CONSIDERATIONS ON MEASUREMENTS AND MEASUREMENT TECHNIQUES UNDER AC INTERFERENCE CONDITIONS

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ABSTRACT

This paper gives a general outline and discussion of measurements and measuring techniques relevant for studying, assessing, or monitoring AC corrosion.

The techniques cover the parameters AC voltage, DC potential (in the "ON" mode or IR compensated), AC and DC current densities through a coating defect, Spread resistance of the coating defect as well as direct corrosion rate measurements on coupons.

The paper is a conglomerate of a contribution given to the CEN committee as suggestions and justifications to cover "Measurements Techniques" included in the merging standard on AC corrosion.

INTRODUCTION

AC corrosion is continuously being discussed in terms of mechanisms, assessment, monitoring etc. and the technical specification CEN/TS 15280 [1] is currently under revision with the goal of preparing a standard. Much debate has been made concerning which parameters to rely on as the criteria for the assessment of the AC corrosion risk. The candidate parameters are:

- AC voltage
- DC potential (in the "ON" mode or IR compensated).
- AC and DC current densities through a coating defect
- Spread resistance of the coating defect.
- Corrosion rate measurements.

This paper is intended as a contribution to this aforementioned debate and gives an (undoubtedly non-exhaustive) discussion of some techniques by which these parameters are quantified and – where appropriate - the feasibility of the techniques and the parameter itself. Part of this paper was presented to the CEN committee as suggestions and justifications to cover "Measurements Techniques" included in the merging standard – just to give a reason for the way it is written.

SELECTION OF TEST SITES

As a prerequisite to taking measurements, the selection of suitable sites along the pipeline must be made. Sites may be selected at test stations in areas such as where:

A. the pipeline is within interference distance,
B. the calculated AC voltage is above the threshold limits,
C. AC corrosion has previously taken place,
D. local DC polarization conditions may favor AC corrosion such as areas with cathodic or anodic DC stray current interference, and areas where excessive or inadequate cathodic protection is present.

T

he selection of test sites will not be further discussed in this paper.

INSTRUMENTATION

The instruments used for measuring any voltages must comply with the conditions set up in EN 13509 - Cathodic protection measurements techniques [2].

It is a fundamental requirement of any measuring instrument that it should not cause any unacceptable changes to the circuit being measured. It shall be chosen to be well adapted to the circuit to be measured.

Reference electrodes should be selected in agreement with EN 13509 annex A. They should be constructed in such a manner that their potential is not affected during voltage measurements.

Typically, the accuracy of the measuring equipment is only one among several factors contributing to the uncertainty of the measurement.

INSTALLATION OF COUPONS

A number of quantities related to the assessment of AC corrosion are made by the use of coupons.

The installation of coupons should be made in such a manner that the representativity is maintained to the greatest possible extent. The following points should be considered:

A. The coupon should be installed in the same soil or backfill as the pipeline itself.

B. The coupon geometry (size, shape, coating thickness, angle between coating and simulated coating defect) influences the spread resistance and should be taken into consideration.

C. The coupon should not cause or receive any electrical interference from adjacent coupons or coating faults unless being part of the purpose of monitoring.

D. The coupon should have and maintain an effective electrical contact to the surrounding soil – unless lack of contact is part of the purpose of monitoring. During the installation process, the soil around the coupon shall be compacted to prevent settlement and voids forming around the coupon. These voids could result in loss of full contact between the coupon surface and the surrounding soil.

As an illustration of point B, figure 1 (left) shows the spread resistance as a function of the defect size. This has been calculated for a circular defect as well as for rectangular defects with length to width ratio ranging from 1:1 to 1000:1 (scratch-like shape). It is generally observed that the spread resistance increases with increasing defect size. As already generally adapted the AC current density will therefore increase with decreasing area – given the same AC voltage level. It is further observed that rectangular geometries exhibit reduced spread resistance compared with the circular shape.

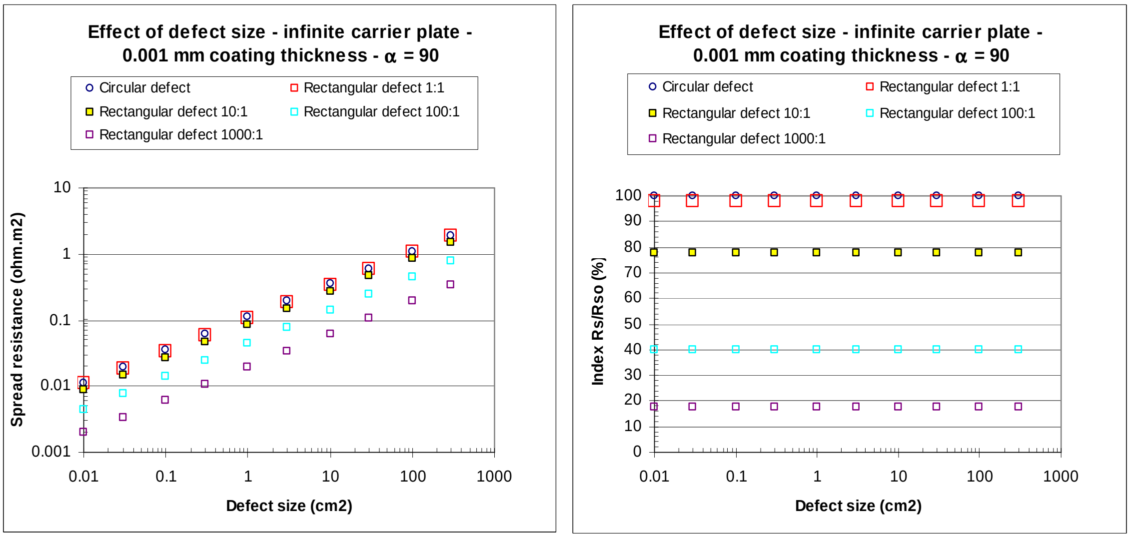


Figure 1. The effect of the size of the coating fault on the spread resistance – circular shape as well as rectangular shapes with various lengths to with ratios. The adjacent coating is very thin.

This has been illustrated further in figure 1 (right). In this figure, the spread resistance of a circular shape has been indexed = 100. For each calculated area, the spread resistance of the rectangular coating defect has been compared with the circular. As observed in this manner a square (L:W = 1:1) coating fault exhibits approximately the same spread resistance as a circular spread resistance – regardless of the area of the coating fault. Increasing the length to width ratio of the rectangular coating defect gradually decreases the spread resistance compared with the circular having equivalent size. Accordingly, the spread resistance of the 10:1 rectangular shape is about 80% of the circular equivalent whereas the scratch-like

1000:1 rectangular shape is less than 20% of the circular defect having equivalent size.

Coupons and the installation of such are further treated in references [3] and [4].

AC voltage measurements

AC voltage measurements are used to determine the level of AC interference.

For this purpose measurements must be made using a data logging device programmed to measure the AC voltage in intervals sufficiently short to capture the variances in the steady state long term interference.

AC voltage measurements are made with reference to remote earth. Applicable position of remote earth may be assessed using the setup in figure 2. This is particularly important when measuring nearby earth electrodes.

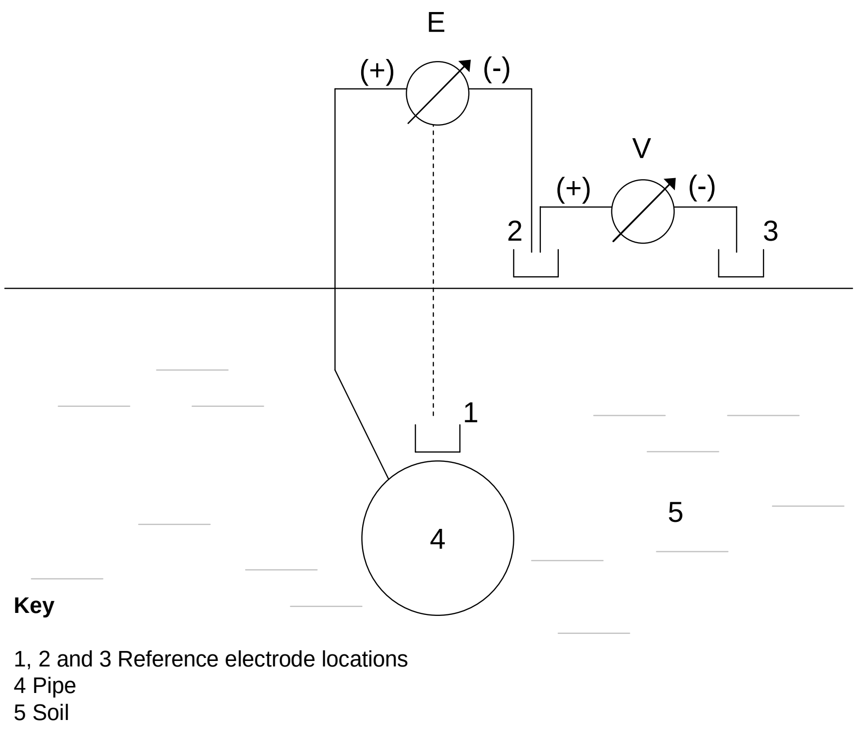


Figure 2. Measurement of the AC gradient and localizing remote earth.

Reference electrode (1) represents IR free condition and is not applicable for AC voltage measurements since – with reference to remote earth – the entire IR drop should be included.

Instead the following (perhaps somewhat academic) procedure can be useful:

1. Place a reference electrode (2) on top of the soil above the pipeline. Connect a (first) voltmeter to the pipeline and this reference electrode and read the AC voltage.
2. Place an additional reference electrode (3) on top of the soil above the pipeline. Connect a second voltmeter between reference electrodes (2) and (3) and read the voltage difference between the two reference electrodes.
3. Change the position of reference electrode (3) 1 m transverse to the pipeline and read the voltmeters.
4. Change the position of the reference electrode (3) another 1 m transverse to the pipeline and read the voltmeters.
5. Remote earth is located when repeating point 4 (continuously increasing the distance from the pipeline to reference electrode (3)) does not change the value of the reading of the second voltmeter connected in between reference electrodes (2) and (3). The reading of the first voltmeter must be constant throughout this procedure – otherwise the AC interference level has changed.
6. Finally measure the AC voltage

Figure 3 shows an example of data-logged AC voltage. The case is from a Danish pipeline interfered by a high voltage power line system. As observed, the daily variation creates minimum values as low as 1.5 V and maximum values as high as 29.5 V. Average value is 16.1 V. This example should illustrate the meaninglessness in measuring a spot wise (single) measurement of the AC voltage as part of a CP measurement campaign, and then compare this value with a spot wise measurement being part of a similar campaign one year later.

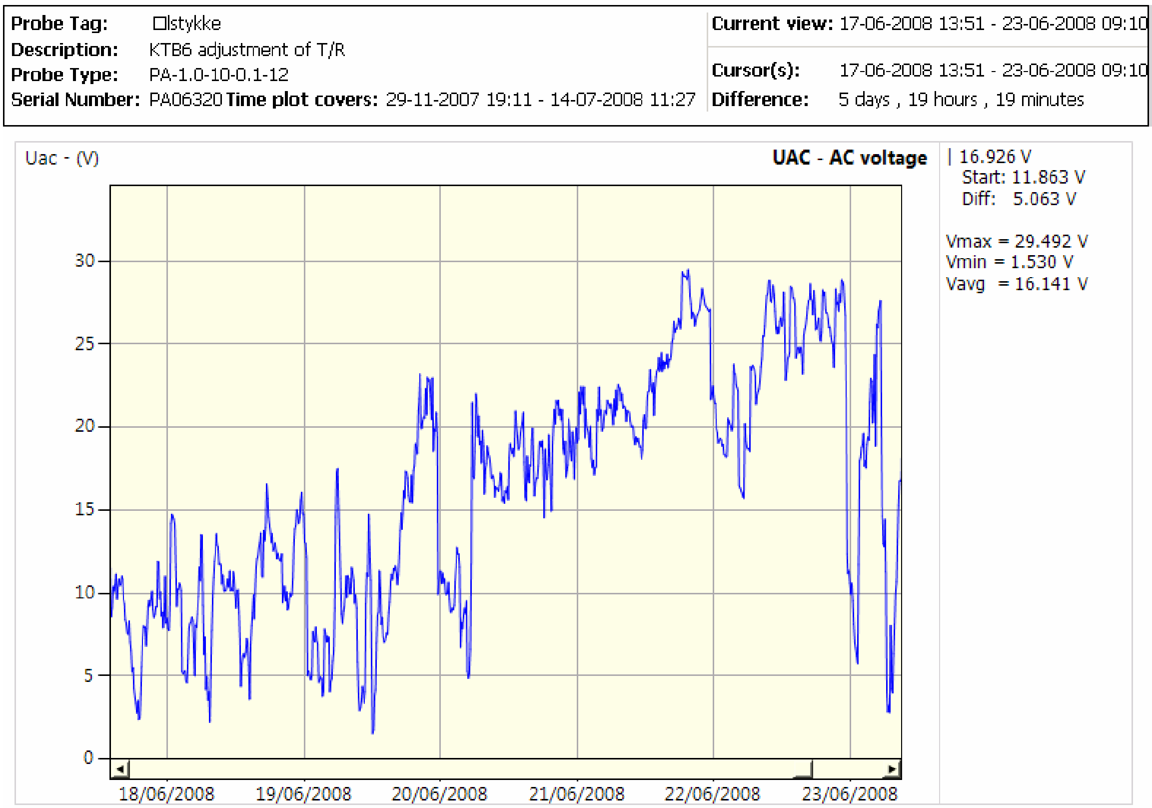


Figure 3. 6 days of data logged AC voltage measurements. Example from a Danish pipeline.

AC voltage measuring methods are further treated in annex C in prEN 50443 [5] with reference to appropriate standards and guides.

DC potential measurements

DC potential measurements and instrumentation for this is treated in EN 13509 - Cathodic protection measurement techniques – [2]. The accuracy of potential measuring equipment is given in annex H (normative) of EN 13509.

When measuring DC potentials in conjunction with AC interfered pipelines due consideration should be taken in relation to the following factors causing uncertainty in the measurement:

A. IR free potentials assessed by the current interruption technique are generally dependant on the filter characteristics of the applied voltmeter and the time after switch off before the reading is made.

B. AC mitigation devices such as capacitors, diodes etc. will influence DC potentials and d.c potential measurements. The reliability of measurements of IR free potentials on the structure itself by interruption techniques may be affected by the time constants introduced by such devices. This problem was addressed in a CeoCor 2010 paper by Blotzky [6].

C. IR free potentials measured on the structure for the purpose of assessing the average coating resistance (ON-OFF measurements combined with line current measurements according to annex I in EN 13509 [2]) should be made with all mitigation devices disconnected (alternative: with due consideration to the effect of installed mitigation devices). Disconnection of mitigation devices will increase the level of AC voltage, and since the AC voltage may cause polarization or depolarization of the structure, the IR free potentials measured in order to ensure compliance with EN 12954 criteria [7] should be made at the AC voltage level of the pipeline in usual operation condition. The use of coupons or external potential test probes may be necessary.

D. IR free potentials are affected by the induced AC voltage (see figure 4). The effect of the AC voltage may alternate the IR free potential in the same frequency as the AC (i.e. 16 2/3 Hz, 50 Hz, or 60 Hz). This reflects the effect of the AC voltage on the DC polarization. Dedicated coupon measurement techniques have also been developed for the purpose of establishing an IR free potential on the coupon. [8, 9]. Also refer to [10].

E. In general the IR free potential may be severely affected by superimposed AC voltage and the reliability of the IR free potential is jeopardized –see figure 7.

The above effects are generally more significant factors than the accuracy of the voltmeter itself regarding the uncertainty of the measurement.

Additional interference sources causing IR-drops as well as possible measuring techniques are given in EN 13509 table 1.

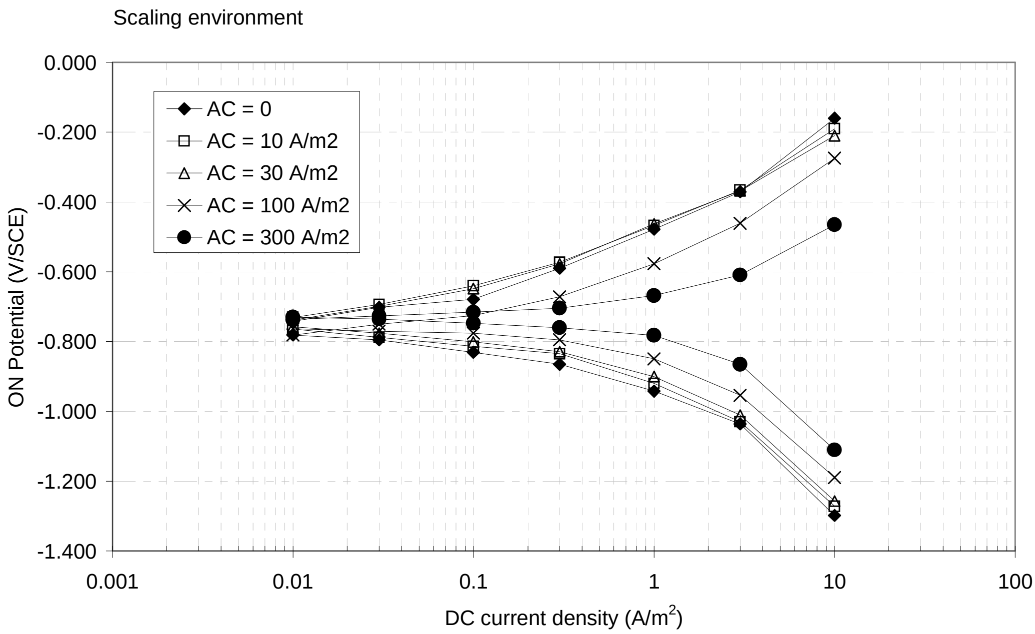


Figure 4. Example of the displacement of the polarization curve with increasing AC.

DC potential measurements and IR free DC potential measurements are often performed by the use of coupons. In relation to ON-potential measurements, the advantage is limited to the knowledge that an artificial coating defect hereby has been systematically introduced via the coupon.

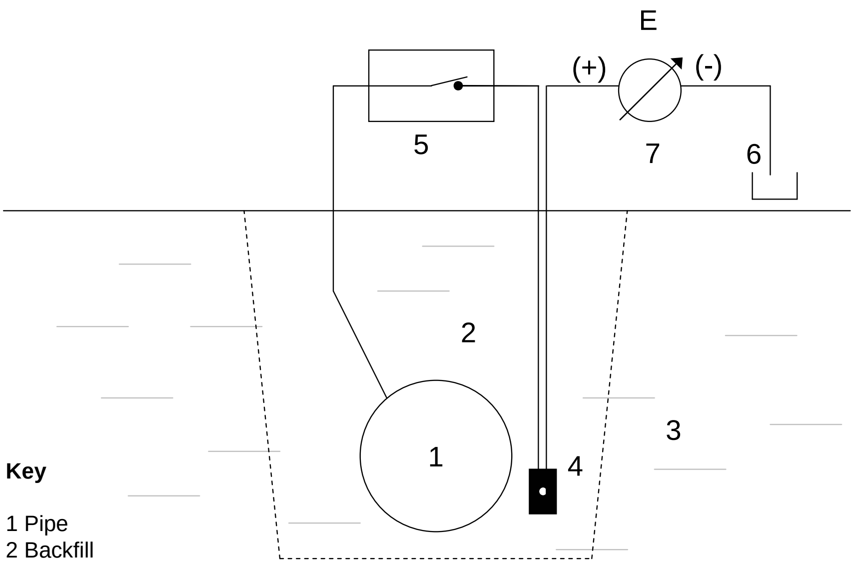
In relation to measurement of the IR free potential three different principles can be utilized for the compensation of the IR drop.

A. Inserting a switch in the test post between the pipeline connection and the coupon connection and measure the potential between the coupon and the reference after switching off the connection between the pipeline and the coupon (see figure 5).

B. Embedding the reference electrode along with the coupon in an external potential test probe (figure 6). It is recommended to test the OFF potential also in this case for the efficiency of the automated compensation provided by the close distance between the coupon surface and the reference – se figure 8 and relating discussion.

C. Quantifying the IR-drop as the product of the DC current density and the spread resistance of the coupon and subtracting this from the ON-potential value.

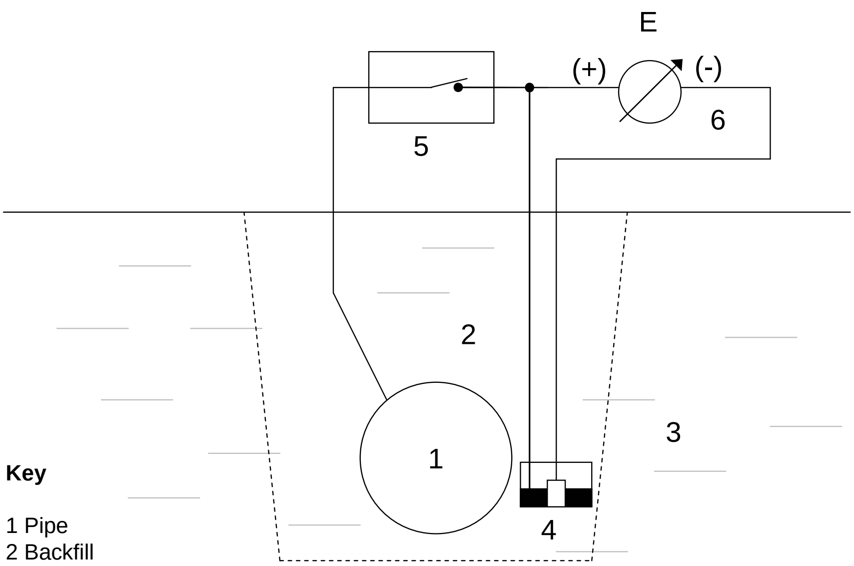
Regardless of the technique due consideration should be taken with regard to the sources causing uncertainty in the measurement.



Key

1 Pipe
2 Backfill
3 Native soil
4 Coupon – double wired
5 Test post with switch (NC)
6 Reference electrode
7 Meter

Figure 5. Coupon test post with switch facility for current interruption.



Key

1 Pipe
2 Backfill
3 Native soil
4 Coupon – with build in reference
5 Test post with switch (NC)
7 Meter

Figure 6. Test post – coupon with build in reference electrode external probe.

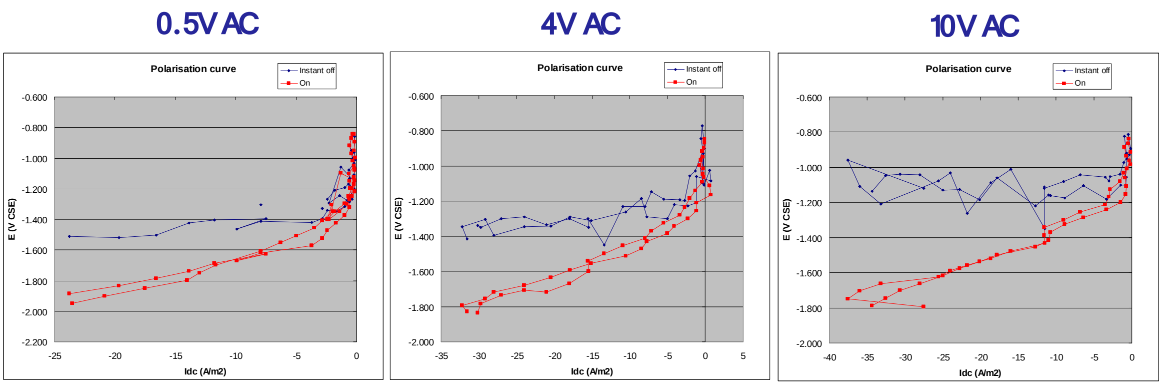


Figure 7. Example of the displacement of the polarization curve with increasing AC.

Figure 7 shows the effect that superimposed AC may have on the establishment of the IR free potential. The x-axis is current density and the Y axis is the potential. As observed, when increasing the AC (0.5 – 4 – 10 V) the established IR free potential seems to become more anodic even though ON potential becomes more cathodic. This specific observation has been realized using the current interruption technique (A) but similar phenomenon has been observed using potential probes and using the I_{DC} x R_{spread} compensation techniques (B) and (C) [11]. The phenomenon has also been illustrated by Büchler et al. [12-15].

Embedding the reference electrode close by the steel surface of the coupon may compensate for some of the IR drop. However, as illustrated in figure 8, it should be controlled that the current interruption technique does not lead to any IR drop between the steel coupon and the embedded reference electrode, otherwise the measurements becomes falsified. Three probes were tested for the IR drop between the internal as well as between an external reference electrode and the steel part of the probes at various potentials.

A. One commercial type having an area of 88 cm^2 and embedded in mortar to give reproducible environments.
B. One commercial type having an area of 10 cm^2 and the reference located in the middle of the circular coupon.
C. One home fabricated type with a circular 1cm^2 area and a small lugging capillary drilled in the center.

Figure 8 illustrates the results. As observed IR drops in the order of 100-200 mV can be set up between the internal reference and the steel part. Best performance was obtained for the home made type C having the smallest surface area.

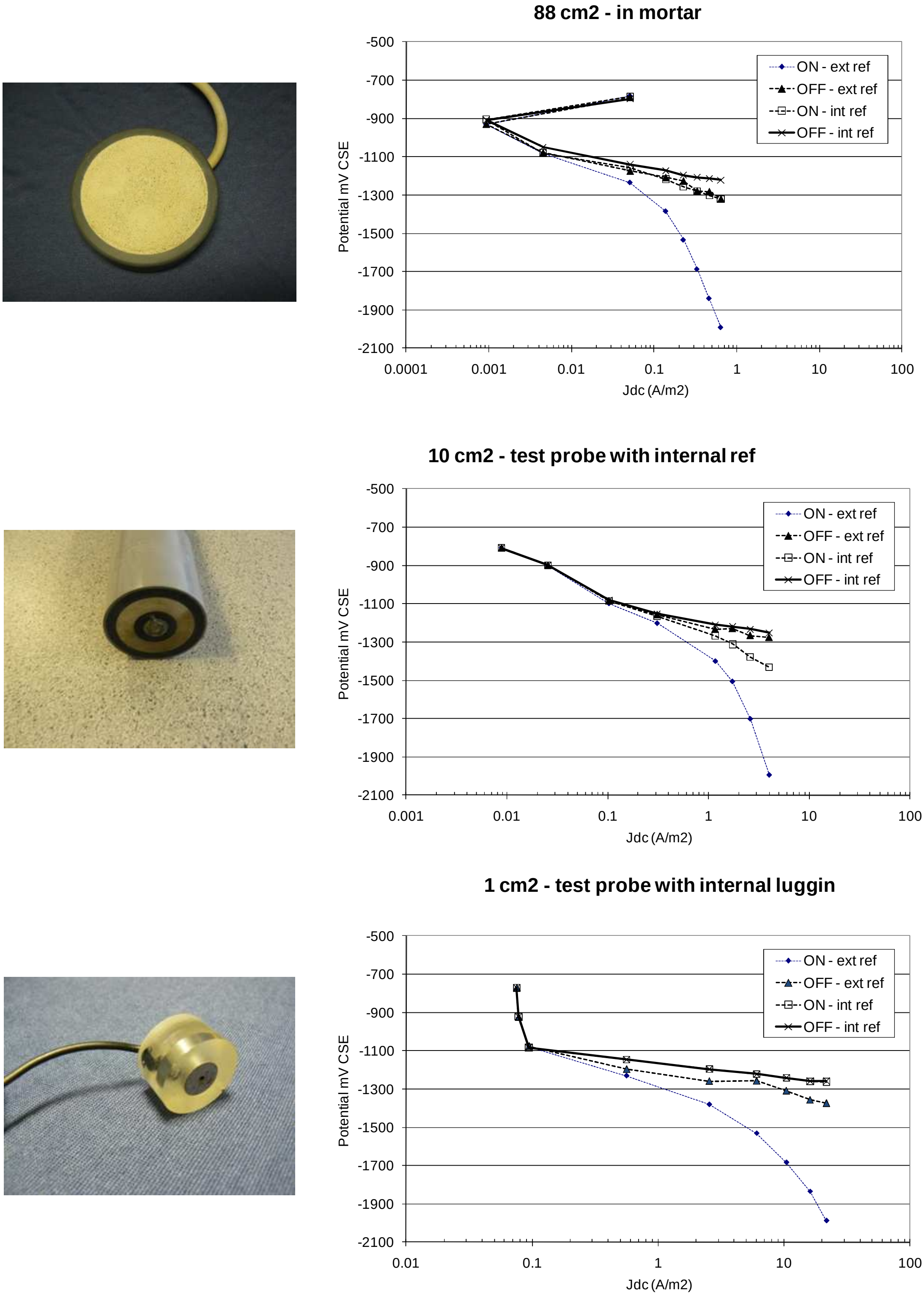


Figure 8. IR free potential tests using different potential probes.

The above was a general test of the potential probe concept. Combined with the IR free potential behavior (figure 7), the establishment of a reliable IR free potential under AC influenced conditions may be quite a challenge.

One further complication arises if a correlation between the corrosion rate and the IR free DC potential is tried established. Figure shows a resulting correlation between ON and OFF potentials and the corrosion rate measured on an ER coupon during a slow potential scan. AC superimposed is 10 V. The definition of a safe IR-free potential region seems difficult.

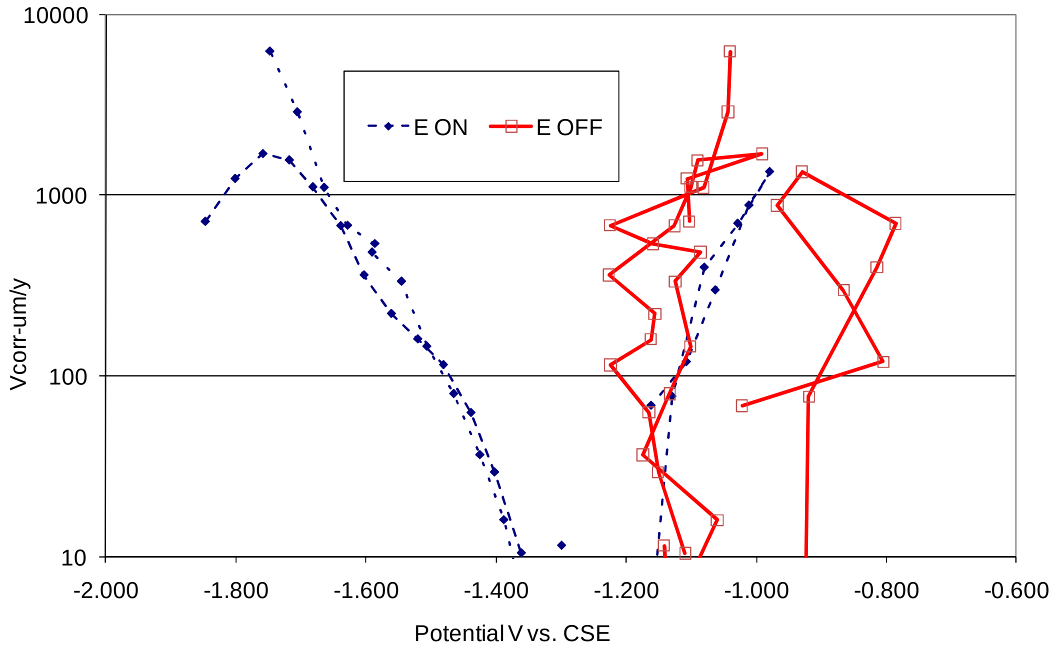


Figure 9. Correlation between ON and OFF potentials and the corrosion rate measured on an ER coupon during a slow potential scan. AC superimposed is 10 V.

Current measurements

Coupon currents (AC or DC) can be measured either by the voltage drop across a series resistor or by zero resistance ammeters. For both AC and DC current measurements the value of the series resistor should sufficiently low to avoid significant disturbance of the system.

For AC current measurements the value of the series resistor should be insignificant compared with the spread resistance of the coupon. For DC current measurements the value of the series resistor should be insignificant compared with the sum of the coupon spread resistance and polarization resistance. The uncertainty of the measurement depends on this selection of the series resistance value, the accuracy of the series resistor and the accuracy of the meter. The series resistor should be verified regularly, and the meter should be part of routine calibration procedures.

The current may be unevenly distributed on the coupon surface due to edge effects etc. but this is true for real coating defects as well.

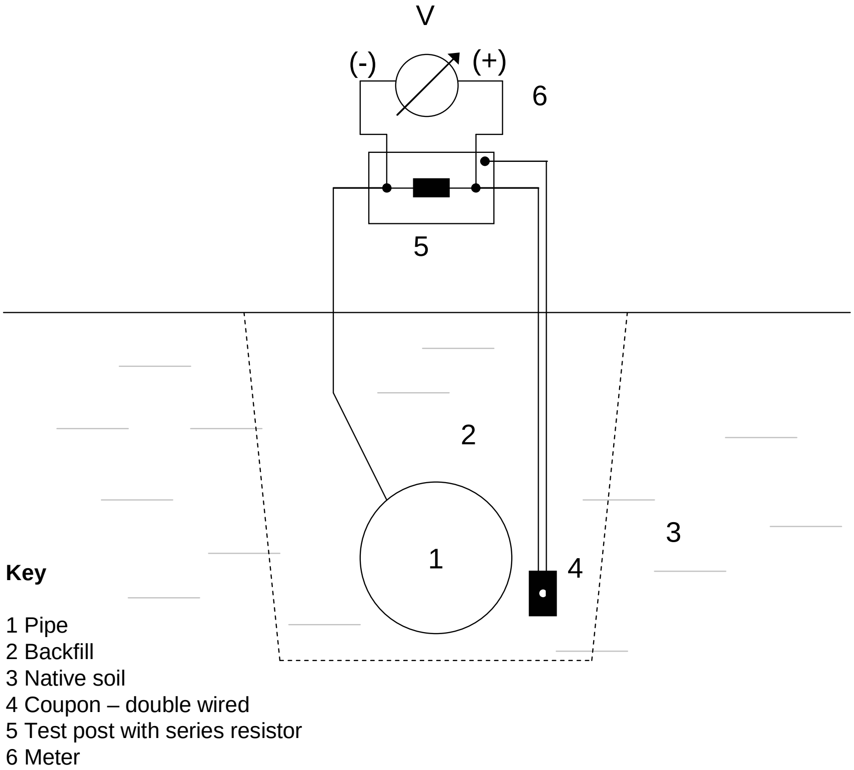


Figure 10. Coupon test post with series resistor for current measurements.

AC VOLTAGE, AC CURRENT AND SPREAD RESISTANCE

At this point, it is worth considering the correlations between the AC voltage,the AC current density and the spread resistance [3]. The magnitude of AC can be expressed either as the AC voltage (U_{AC}) measured between the pipeline and remote earth, or as the AC current (I_{AC}) or AC current density (J_{AC}) exchanged between the pipe and the adjacent soil through a coating defect. The correlation between these two parameters is given as:

$$U_{AC}(V) = R'_S(\Omega) \cdot I_{AC}(A) \qquad (1)$$

or

$$U_{AC}(V) = R_S(\Omega \cdot m^2) \cdot J_{AC}(A/m^2) \qquad (2)$$

R'_S denotes the spread resistance in ohm whereas R_S denotes the spread resistance in ohm.m^2.

Usually, the spread resistance related to a circular coating defect with area (A) and diameter (d) embedded in soil with a soil resistivity ρ_{soil} is expressed as [see reference 16 p. 540]:

$$R'_S\,(\Omega) = \frac{\rho_{soil}\,(\Omega \cdot m)}{2 \cdot d\,(m)} \tag{3}$$

or

$$R_S\,(\Omega \cdot m^2) = \frac{\rho_{soil}\,(\Omega \cdot m)}{2 \cdot d\,(m)} \cdot A\,(m^2) \tag{4}$$

Substituting (3) into (1) gives:

$$U_{AC}\,(V) = \frac{\rho_{soil}\,(\Omega \cdot m)}{2 \cdot d\,(m)} \cdot I_{AC}\,(A) \tag{5}$$

Substituting (4) into (2) gives

$$U_{AC}\,(V) = \frac{\rho_{soil}\,(\Omega \cdot m)}{2 \cdot d\,(m)} \cdot A\,(m^2) \cdot J_{AC}\,(A/m^2) \tag{6}$$

It is a feasible discussion whether the AC voltage (considered as the driving force) or the resulting AC current density should be used as a parameter to judge the likelihood of AC corrosion at a particular location.

At a given location – providing that the soil resistivity as well as the geometry and dimensions of the coating defect of matter are fixed values in equations (5) and (6), both equations suggest that there is a well defined constant correlation between the pipe to earth AC voltage and the density of the AC current exchanged between the pipe and the adjacent soil through this coating defect.

In such case, it wouldn't matter which parameter (AC voltage or AC current density) is chosen to assess the AC corrosion likelihood – provided that the sol resistivity and the coating defect geometry and size are known and constant.

Therefore, assuming a constant proportionality between AC voltage and AC current density (equations 5 and 6), the simplest way to judge the AC corrosion likelihood would be simply by measuring or logging the pipe to earth AC voltage.

However, the above rationale is <u>not feasible</u>.

The reason for this is that the very nature of the AC corrosion process involves a modification of the resistivity of the soil in the close proximity of the coating defect – particularly through the production of hydroxyl ions from water through by the cathodic protection current. This has been discussed in greater details in reference [3].

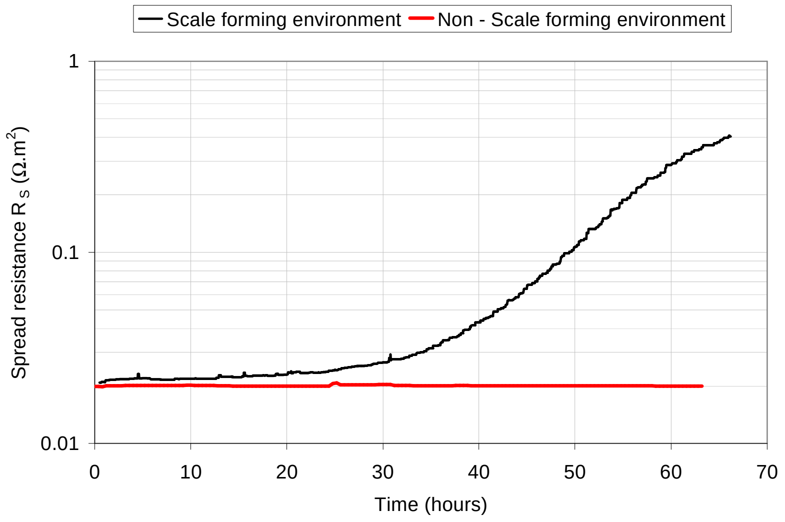


Figure 11. Development of the spread resistance in a scale forming environment versus a non-scale forming environment under mild cathodic protection

Figure 11 shows a case where the spread resistance increases due to the CP current interaction with scale forming earth alkaline cat-ions.

Figure 12 and 13 show the possible effect that cathodic protection current density decreases the spread resistance and therefore increases the AC current density at constant Ac voltage – hereby introducing the vicious circuit of AC corrosion:

A. Excessive CP may lead to alkalization at the coating fault
B. The alkalization may lead to reduced spread resistance (figure 12 + 13).
C. Reduced spread resistance increased the AC current density.
D. Increased AC current density may lead to increased DC current density (figure 4).
E. This bits its own tail by repeating A through D
F. AC corrosion is initiated at a certain pH and a certain AC/DC current.
G. Point F depends on the specific type of soil in which the scene takes place.

This above vicious circuit has been illustrated e.g. in reference [17].

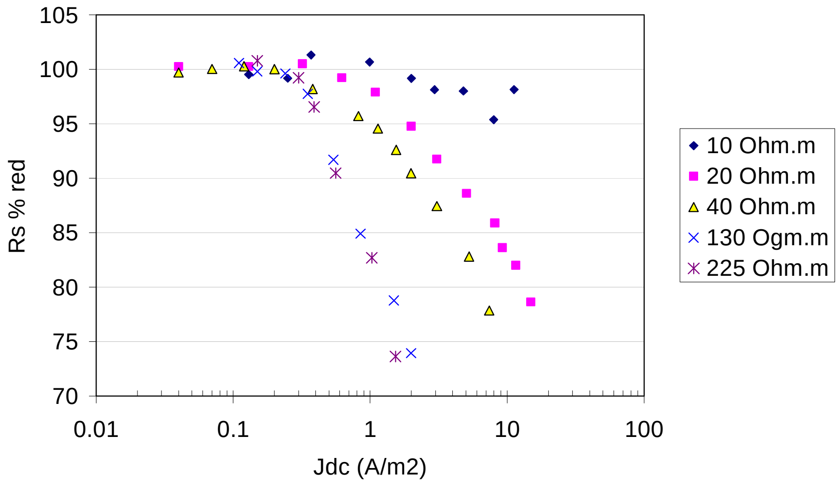


Figure 12. Effect of the cathodic protection DC current density on the spread resistance [3].

From these results illustrated in figure 12 assessment of the threshold cathodic protection current density – above which the spread resistance decreases – was established as a function of the soil resistivity – see figure 13.

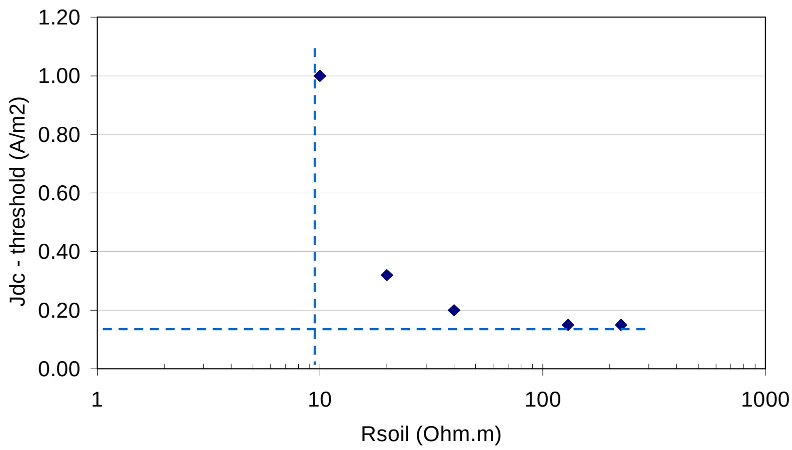


Figure 13. Threshold cathodic DC current density above which the spread resistance decreases – as a function of the soil resistivity [3].

Corrosion rate measurements

Direct measurements of the corrosion rate on a coupon are a reasonable alternative to the potential and current measurements, which under AC conditions are difficult to interpret in terms of corrosion threat.

Three general types of corrosion rate measurements can be applied:

- Weight loss measurements
- Perforation measurements
- Electrical Resistance (ER) measurements

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Weight loss measurements require installation of pre-weighed coupons. After some time of operation (months – years) the coupon is excavated and brought to a laboratory for cleaning, inspection and weighing. The primary advantage of the procedure is that the visual inspection provides detailed information of the corrosion topography – maximum as well as an average corrosion rate. The primary disadvantage is that the coupon provides no information until it is excavated.

Perforation measurements are made on special perforation coupons. A signal is generated when the corrosions process has perforated the wall thickness of the coupon. The primary advantage is that the maximum (localized) corrosion depth is registered without having to excavate the coupon. The primary disadvantage is that this information is not available until the coupon is perforated.

Electrical resistance measurements require the installation of electrical resistance probes (ER coupons). The corrosion is detected by the increase of the electrical resistance of the coupon when corrosion progressively decreases the thickness of the coupon. The primary advantage is that the average corrosion rate can be followed continuously and used to optimize cathodic protection measures. The primary disadvantage is that localized corrosion rate is detected with less accuracy until he coupon is perforated.

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