

# **Determination of the Off-potential on ER Coupons of AC-influenced Pipelines**

Ulrich Bette, Laboratory for Cathodic Protection and Interference,  
Technische Akademie Wuppertal, Hubertusallee 18, DE-42117 Wuppertal

Within the scope of laboratory tests of AC corrosion measurements were made on ER coupons with a 16-bit digital storage oscilloscope. Due to the synchronous registration of the test sample current and the test sample/ground-potential the off-potential could be calculated by way of a correlation measurement without having to separate the test sample electrically from the pipeline.

Further correlation calculations revealed the time characteristic of the IR-free potential and of the current floating through the phase interface. Thanks to these results it was also possible to assess whether AC corrosion occurs or not.

## **Ermittlung des Ausschaltpotentials an ER-Coupons von wechselfspannungsbeeinflussten Rohrleitungen**

Im Rahmen von Laboruntersuchungen zur Wechselstromkorrosion wurden Messungen an ER-Coupons mit einem 16-Bit-Digital-Speicher-Oszilloskop durchgeführt. Durch die synchrone Erfassung von Messprobenstrom und Messproben/Boden-Potential kann das Ausschaltpotential durch eine Korrelationsmessung rechnerisch bestimmt werden, ohne die Messprobe von der Rohrleitung elektrisch abtrennen zu müssen.

Weiterführende Korrelationsrechnungen ergaben den zeitlichen Verlauf des IR-freien Potentials und des durch die Phasengrenze fließenden Stroms. Anhand dieser Ergebnisse konnte zusätzlich beurteilt werden, ob Wechselkorrosion stattfindet oder nicht.

## Détermination du potentiel Off sur des éprouvettes de résistance électrique de canalisations sous influence C.A.

Ulrich Bette, Laboratory for Cathodic Protection and Interference,  
Technische Akademie Wuppertal, Hubertusallee 18, DE-42117 Wuppertal

Dans le cadre d'essais en laboratoire sur la corrosion C.A., des mesures ont été réalisées sur des éprouvettes de résistance électrique avec un oscilloscope à mémoire numérique 16 bits. En raison de l'enregistrement synchrone du courant d'échantillonnage mesuré et de l'échantillon d'essai/potentiel du sol, le potentiel Off a pu être calculé par le biais d'une mesure de corrélation sans devoir séparer électriquement l'échantillon d'essai de la canalisation.

Des calculs de corrélation supplémentaires ont révélé les caractéristiques temporelles du potentiel sans chute ohmique et du courant s'écoulant à travers l'interface de phase. Grâce à ces résultats, il a également été possible d'évaluer si une corrosion C.A. intervient ou non.

### Introduction

At the CeoCor Congress in 2012 the lecturer reported on laboratory tests concerning AC corrosion, which were performed on ER coupons with a two-channel 16-bit USB oscilloscope. The ER coupons were embedded in an artificial soil solution in which no protective layer can occur. The resistivity was between  $17 \Omega\text{m}$  and  $18 \Omega\text{m}$ . As alternating voltages, which varied much on a time average, were supplied to the samples, the values relevant to the cathodic corrosion protection were measured with the 16-bit oscilloscope. The sampling rate was set to 10 kHz, which corresponds to a resolution of 0.1 ms. Fig. 1 shows the measuring arrangement.

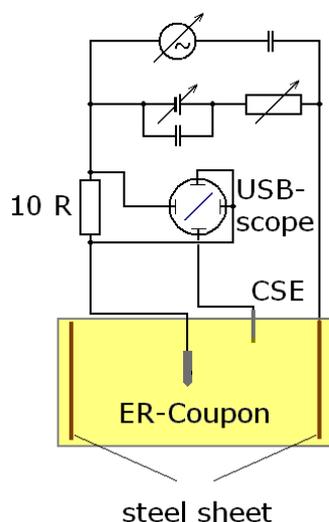


Fig. 1 - Measuring arrangement

Diagram 1 shows an example of time characteristics of the pipe/ground potential and the flowing current. Due to the superimposed direct voltage and the protective current entering the sample the voltage and the current seem to have a phase shift. At the

zero passage from negative to positive values, the current seems to be ahead, whereas it is behind at the zero passage from positive to negative values.

These apparent phase shifts can be neglected if the direct components are subtracted from the time characteristics, see diagram 2. This result was given for all 20 test samples, which were examined in respect of AC corrosion. Therefore, the IR-free potential was calculated on the basis of the time characteristics of the potential and the current. The calculation method is described below.

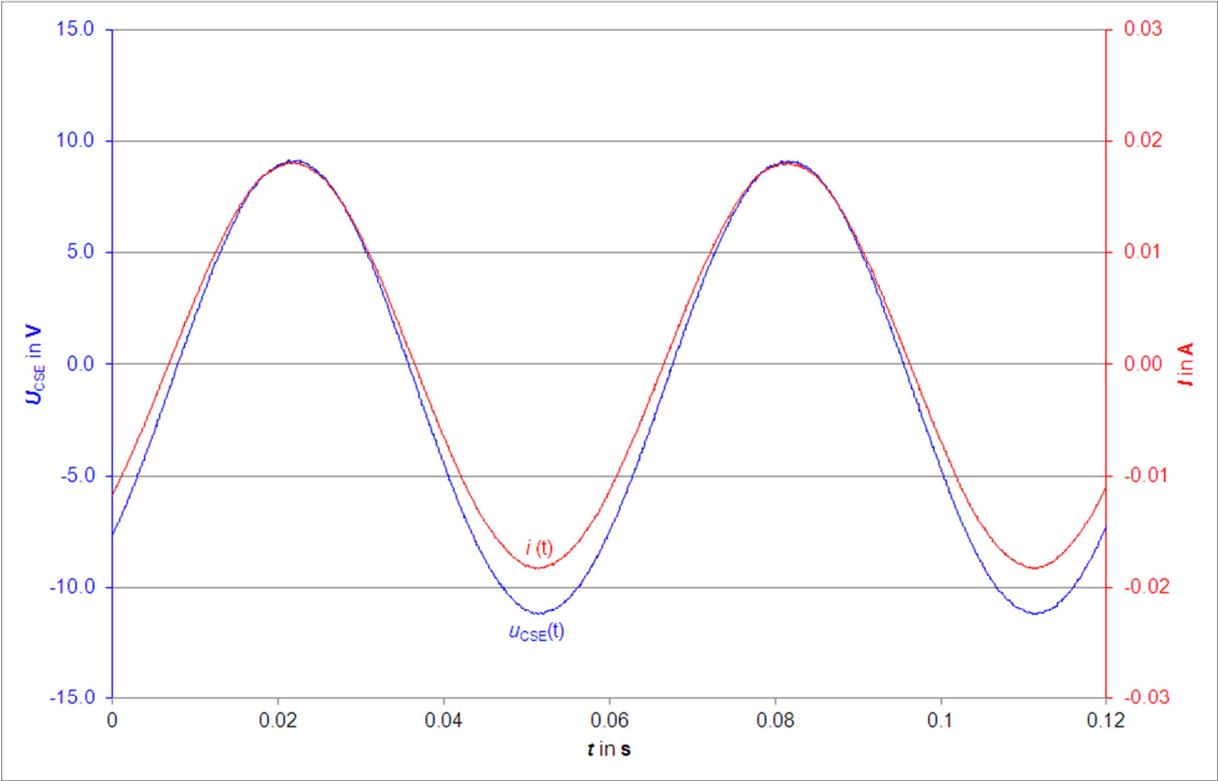


Diagram 1 – Coupon/ground potential and total current flowing, 17/11/2009

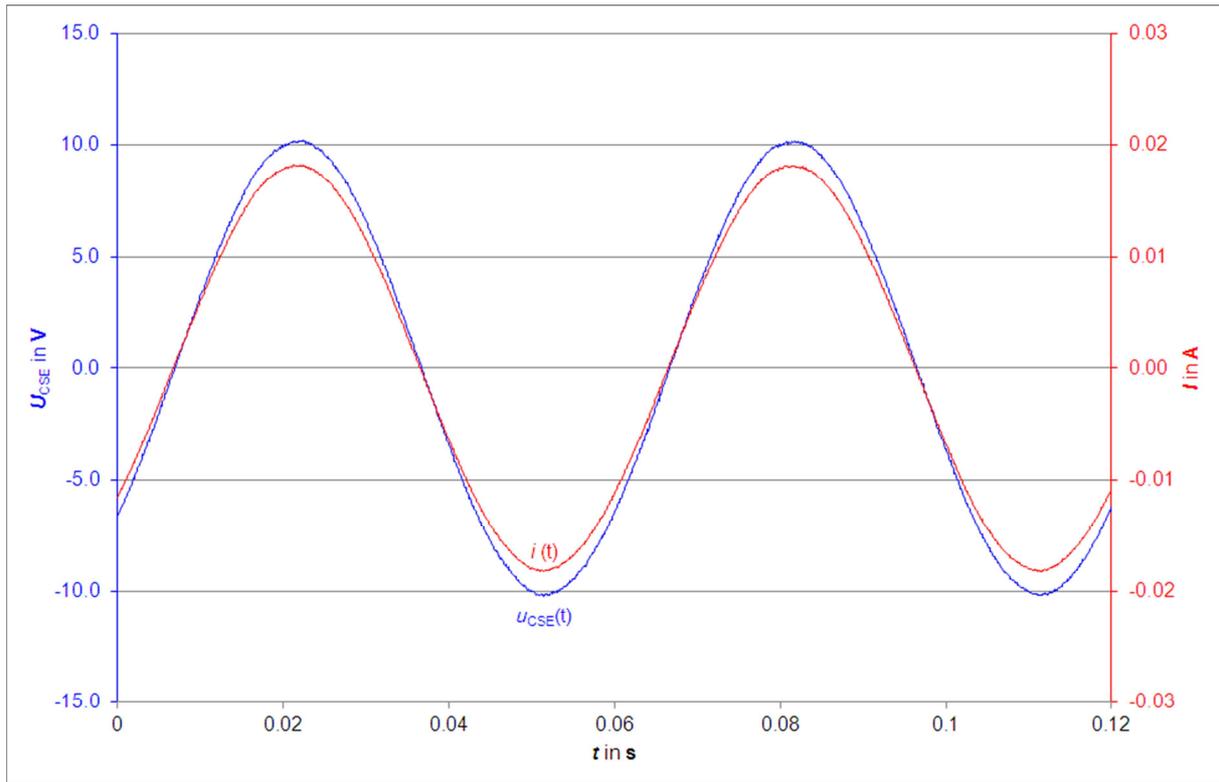


Diagram 2 – Alternating voltage and alternating current flowing, 17/11/2009

### Calculation of the IR-free potential

It is a condition for the calculation of the IR-free potential that the period taken as a basis corresponds to the period of the superimposed alternating voltage or to a multiple of this period. In the shown diagrams the frequency amounts to  $16 \frac{2}{3}$  Hz, which means that the calculations have to be made at least for a period of 60 ms. 600 measured values or a multiple result at a sampling rate of 0.1 ms.

Thereafter, the direct components and the alternating components of the potential and the current are calculated on the basis of the single values measured. In relation to the pipe/ground potential the equations are as follows:

- Direct component (time average of the on-potential):

$$\overline{U_{CSE,on}} = \frac{1}{n} \sum_{i=0}^n u_{CSE,i} \quad (1)$$

- Alternating component (effective value of the superimposed alternating voltage):

$$U_- = \sqrt{\frac{1}{n} \sum_{i=0}^n (u_{CSE,i} - \overline{U_{CSE,on}})^2} \quad (2)$$

Where:

$\overline{U_{CSE,on}}$	is the time average of the on-potential
$u_{CSE,i}$	is a single potential value measured
$U_{\sim}$	is the effective value of the superimposed alternating voltage
$i$	is the control variable
$n$	is the number of values measured

The direct component and the alternating component of the current flowing through the ER coupon are calculated in the same way.

If the alternating voltage is then divided by the flowing alternating current, the ground impedance of the test sample is found. As it has been determined that the phase shift can be neglected under the test conditions, the result of this division is the ohmic ground resistance  $R$ :

$$R = \frac{U_{\sim}}{I_{\sim}} \quad (3)$$

Considering equation (3) the IR-free potential results to:

$$\overline{U_{CSE,IR-free}} = \overline{U_{CSE,on}} - \left( U_{\sim} \cdot \frac{\overline{I_{\sim}}}{I_{\sim}} \right) \quad (4)$$

Where:

$\overline{U_{CSE,IR-free}}$	is the time average of the IR-free potential
$\overline{U_{CSE,on}}$	is the time average of the on-potential
$U_{\sim}$	is the effective value of the superimposed alternating voltage
$\overline{I_{\sim}}$	is the protection current
$I_{\sim}$	is the effective value of the alternating current

As regards the practical evaluation the time characteristics of the potential and the current are exported to Excel so that the necessary calculations can be performed by way of the statistical functions available with that programme.

Moreover, Excel makes it possible to evaluate the measurements by way of a correlation calculation, in which the correlation between the potential and the current is examined. Diagram 3 shows the result of the time characteristics shown in diagram 1. If the trend line is added, the result is a nearly linear correlation with a coefficient of determination of 99.97 %. The slope of the trend line corresponds to the real part of the ground resistance and the so-called offset to the mean IR-free potential.

As the phase shift can be neglected, the real part and the impedance of the ground resistance more or less have the same size. In the shown example the impedance is calculated to 560.11  $\Omega$  and the real part to 560.02  $\Omega$ .

The mean IR-free potential amounts to  $\overline{U_{CSE,IR-free}} = -0.977$  V according to the correlation calculation.

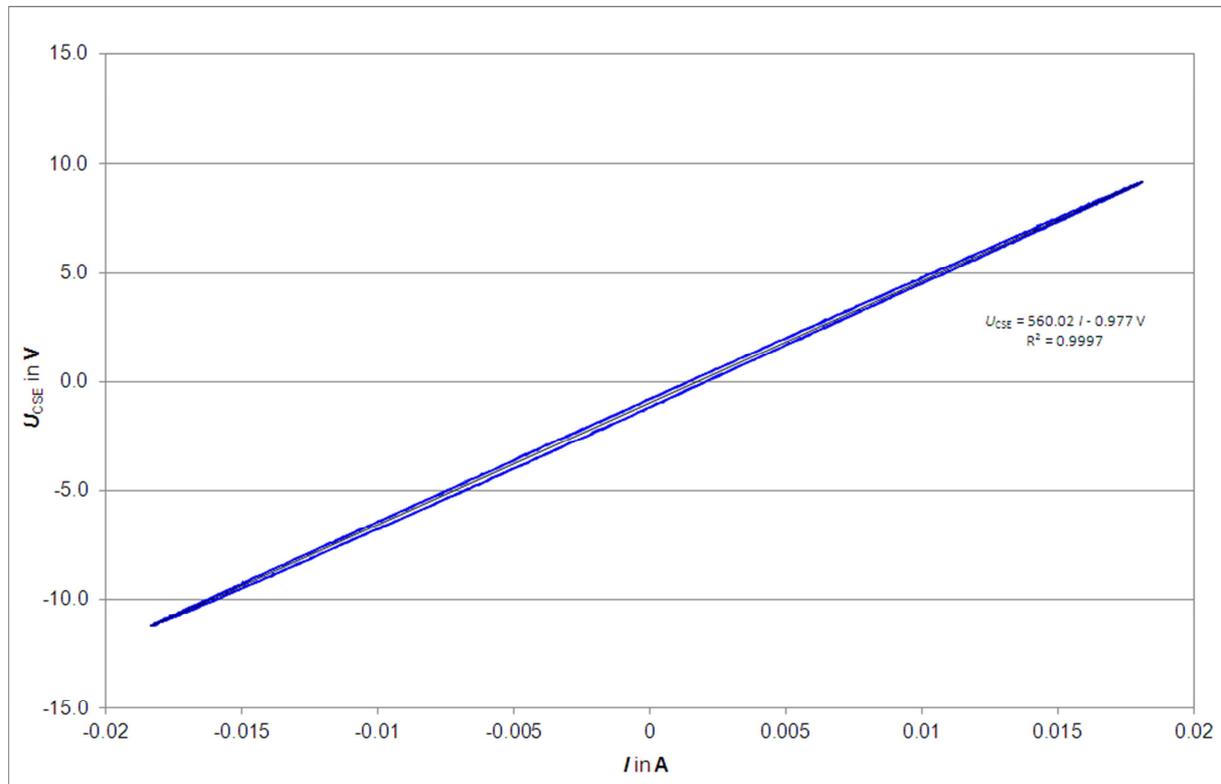


Diagram 3 – Correlation calculation: ground resistance and mean IR-free potential, 17/11/2009

As mentioned in the introduction, the values shown in diagram 1 were generated by the oscilloscope because they varied much on a time average. If the influence is constant, the values can also be measured one after the other and calculated by way of equation (4). However, it is a condition that the ground resistance is nearly purely ohmic and that the applied measuring instruments can measure both the direct components and the alternating components exactly.

### Potential profile at the phase interface between the metal and the electrolytic solution

The IR-free potential determined via the correlation calculation was called the mean IR-free potential. The reason for this designation appears from diagram 4, which shows the potential profile at the phase boundary and which was calculated as follows on the basis of the instantaneous values:

$$u_{IR-free}(t) = u_{CSE}(t) - i(t) \cdot R \quad (5)$$

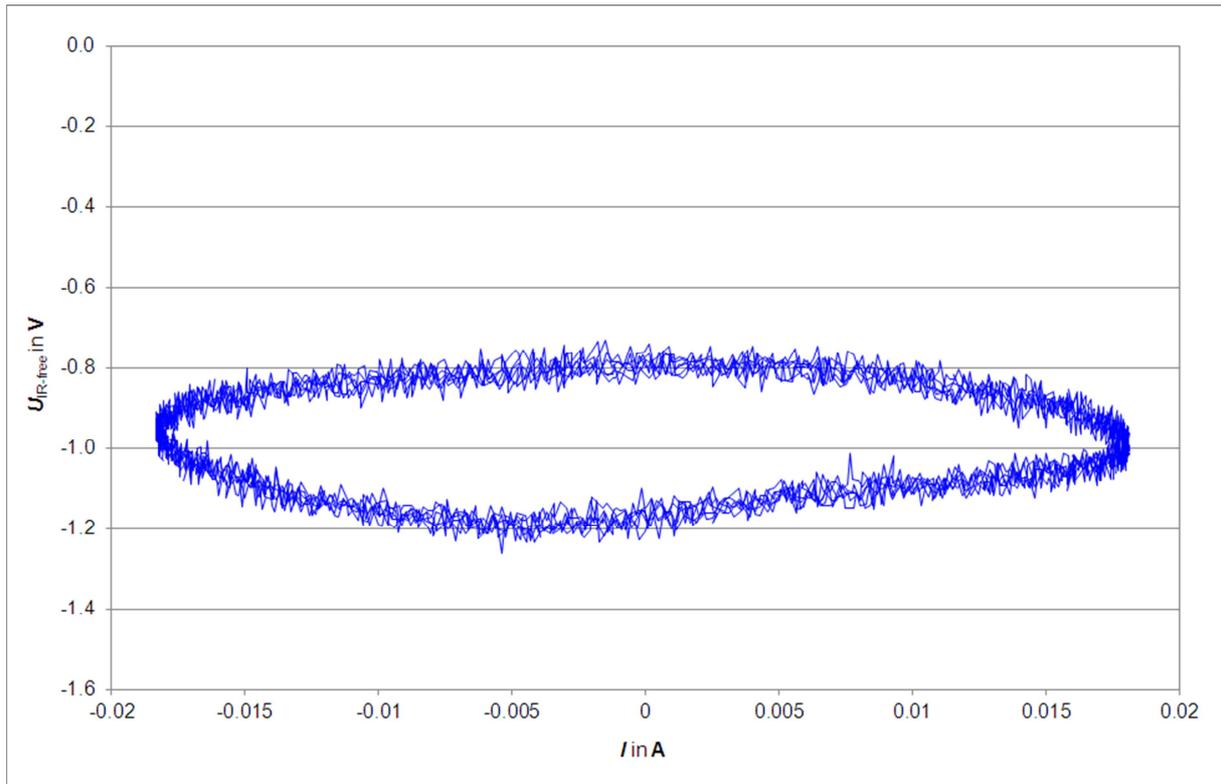


Diagram 4 – IR-free potential as a function of the flowing current, 17/11/2009

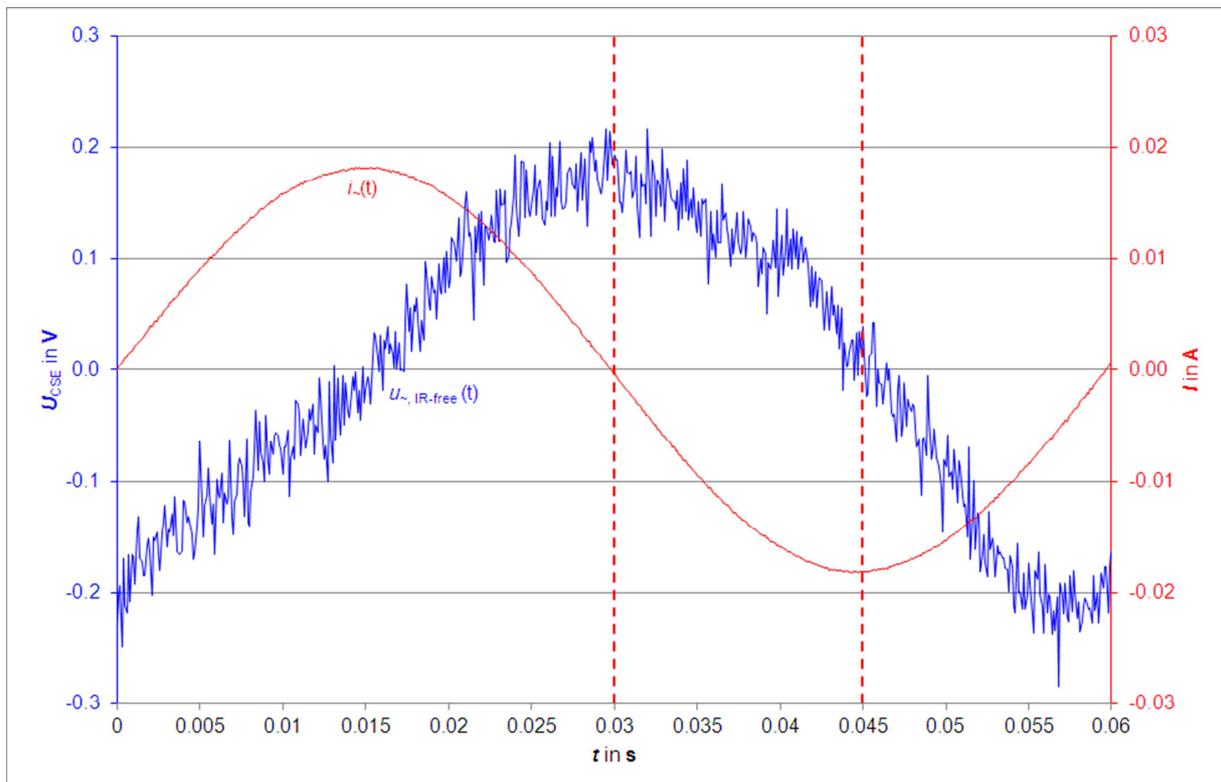


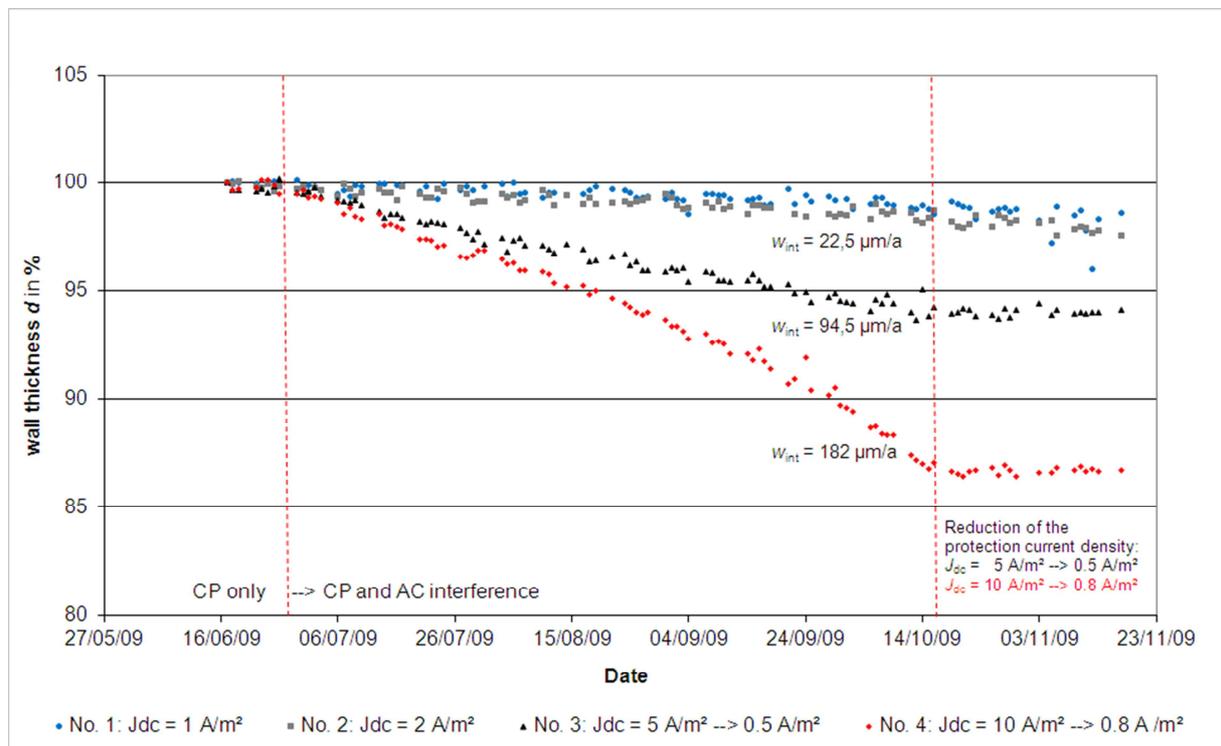
Diagram 5 – Alternating voltage and alternating current at the phase boundary between the metal and the electrolytic solution, 17/11/2009

The result is a Lissajous curve, from which it appears that the potential changes at the phase boundary as a function of the current flowing. Moreover, diagram 4 shows a certain potential noise. Diagram 5 shows the time characteristics of the alternating voltage at the phase boundary and of the alternating current flowing. The current is about 15 ms ahead of the voltage, i.e. the current is phase shifted by  $-90^\circ$ . Last year the lecturer reported that no corrosion was found during laboratory tests if the most negative potential at the phase interface is not more negative than  $-1.2$  V. At that time the potential noise was filtered out.

These results led to discussions with several experts. Thus, e.g. Dr. Büchler was of the opinion that the phase shift between alternating current and alternating voltage should be smaller than  $-90^\circ$  if corrosion takes place.

Diagram 6 shows the corrosion rates found on four ER coupons. Protective current densities from  $1 \text{ A/m}^2$  to  $10 \text{ A/m}^2$  and an alternating voltage, which changed during the time, at a frequency of  $16 \frac{2}{3} \text{ Hz}$  were supplied to these ER coupons. The time average of the alternating voltage amounted to  $7.1 \text{ V}$  at a standard deviation of  $4.7 \text{ V}$ .

At the beginning the ER coupons, to which a protective current density of  $5 \text{ A/m}^2$  and  $10 \text{ A/m}^2$  was supplied, showed noteworthy corrosion rates of  $94.5 \mu\text{m/a}$  and  $182 \mu\text{m/a}$ . On 16/10/2009 the protective current densities were reduced to  $0.5 \text{ A/m}^2$  and  $0.8 \text{ A/m}^2$ , respectively.



Below the results of the tests on ER coupon No. 4 on 17/11/2009 (no corrosion) and on 01/10/2009 (corrosion) are described.

Diagrams 1 to 5, which I have already shown, were made on 17/11/2009, i.e. at a time at which corrosion did not occur anymore. As the phase shift amounted to  $-90^\circ$ , the alternating current flowing through the phase boundary between the metal and the electrolytic solution is a fully capacitive current, which does not cause a Faraday mass change. Thus, only the protective current flows through the phase boundary. Diagram 7 shows the correlation between the potential at the phase boundary and the current decisive for the corrosion procedures. The important characteristic values and Diagrams of the described evaluation are summed up in table 1, see page 12.

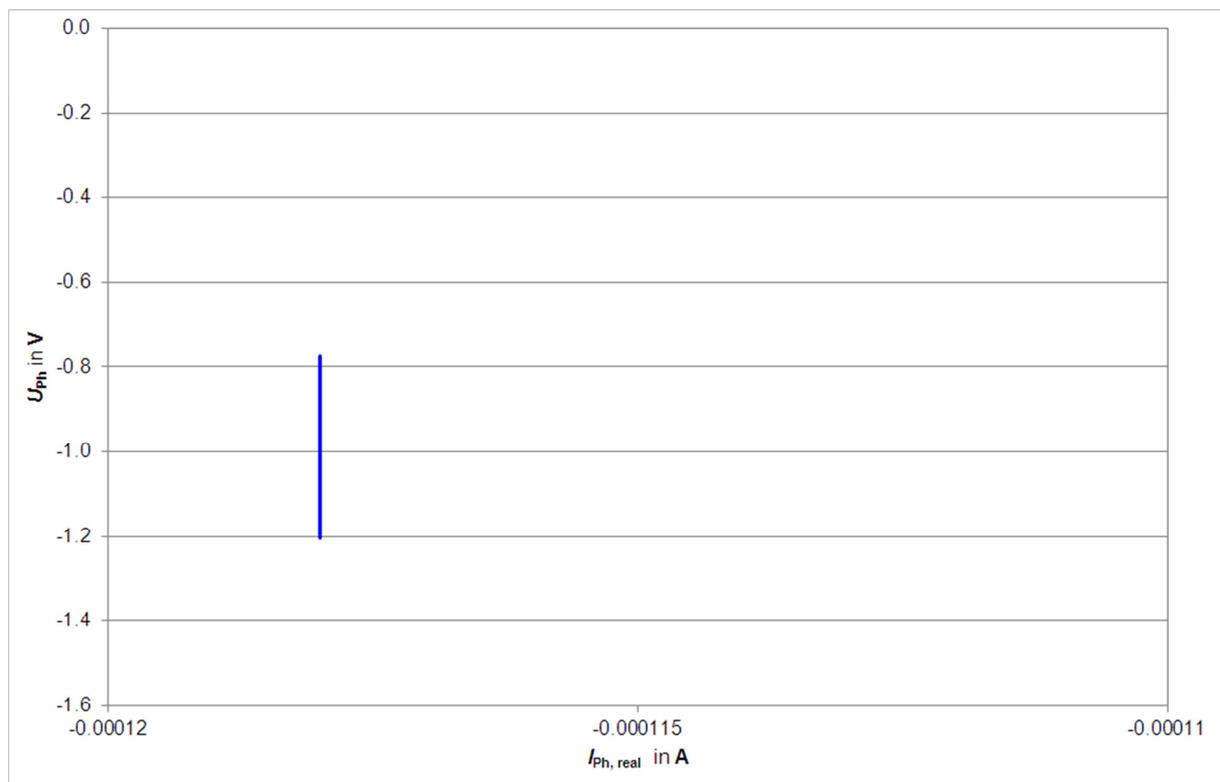


Diagram 7 – IR-free potential and current flowing through the phase boundary, 17/11/2009

On 01/10/2009 the time characteristics shown in diagram 8 were generated on the ER coupon by the oscilloscope. The subsequent correlation calculation, diagram 9, shows a ground resistance of  $214.7 \Omega$  and a mean IR-free potential of  $U_{\text{CSE,IR-free}} = -1.025 \text{ V}$ .

The actual characteristics of the IR-free potential appear from diagram 10 as a function of the total current flowing. It is seen that the potential at the phase boundary is temporary more negative than  $-1.2 \text{ V}$ . From diagram 11 it appears that the alternating current is  $14.5 \text{ ms}$  ahead of the alternating voltage, i.e. there is a phase shift of  $-87^\circ$ . Thus, a real alternating current, which is superimposed by the protective current and which can cause material removal, flows through the phase interface between the metal and the electrolytic solution.

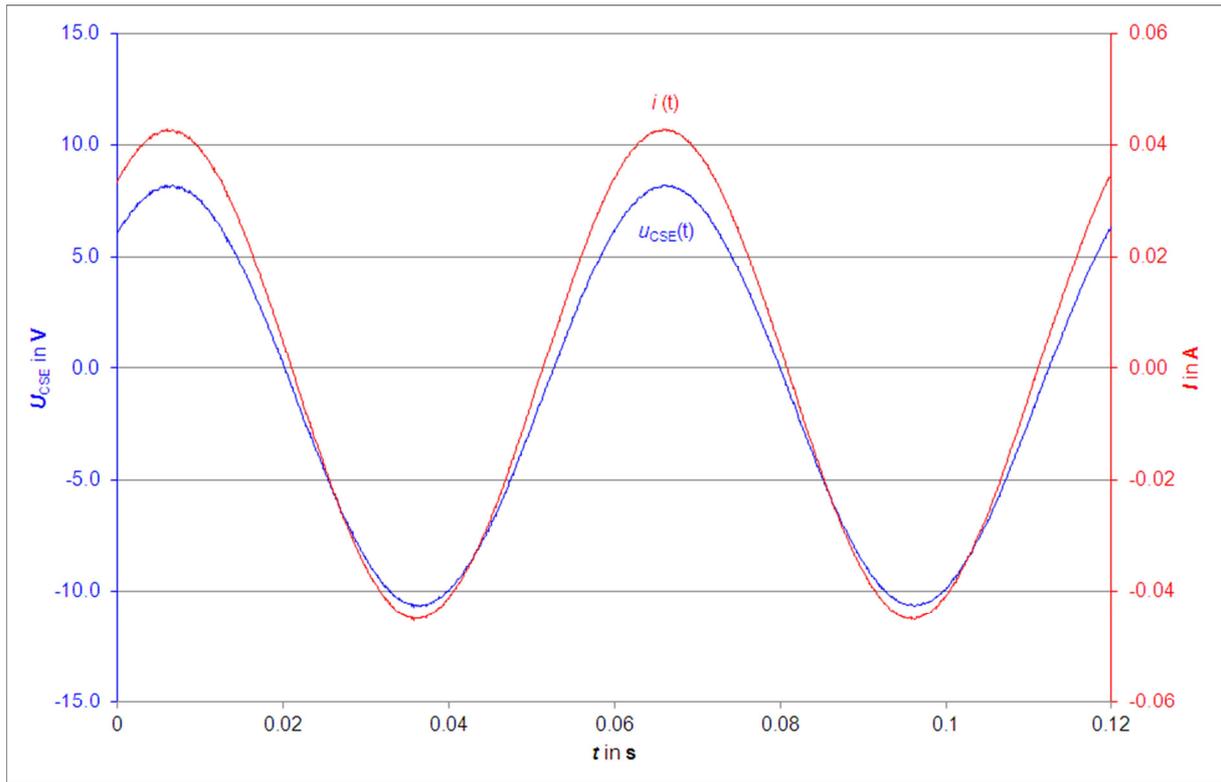


Diagram 8 – Coupon/ground potential and total current flowing, 01/10/2009

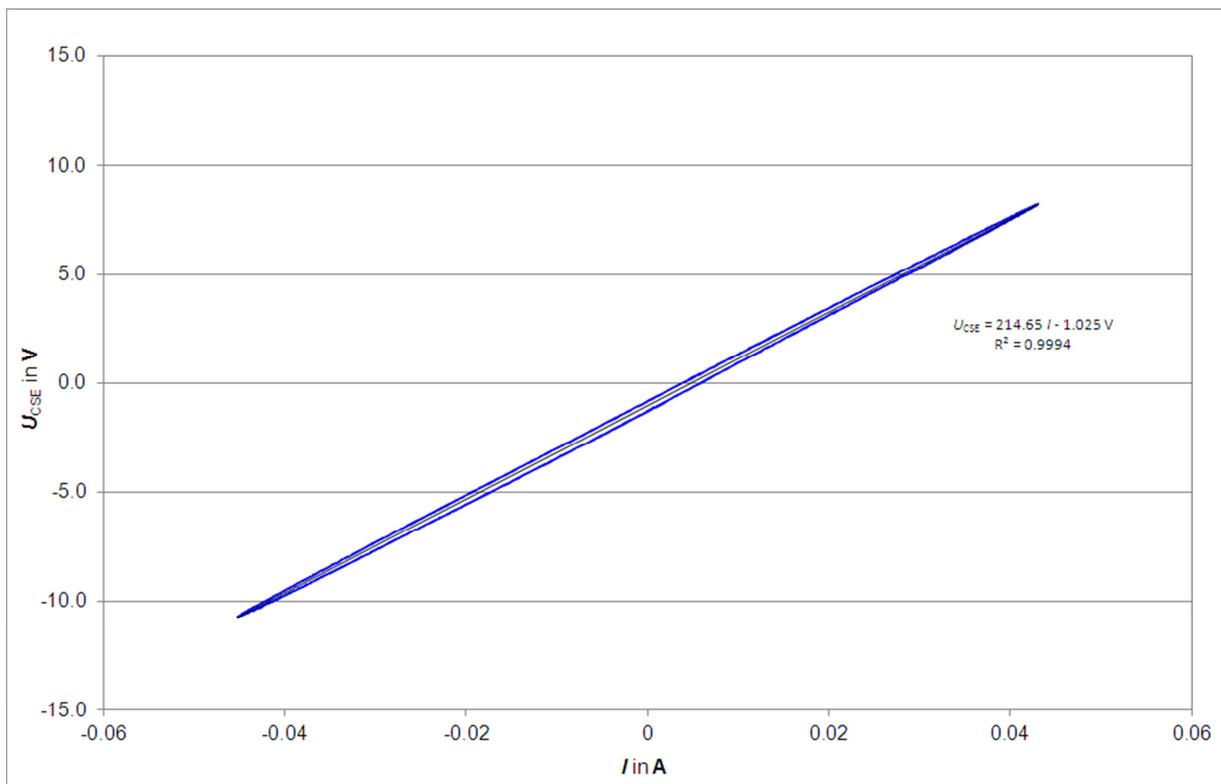


Diagram 9 – Correlation calculation: ground resistance and mean IR-free potential, 01/10/2009

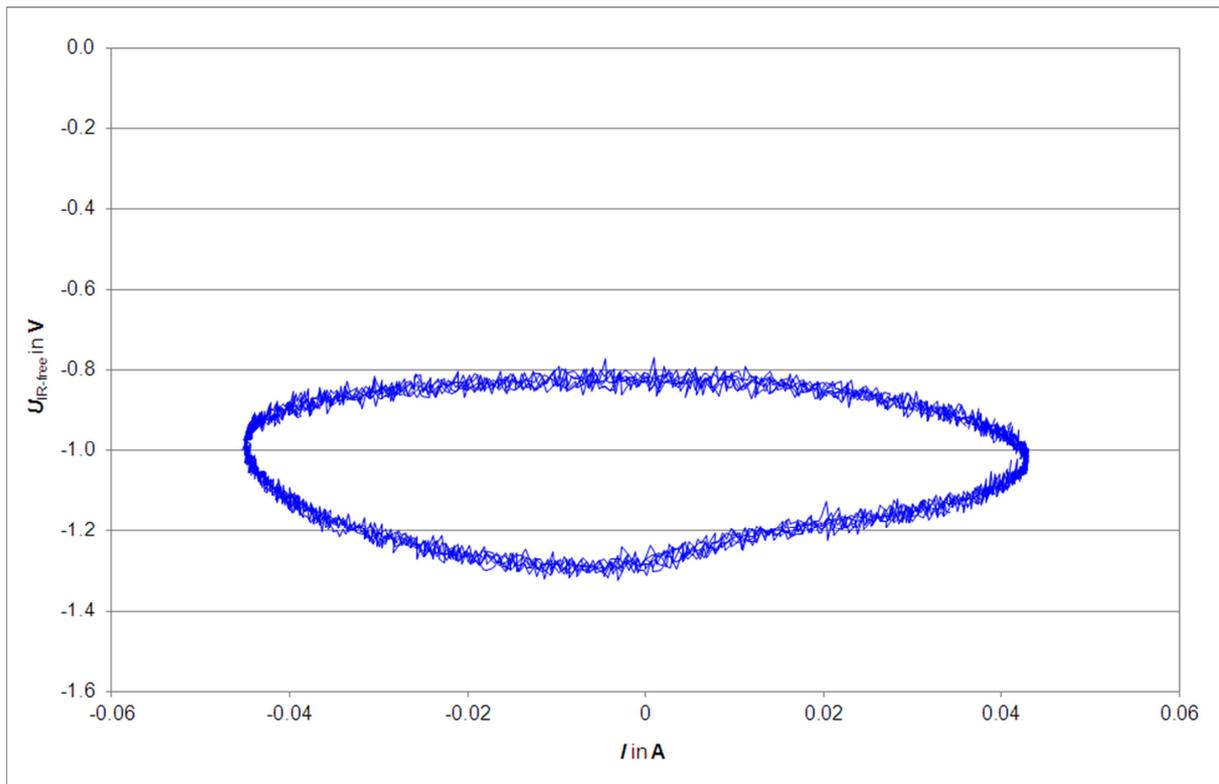


Diagram 10 – IR-free potential as a function of the flowing current, 01/10/2009

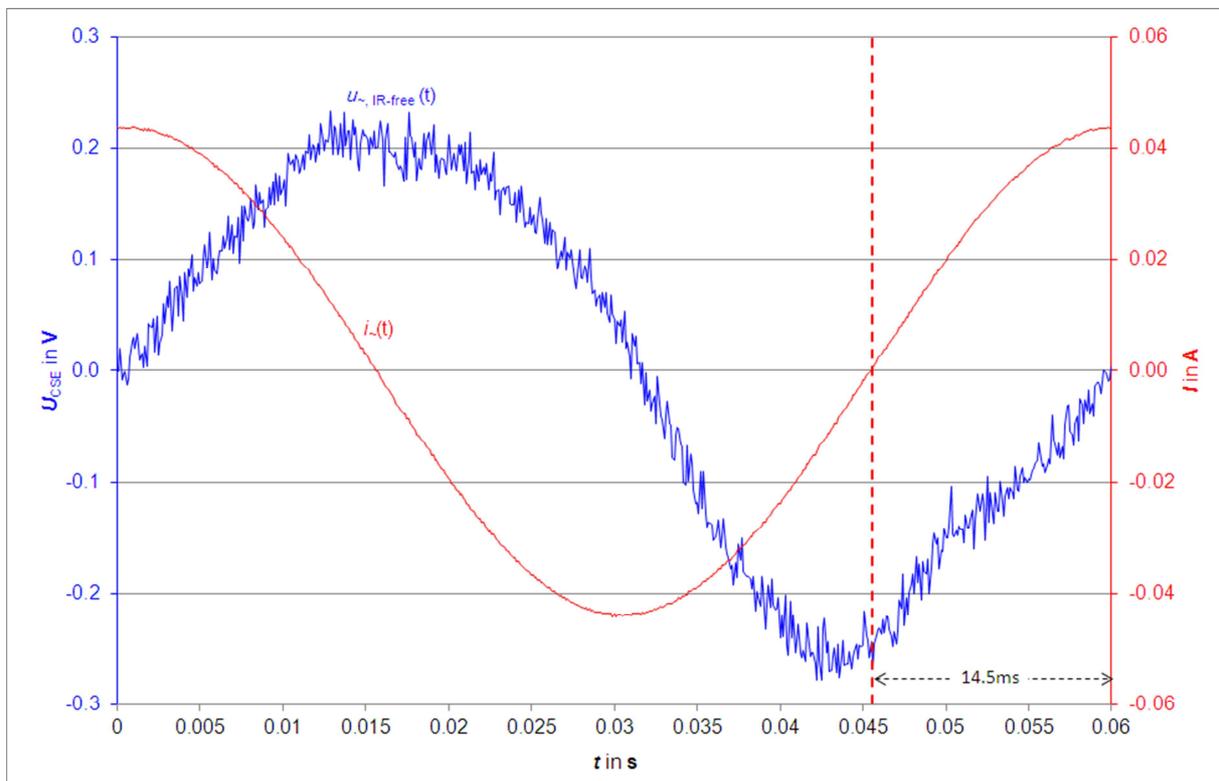


Diagram 11 – Alternating voltage and alternating current at the phase boundary between the metal and the electrolytic solution, 01/10/2009

ER Coupon No. 4: 17/11/2009

$ Z $ in $\Omega$	$U_{IR-free}$ in V	$U_{on}$ in V	$U_{\sim}$ in V	$J_{\sim}$ in A/m <sup>2</sup>	$J_{\sim}$ in A/m <sup>2</sup>	$J \cdot J_{\sim}$	$ Z_{Ph} $ in $\Omega$	$\varphi_{Ph}$ in $^{\circ}$
560.1	-0.977	-1.034	7.2	-1.02	127.9	126.0	10.26	-90

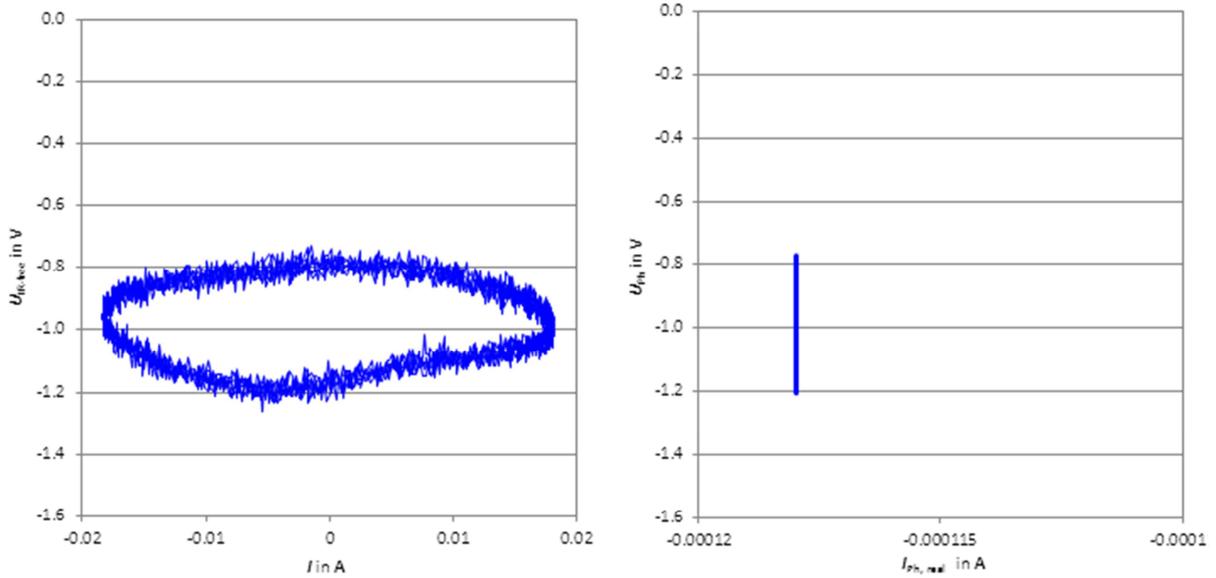


Table 1 – Characteristic values for CP on ER coupon, coupon is protected

ER Coupon No. 4: 01/10/2009

$ Z $ in $\Omega$	$U_{IR-free}$ in V	$U_{on}$ in V	$U_{\sim}$ in V	$J_{\sim}$ in A/m <sup>2</sup>	$J_{\sim}$ in A/m <sup>2</sup>	$J \cdot J_{\sim}$	$ Z_{Ph} $ in $\Omega$	$\varphi_{Ph}$ in $^{\circ}$
214.7	-1.025	-1.254	6.6	-10.68	309.0	28.9	5.09	-87

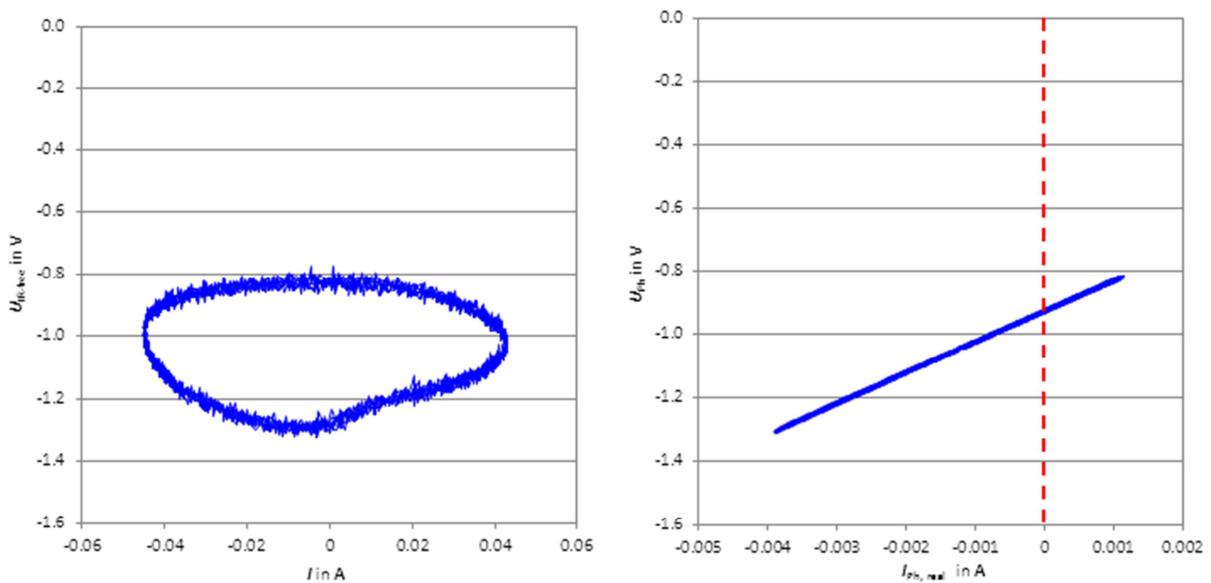


Table 2 – Characteristic values for CP on ER coupon, corrosion actually takes place

Table 2 shows the values and diagrams relevant to the cathodic corrosion protection. The left diagram shows - as already mentioned - that the IR-free potential is temporary more negative than -1.2 V. The right diagram shows that current actually leaves the ER coupon via the phase boundary. Both facts indicate that AC corrosion actually takes place.

During the evaluation of the measurements it was noticed that the selected sampling rate is apparently still too low. The sampling rate of 0.1 ms corresponds to a resolution of merely  $0.6^\circ$  at  $16\frac{2}{3}$  Hz and of  $1.8^\circ$  at 50 Hz relating to the phase shift.

## **Outlook**

Up to now, the described observations have only been proved under laboratory conditions. Therefore, these correlations will be further examined during the next two years in a field test promoted by the "Klaproth-Stiftung" (Klaproth Foundation). This foundation supports e.g. science and research, especially in the field of railway and transport. The field tests will be performed by the Laboratory for Cathodic Protection and Interference of the Technische Akademie Wuppertal. DB Systemtechnik GmbH will be the responsible partner. One of the main objectives of these tests is to prove that the permissible values mentioned in FprEN 15280 also apply to alternating voltages varying much on a time average at a frequency of  $16\frac{2}{3}$  Hz.