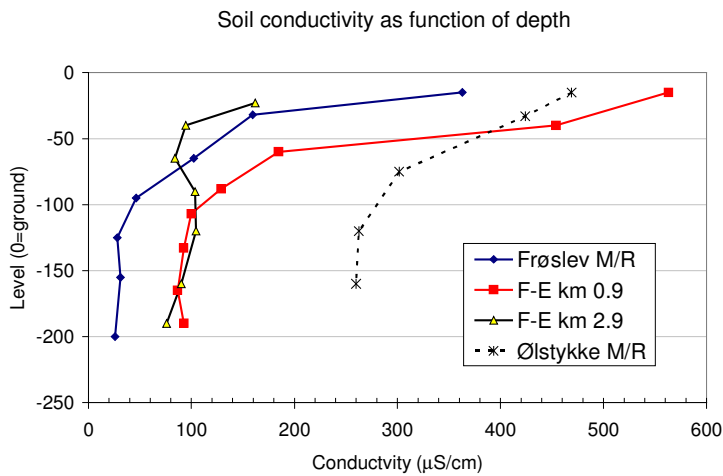


Figure 8. Soil conductivity as a function of depth (various examples).

The (main) difference between local soil conductivity measurements performed by adding distilled water to a dried sample and local Miller soil box 4 point Wenner measurements performed on site is that when performing the measurements on site, the humidity of the soil this particular day is a major conducting factor, whereas when drying out the soil and wetting afterwards, the parameter becomes more descriptive of the capability of the soil if totally wetted by groundwater. The shape of the curves (depth-conductivity) all show highest conductivity just beneath the surface and then decreasing with depth until a fairly stationary level is reached.

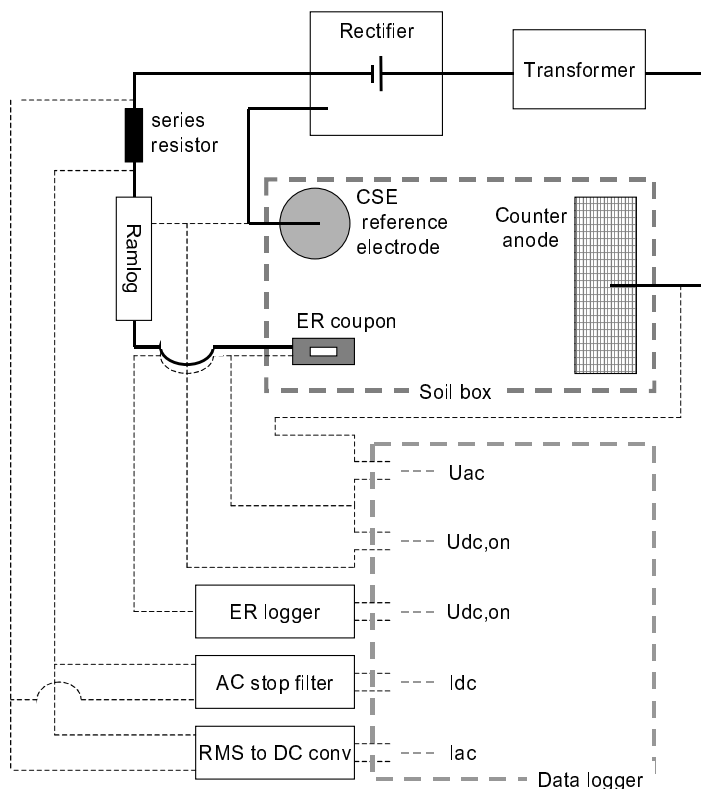


Figure 9. Circuitry for laboratory soil box experiments.

Laboratory studies in soil box environments under controlled AC/DC conditions are applied as supplement to the field observations. Figure 9 shows a typical laboratory setup involving three electrodes buried in the soil box. As the working electrode, ER coupons are usually employed

to give direct information on the corrosion condition. A rectifier and a transformer apply DC and AC current to the coupon via an anode, and an CSE is used for reference. A Ramlog correal recorder is applied for potential vibration measurement, and a datalogger collects AC and DC parameters (voltage, current).

Presentation and discussion of selected results from the field studies

From the spotwise measurements at the established test stations, sites with particular capacity of causing AC corrosion have been selected for intensified measurements. Some results will be shown for two such sites. The first is the Frøslev site located in the south of Jutland nearby the German border (figure 4) along a transmission line owned and operated by Gastra A/S. The second is the Ølstykke site at a meter & regulator (M/R) station at the HNG owned and operated distribution line located in proximity of Copenhagen (figure 4).

The Frøslev site was established 0.9 km north of an M/R station at which initial spotwise measurements showed zero corrosion on 12 ER coupons buried in 1.4 meter depth. Spotwise measurements at the selected site 0.9 km further north showed very high corrosion although the chemistry and the textural characteristics of the two sites were apparently identical. The AC voltage and DC on-potential of coupons at each site were controlled by the same pipeline and identical. However, spread resistances of the coupons at the M/R station were far higher than these of the coupons at the corrosive site 0.9 km away. At the corrosive site, the initial spread resistances were $0.12 \Omega \cdot \text{m}^2$, after which a further decrease occurred to around $0.04 \Omega \cdot \text{m}^2$. The spread resistance of the coupons at the non-corrosive site were around $10 \Omega \cdot \text{m}^2$.

All probes established at the km 0.9 (corrosive site) were corroding very fast (mm^3/yr), and several reproductions were made. However, quite suddenly the corrosion decayed and stopped. At this time, it was decided to establish a monitoring of the ground water level at the site, and compare this with the depth to which the probes were positioned. Figure 10 shows the development in the groundwater level monitored over a 18 months period. The positioning of the probes and the time of installation are plotted in as well. As observed, the ground water level varies within a spring layer of 1 meter, and the corrosion measurements showed that the corrosion stopped when the probes became dried out.

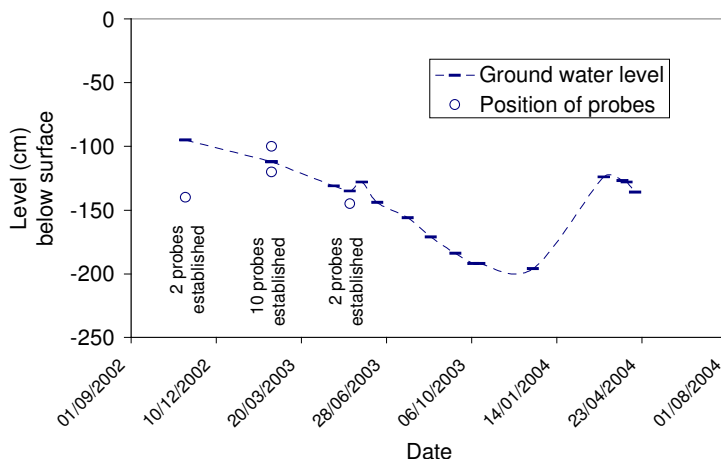


Figure 10. Ground water level seasonal variation at the corrosive test site F-E km 0.9.

Corrosion measurements were initiated also on probes exposed in the pure soil solution in an established well. On such probes, although treated exactly identical with regard to pipe connections, no corrosion could be identified. Although no careful analysis of the water was made and therefore no thorough comparison between the pore water and the open water of the well has been conducted, it was anticipated that the free water was in good chemical equilibrium with the pore water. Therefore, this difference in corrosion behaviour was taken as a strong indication that critical environment for AC corrosion cannot be formed in open water; some solid phase capable of immobilising the water is necessary.

During the period with lowering of the ground water level, ER coupons were inserted deeper into the sediment (below the present ground), and as a consequence, the coupons corroded gladly. At the original test station (M/F Frøslev where the spread resistance was very high), it was investigated that the ground water level was at least 1 meter lower than at the corrosive F-E 0.9 site, and the high spread resistance was due to the fact that all probes had been exposed in perfectly dry gravel. Accordingly, ER coupons were mounted to a 3 meter depth (below the ground water level for certain) and it was expected that these coupons would readily corrode. At present, they have been exposed for a year (still of course with CP and AC as conducted by the pipe), and no corrosion had yet occurred. To explain this behaviour, samples of soil were taken and the conductivity of the soil was determined as defined in the “experimental” section. A few relevant results have been shown in figure 8. These roughly show that the conductivity of the soil below 1½ meters depth is rather constant, but around a factor of 6 lower than the conductivity of the soil present at the corrosive F-E km 0.9 site. An explanation for this difference may be the lack of nutrients and de-icing salt at the M/R station, as the F-E 0.9 site is located at a borderline between a road and an agricultural field. However, no differences in the Na^+ ion concentrations were found so this remains un-investigated.

This above information tricked the question of whether the grain size of the soil – i.e. the soil texture – plays a role in the extent to which the soil is capable of immobilising the water (refer to figure 1 for the mass balance of produced hydroxyl ions). Therefore textural analysis was included in the soil analysis procedures (table 1). Experiences have shown in this context that corrosion can be provoked in both coarse grained gravel-like soil as found at the corrosive Frøslev site as well as at sites with more fine grained clayish types of soil, as well as mixtures as for the Ølstykke site (see figure 7).

In conclusion to the above – it seems that ground water has to be available, but in a pure condition the accumulation of OH^- ions is not possible. The solid soil phase therefore seems to be a crucial requisite, but the texture of the soil seems not to be important. The conductivity of the soil (probably in conjunction with the magnitude of the ac voltage) determines whether the AC corrosion mechanism is tricked.

A similar row of questions could be set up with regard to the OH^- neutralising effect of the soil, i.e. the buffer capacity when “titrating” with hydroxyl. The CP system is regarded as the OH^- donator, and the capacity of the soil to withstand this donation without increasing its pH is defined as the BNE value (base neutralising effect), see figure 1. A procedure has been developed in collaboration with the Geographical Institute at the University of Copenhagen by which the BNE value is defined. A sample of soil is dried and divided into 5 grams fractions. 15 ml solution of different (increasing) concentrations of NaOH is added to each fraction, and the samples are shaken for 24 hours before the pH is measured in the water phase. The amount of NaOH (cmol/kg soil) needed to create a pH of 10 is taken as the BNE value. This analysis applied on a wide range of the Danish types of soil show that 80% is within 0 and 5 cmol/kg,

and the peak is around 16 cmol/kg. Corrosion has been found to occur regardless of the BNE value in the above defined region (data in table 2 show that the sites Frøslev and Ølstykke are both in the low end), and the BNE value may rather influence the length of the incubation period during which the soil adjacent to the coating defect is being adequately alkalisied.

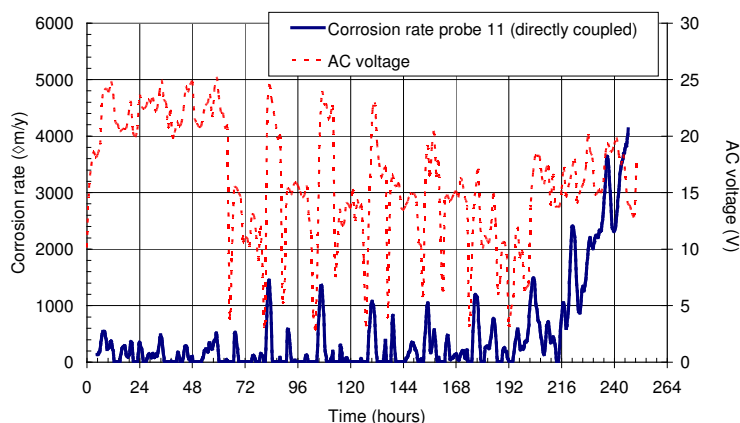


Figure 11. Comparison of the AC voltage and the corrosion rate throughout an experimental period at F-E 0.9 site.

Figure 11 is an example of the corrosion rate throughout time of an ER coupon connected to pipe and the correspondent ac voltage. The AC voltage is observed to alter throughout the day in a pattern conducted by the amount of current transmission in the overhead power line. The corrosion rate is observed to show some dependency of the AC voltage throughout the whole period, however, a steady increase in corrosion occurs after some period of incubation (around 8 days). Until this day, the corrosion decays when (and sometimes even before) the AC voltage diminishes.

Figure 12 and 13 are examples from M/R Ølstykke. Here, the ER coupon was connected to the pipe via resistors that could be changed in values so that this resistor added to the spread resistance causing diminishing of the AC voltage experienced by the coupon in comparison with the pipe.

In period 1, the coupon was directly coupled experiencing the full AC voltage and the coupon corrosion rate peaks at 2 mm/yr at 10 V AC. The on-potential in this period was rather negative (some -1400 mV CSE). In period 2, the coupon was connected via 800 ohm and the AC voltage as well as the corrosion rate decreased significantly. In period 3, the series resistor value was increased and no corrosion occurred. In period 4, the resistor was exchanged with a 5 mF capacitor to experience the full AC of the pipe (though not higher than 8 volts in this period) whereas the CP is blocked and the DC potential approaching its OCP, and no corrosion was registered. In period (5) the coupon was disconnected and corrosion increased throughout this period of time (actually rather high, up to 0.3 mm/yr). In the proceeding 6th period where the coupon was directly connected once again, the corrosion rate builds up again. In period 7, the rectifier DC potential was adjusted to give a very mild cathodic protection and corrosion decays.

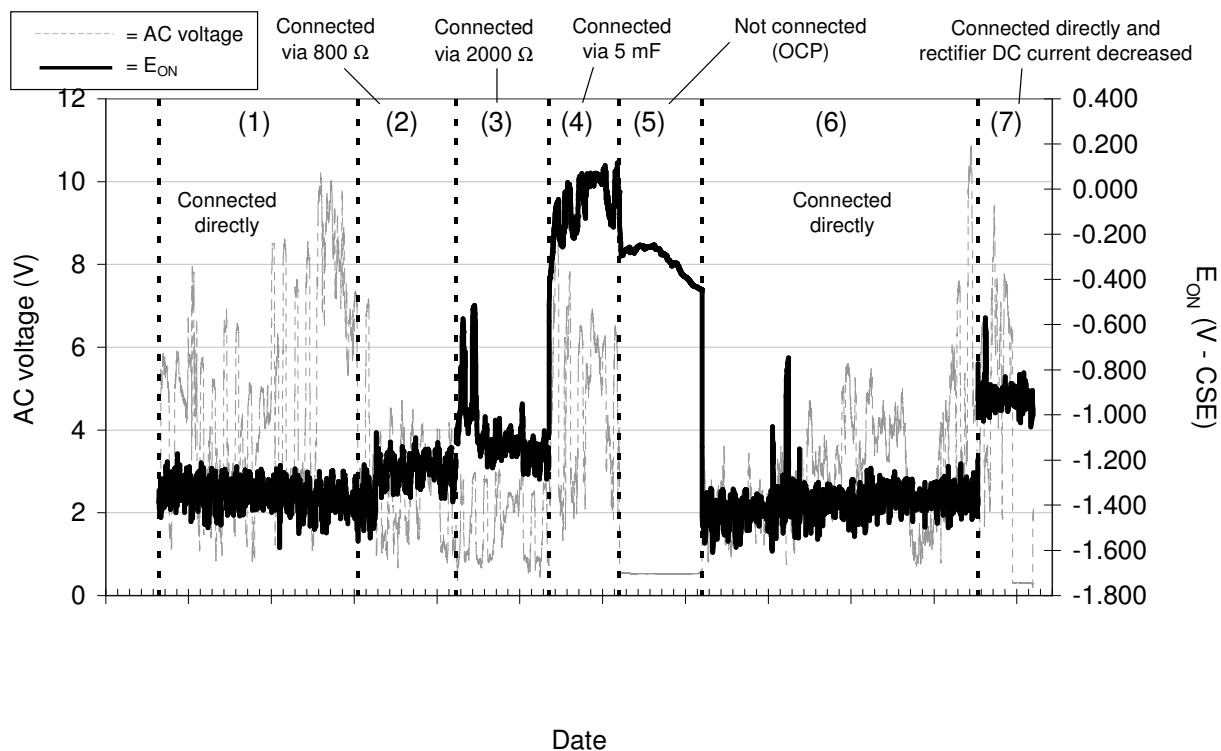


Figure 12. AC voltage and DC on potential throughout a test period at M/R Ølstykke.

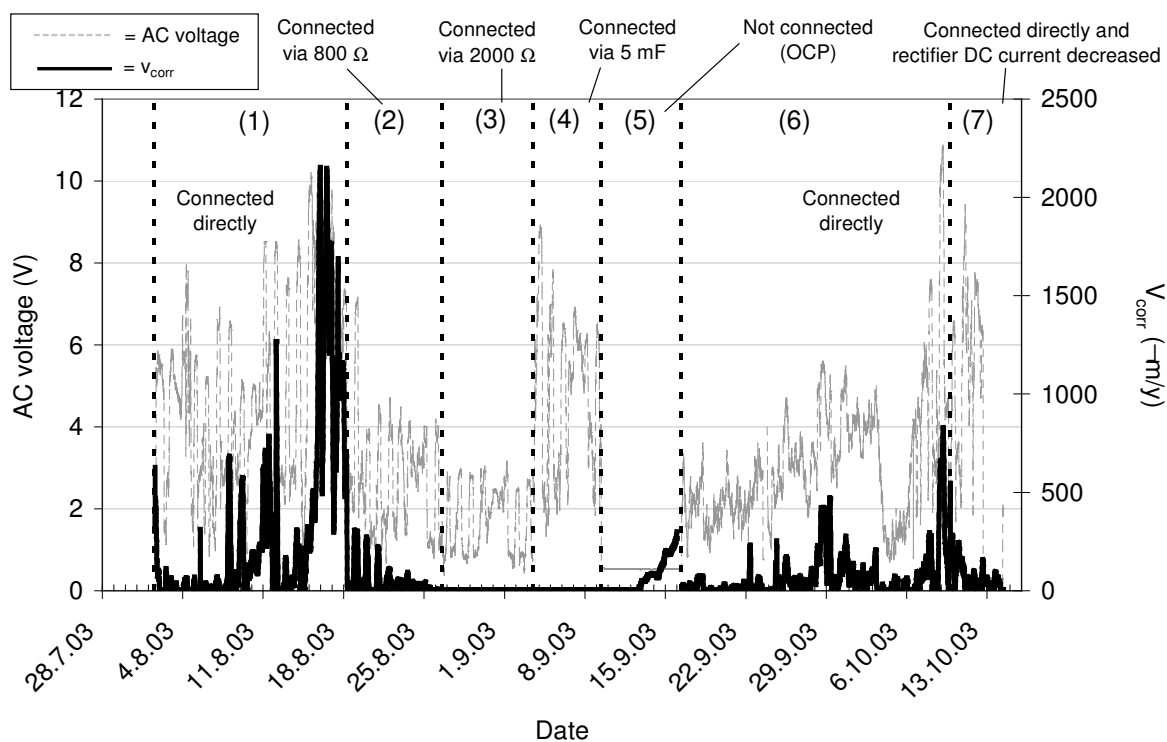


Figure 13. AC voltage and corrosion rate throughout a test period at M/R Ølstykke.

Some experiences from laboratory soil box experiments

In order to further describe the impact of the DC level on AC induced corrosion a controlled soil box experiment was initiated with an experimental setup as illustrated in figure 9. Inert quartz sand was used as the water demobilising particle phase whereas a dilute solution of NaCl was used as the electrolyte-solution. The molarity of the NaCl solution was adjusted so as to reach an initial spread resistance under OCP conditions on the ER coupons as experienced at the corrosive Frøslev site ($0.12 \Omega \cdot \text{m}^2$). The vario transformer was adjusted to give 15 V AC on the coupon, and this value was kept throughout the experimental period (some few adjustments were made on a daily basis on the vario transformer in order to keep this voltage).

The first challenge – to establish the corrosion after some period of incubation – has manifested itself in the on-potential established on the coupon. Figure 14 shows the corrosion rate throughout time, and as observed no corrosion occurs for the first 28 days. In this incubation period, the on-potential was changed rather un-motivated (indicating a rather impatient operator) from moderate (-1250 mV “on” corresponding -920 “off”) via low CP (-850 mV CSE “on”) to the severe -2200 mV CSE “on”, which corresponds -1100 to -1200 mV “off”, which was kept until corrosion sets on. After 10 days with high CP, the corrosion increases but finds some steady state condition for some days at a low rate (10 micron/yr). After 37 days, the corrosion starts increasing again, and no doubt seemed to exist that the scenario with incubation followed by corrosion had been re-produced from the field. After 48 days, the corrosion rate exceeded 120 micron/yr, and for the purpose of studying the particular effect of the DC potential, the CP was decreased to -850 “on” (still 15 V AC), and the corrosion decayed. Subsequent alternations with a few days interval in DC potential between -850 and -2250 mV was made in order to study the systems reaction in this balancing on the edge of AC corrosion. As observed from figure 14, the corrosion can be entirely controlled by decreasing CP. The recorded AC current density appears from figure 15. A steady increase in AC current density occurs after heavy CP is applied (around day 16), indicating a steady decrease in spread resistance. The development in spread resistance calculated by the fraction U_{ac}/I_{ac} is observed in figure 16. The spread resistance so calculated seems to decrease as the coupon-close environment alkalis. The DC off potential has been calculated as the on-potential minus the $I_{dc} \times R_s$ drop and shown in figure 17. As observed, the severe CP on-condition (-2250 mV CSE) corresponds between -1100 and -1300 mV CSE (off) depending on the actual magnitude of the IR drop.

The last days of the experiment (days 57 – 60) were utilised to characterise the difference between the corrosive and the non-corrosive condition. Figure 18 shows DC polarisation curves obtained at a time corresponding an active corrosion and high dosed CP. The polarisation curve was prepared by stepwise changes of the on-potential while AC voltage 15 V was still supplied. By changing in steps the on-potential (from low CP to high CP) and noting AC current and DC current, the DC off potential could be calculated as described above, involving the calculation of the spread resistance. This spread resistance is shown for the same DC current values in figure 19. The same procedure as described here was employed 1 and 3 days after decreasing the CP to a mild condition (-850 mV). Figures 18 and 19 show the behaviours of both DC polarisation and spread resistance.

Regarding the polarisation behaviour, the obvious feature in the corrosive (high alkaline) environment is that the dc current turns positive at -1000 mV, which is probably an identification of the high pH corrosion domain of the Pourbaix-diagram (figure 2).

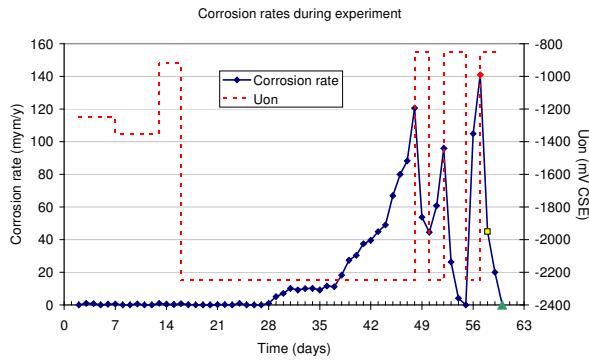


Figure 14. Overview of the DC on-potential throughout the experimental period as well as the corrosion rate measured on the ER coupon.

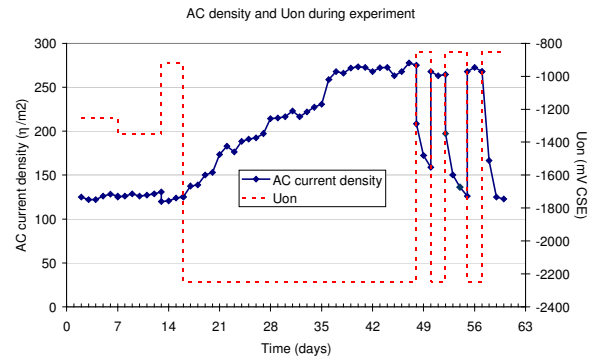


Figure 15. DC on-potential and AC current density on the ER coupon.

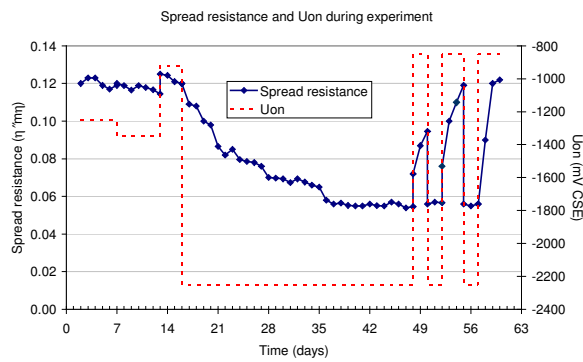


Figure 16. DC on-potential and spread resistance calculated as U_{ac}/I_{ac} .

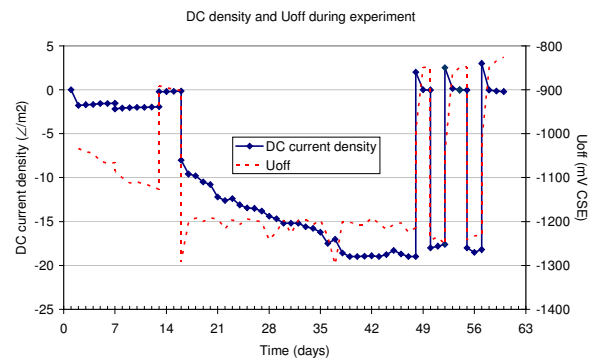


Figure 17. DC current density and off-potential calculated as the on-potential subtracted by spread resistance $\times I_{dc}$.

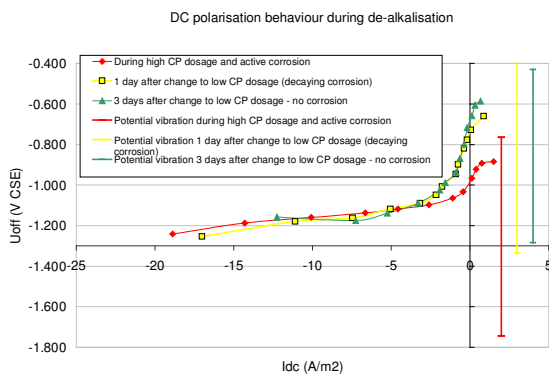


Figure 18. Polarisation curves during de-alkalisation after last shift to mild CP.

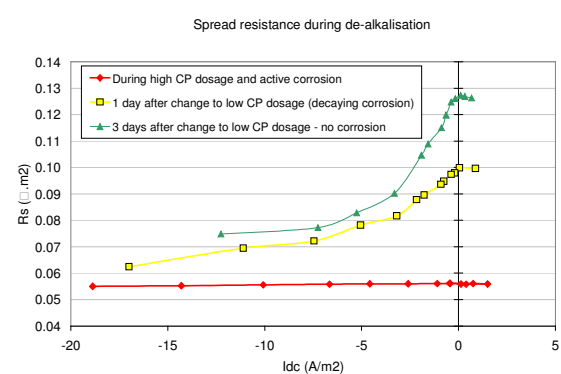


Figure 19. Calculated spread resistance as a function of the DC current during de-alkalisation.

The curve run one day after the change to the mild CP condition (still some corrosion occurring) shows a transition between anodic and cathodic DC current at a higher (more anodic) DC potential (-700 mV) and the curve run three days after show another shift in the potential where the current changes from anodic to cathodic. In figure 18, the potential vibration measured by Ramlog correal recorder has been plotted as well.

Figure 19 showing the spread resistance during the uptake of the polarisation curve gives some interesting indications. The spread resistance seems to be constant and low during the curve made under the heavy CP-condition. When CP is weakened and the OH^- allowed to diffuse away from the surface, the spread resistance increases, however, when the cathodic dc current is increased during the scan, the spread resistance seems to lower again and asymptotically approaching the low spread resistance value existing in the high alkaline environment.

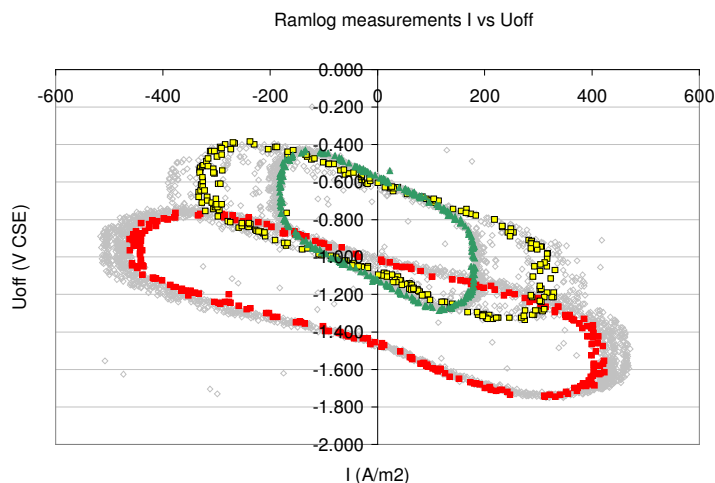


Figure 20. Ramlog correal recordings during the de-alkalisation.

Figure 20 shows the Ramlog curves obtained under the three above identified conditions. The CP is observed to control position of the centre of the curve, and the curves can be used to assess the magnitude of the potential vibration. The interpretation of the curves with respect to risk of AC corrosion does not seem to be obvious, however, the usage of the sister equipment “correac” or similar may clarify this.

Conclusions

Field research activities at AC corrosion monitoring stations along the Danish gas grit system have given successful on-line and real time measurements of AC induced corrosion risk using ER coupons and related instrumentation combined with logging of the electrical data of the coupons.

Studies have given further evidence for the alkalisation mechanisms, and it has been indicated in the field and further proven by laboratory soil box experiments that AC corrosion stops at low CP dosage and accelerates at high dosage of CP.

Field investigations at a site with alternating ground water level have shown that corrosion stops when the water disappears from the coupon’s sphere, and therefore the presence of the

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The base (OH⁻) neutralising capacity of the soil has been investigated and apparently has no effect on whether or not AC corrosion develops – perhaps rather on the incubation period.

Investigations in laboratory soil boxes have shown that the spread resistance is a function of the OH⁻ concentration and decreases with increasing DC current (CP) dosage. By obtaining polarisation data, the high pH general corrosion domain has been identified as a result of the OH⁻ production by the CP.

Further activities will include establishment of yet an amount of field test stations with the purpose of generating complete evidence that AC corrosion risk will be minimised if the CP is kept low. Further, the effect of DC stray currents on corrosion will be investigated under decreased CP conditions. These field measurements will be sustained by controlled soil box experiments (as described further in the attached annex).

Intelligent pigging of the Gastra F-E pipeline has been scheduled with the purpose of evaluating if the critical AC corrosion conditions found at coupons have actually developed attacks in the pipe.

Acknowledgements

Soil analyses and geo-chemical assistance by Professor H. Breuning-Madsen, Geographical Institute at Copenhagen University is highly appreciated.

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Annex:

Description of further activities within the Danish sector (proposal approved and under implementation).

Parties: HNG I/S, Gastra A/S, Naturgas Midt Nord I/S, Naturgas Fyn I/S, DONG Distribution A/S, MetriCorr, Aps, Balslev consulting engineers.

General background

In situ measurements at Ølstykke M/R Station have shown that AC induced corrosion at ER coupons connected to the pipe system may be reduced and perhaps even eliminated if the CP dosage is reduced hereby reducing alkalinity production.

However, this may conflict with the degree of CP necessary for prohibiting corrosion due to DC stray current from the adjacent railway electrical system. Optimum CP will in this case normally be ensured by dosage of CP to a level ensuring that the amount of cathodic current supplied by the rectifier will at any time be larger than part time anodic DC stray currents supplied by the railway system.

Suggestions for investigations that may contribute to a clarification of the conflict are therefore invited.

Theoretical considerations

- In proximity of a coating fault to which CP cathodic current is flowing, the pH is expected to be elevated compared with remote soil. According to the Pourbaix diagram, an anodic peak current in the pH region 9-12 should displace the potential towards (and perhaps into) the passive domain.
- However, it is known that passivity requires a formation of ferrous oxides, and this is a process that lasts an amount of time – a time constant can be attributed to the process. If assumed that creation of passivity is fast in comparison with a time period of anodic DC stray current, the steel is expected to passivate. In this case, the anodic DC stray current would not be expected to create ferrous dissolution (corrosion); the anodic current is escorted by some other process. Oxygen production requires a rather high anodic potential compared with the cathodic protection potential, but at very reduced conditions this may be an option?
- Under circumstances where a passive film may decompose, for instance under the presence of chlorides, an anodic DC stray current may be able to initiate pitting corrosion. Pitting is likewise a process to which a time constant can be associated. The pitting process can be characterized by a critical pitting potential above which pitting is initiated, and a re-passivation potential below which the pitting is blocked and passivation re-established.

In relation to the above considerations, the questions seem to be:

- I. Can it be confirmed on a broader experimental basis that the AC corrosion risk is reduced if the CP dosage is decreased?
- II. Would it be possible to adjust this CP dosage so as to avoid both AC induced corrosion and DC stray current corrosion...

...either by

- a. The CP is not dosed unnecessarily higher than needed for compensation of the DC stray current peak.

...or by

- b. Keeping a balance in the CP dosage so that pH is not elevated to a degree that induces AC corrosion, however high enough to guide the coating defect in to the passive region during an anodic stray current. Is this potential balance dependant on chloride contaminants?

- III. How is the above affected by specific soil conditions like level of groundwater, pH, presence of CaCO_3 , conductivity of the soil, chloride and BNE value (base neutralizing capacity)?

Suggestions for actions

Point I can be investigated from different angles:

1. In situ measurements where ER probes are established on locations where AC induced corrosivity have been demonstrated. A number of probes should be established both below and above ground water levels. These probes should be varied with respect to area of the coating defect. AC corrosion detectors that measure AC parameters, spread resistance and corrosion should be installed in the measuring posts. The rectifier potential should be altered between moderate/low CP and high CP dosage.
2. Laboratory investigations in AC corrosive soil where a constant AC voltage is maintained whilst the DC cathodic potential is varied. Two different AC loads for each of which the DC level is changed within 5 levels. High sense ER measuring the corrosion rate.

Point II as well can be investigated from different angles:

3. Balslev consulting engineers have pointed out 19 locations along the HNG pipeline system where DC stray currents are measurable. Soil samples should be collected from these sites and characterized with respect to chalk, chloride, pH, conductivity and ground water level. These will subsequently be categorized (wet/dry, acidic/alkaline etc.). Two ER coupons are installed and the corrosion is followed during a one-year period. In this period, the CP-level is changed from low via moderate to high, and spotwise ER measurements, spread resistance measurements. At the end of each CP condition, a measuring campaign is completed in which a close-up logging of the

current and potential relations is performed. During these campaigns the probes are shortly de-coupled from the pipeline system so as to verify the open circuit potential drift under the chemical conditions formed due to the relevant CP condition. Optionally, the probes are characterized by Ramlog correal measurements.

4. Laboratory investigations where CP of ER probes exposed in a soil environment leads to a build-up of an alkaline environment. At certain intervals an anodic polarization is realized with size and duration that corresponds a “typical” stray current. DC parameters (current /potential) are registered. For a number of CP-level/stray current combinations the corrosion rate is recorded by the high sense equipment. In parallel investigations the probes are connected to a larger steel structure that has not been cathodically polarized and for this reason does not passivate by anodic polarization. The current distribution between this structure and the probes is registered and it is investigated whether the corrosion rate is affected by the coupling procedure.

Each of the 4 phases is reported continuously.

Implementation

The above identified 5 points of action are realized according to the below time-schedule.

Activity	2004				2005			
	1	2	3	4	1	2	3	4
1. In situ AC corr.								
2. Lab investigation AC corr.	—							
3. In situ DC stray current corr.		—						
4. Lab investigations DC stray		—	—					
5. Final report			—	—	—	—	—	—

Phase 1 (AC investigations in the field) is initiated in direct continuation of the present investigations along the HNG line.

Phase 2 (AC investigations in lab) is initiated directly subsequent to budget approval, and will continue for the proceeding 3 months

Phase 3 (DC stray current in field) involves a preliminary investigation of the soil conditions after which the actual field measurements can be initiated around 4th quarter of 2004.

Phase 4 (DC stray current investigations in laboratory.) Initiated directly after the AC investigations in lab (phase 2) and will proceed for 3 months.