A.C. Corrosion – Results of Measurements on ER-Coupons with a 16-Bit-Digital- Oscilloscope

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Abstract

Within the scope of laboratory tests of a.c. corrosion measurements were made on ER-coupons with a 16-bit-digital-oscilloscope. The synchronous registration of the probe current and the probe to soil potential made it possible to directly determine the applied alternating voltage and the flowing alternating current, their frequency and the on-potential as well as the protective current entering the probe. Furthermore, the ground resistance and the off-potential were found by way of the subsequent correlation calculation without disconnecting the probe. The evaluation of the measurements shows that the a.c. earth resistance and the d.c. earth resistance is almost the same, i.e. almost purely ohmic. If the voltage drop calculated from the earth resistance and the flowing current is subtracted from the potential measured, the potential profile at the metal/electrolyte interface is found, which shows a phase shift as against the current. An equivalent circuit diagram of a fault location under a.c. influence deviating from the familiar equivalent circuit diagram follows from the results of these tests.

Wechselstromkorrosion – Ergebnisse von Messungen an ER-Coupons mit einem 16-Bit-Digital-Speicher-Oszilloskop

Zusammenfassung

Im Rahmen von Laboruntersuchungen zur Wechselstromkorrosion wurden Messungen an ER-Coupons mit einem 16-Bit-Digital-Speicher-Oszilloskop durchgeführt. Die synchrone Erfassung von Messprobenstrom und Messproben/Boden-Potential ermöglichten, die anstehende Wechselspannung und den fließenden Wechselstrom, deren Frequenz und das Einschaltpotential sowie den in die Messprobe eintretenden Schutzstrom direkt zu bestimmen. Durch nachfolgende Korrelationsrechnung erhält man außerdem den Ausbreitungswiderstand und das Ausschaltpotential ohne die Messprobe zu takten.

Die Auswertung der Messungen zeigt, dass Wechselstrom- und Gleichstrom-Ausbreitungswiderstand nahezu gleich sind, d.h. nahezu rein ohmsch sind. Wird der aus dem Ausbreitungswiderstand und dem fließenden Strom berechnete IR-Anteil von dem gemessenen Potential subtrahiert, ergibt sich der Potentialverlauf an der Phasengrenze Metall/Elektrolytlösung, der gegenüber dem Strom eine Phasenverschiebung aufweist. Aus den Ergebnissen dieser Messungen ergibt sich das Ersatzschaltbild einer Fehlstelle unter Wechselspannungsbeeinflussung, das von dem geläufigen Ersatzschaltbild abweicht.

Corrosion c.a. – Résultats des mesures en éprouvettes ER avec un oscilloscope numérique 16 bits

Résumé

Dans le cadre d'essais en laboratoire sur la corrosion c.a., des mesures ont été effectuées en éprouvettes ER avec un oscilloscope numérique 16 bits. L'enregistrement synchrone du courant de sonde et du potentiel sonde/terre a permis de déterminer directement la tension alternative appliquée et le courant alternatif passant, leur fréquence et le potentiel On, ainsi que le courant de protection entrant dans la sonde. En outre, la résistance de terre et le potentiel Off ont été déterminés par le calcul de corrélation ultérieur sans détacher la sonde. L'évaluation des mesures montre que la résistance c.a. de terre et la résistance c.c. de terre sont pratiquement les mêmes, c'est-à-dire presque purement ohmiques. Si la chute de tension calculée à partir de la résistance de terre et du courant passant est soustraite du potentiel mesuré, on obtient le profil potentiel aux limites de phase métal/électrolyte, qui montre un écart de phase par rapport au courant. Il se dégage des résultats de ce test un schéma électrique équivalent d'une localisation de panne sous influence c.a. différent du schéma électrique équivalent habituel.

Preliminary Remarks

Laboratory tests concerning a.c. corrosion on ER coupons from the firm of MetriCorr ApS were carried out on behalf of Amprion GmbH and the Deutsche Bahn AG.
The ER coupons were embedded in a soil solution in which no protective layer occurred due to the cathodic protection. A steel sheet bent cylindrically was used as the counter-electrode so that both the protective current and the alternating current could flow evenly to the holiday of the ER coupon from all sides. Fig. 1 shows the test set-up. The distance between the ER coupon and the counter-electrode amounted to 13 cm. The copper/copper-sulfate electrode was placed in the middle between the holiday of the ER coupon and the counter-electrode.
The ER coupon was connected to the negative pole of the rectifier and to the a.c. voltage source via a series resistor of 10 Ω to detect the flowing currents by measuring the voltage drops.

As the induced a.c. voltages can be subject to strong variations, particularly in case of railway influence, the specific values should not be measured one after the other as usual, but synchronously. The results of the first tests with a standard two-channel digital oscilloscope were not satisfactory as the resolution of the oscilloscope was insufficient. Many standard digital oscilloscopes have a resolution of 8 bits. If the a.c. voltage to be measured amounts to e.g. 25 V, the oscilloscope is to be set to a measuring range of 10 V/Div., which corresponds to 80 V. The resolution then amounts to 0.31 V, which is not acceptable for determining the on- and off-potentials. Therefore, the measurements were made with a two-channel USB oscilloscope, see Fig. 2, which has got a resolution of 16 bits and which can be connected directly to a notebook so that the values can be recorded for a relatively long period, just as in case of a datalogger. With reference to the above mentioned example the resolution then amounts to 1.2 mV. The sampling rate was set to 10 000 measurements/sec.

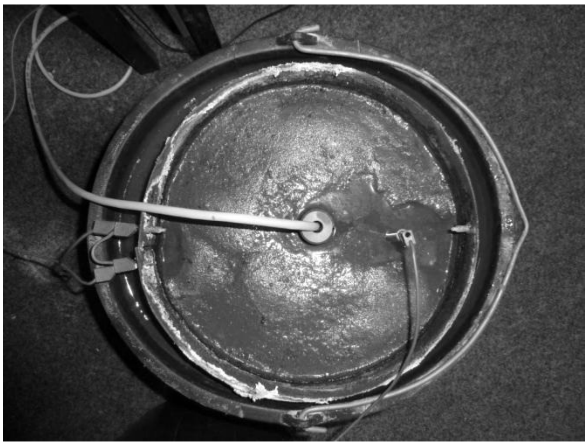

Fig. 1 – Test set-up

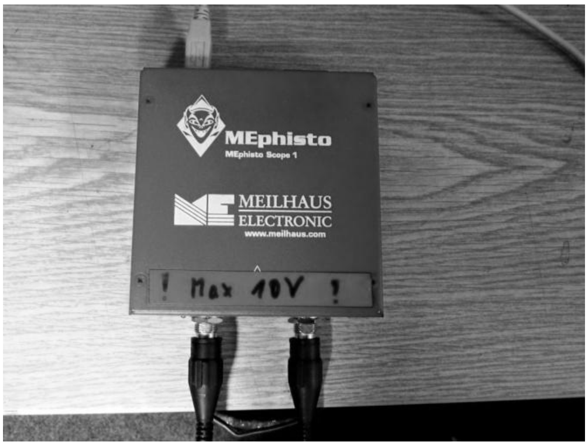

Fig. 2 – USB oscilloscope

Evaluation of the Oscillograms

Diagram 1 is an example of the time characteristics of the coupon/ground potential (blue) measured on an ER coupon with the USB oscilloscope and of the current (red). This ER coupon was protected cathodically. An alternating current of 16.7 Hz was applied to it.

In the zero crossing area the current seems to be ahead of the potential, which at first indicates a phase shift. However, a phase shift cannot be ascertained as the potential and the current reach their maximum values. A correlation calculation, in which the correlation between the potential and the current is examined, see diagram 2, results in a straight line with a coefficient of determination of 99.96 %. The gradients of the straight lines correspond to the ohmic earth resistance of the ER coupon; it amounts to 441.4 Ω. The earth resistance measured with an a.c. measuring bridge also amounts to 441 Ω. Thus, it follows that it may be assumed in practice that the d.c. resistance and the a.c. resistance are equal.

The so-called offset of the line equation determined corresponds to the mean off-potential; it amounts to $U_{CSE, off}$ = -0.99 V. Therefore, it is not necessary to disconnect the probe.

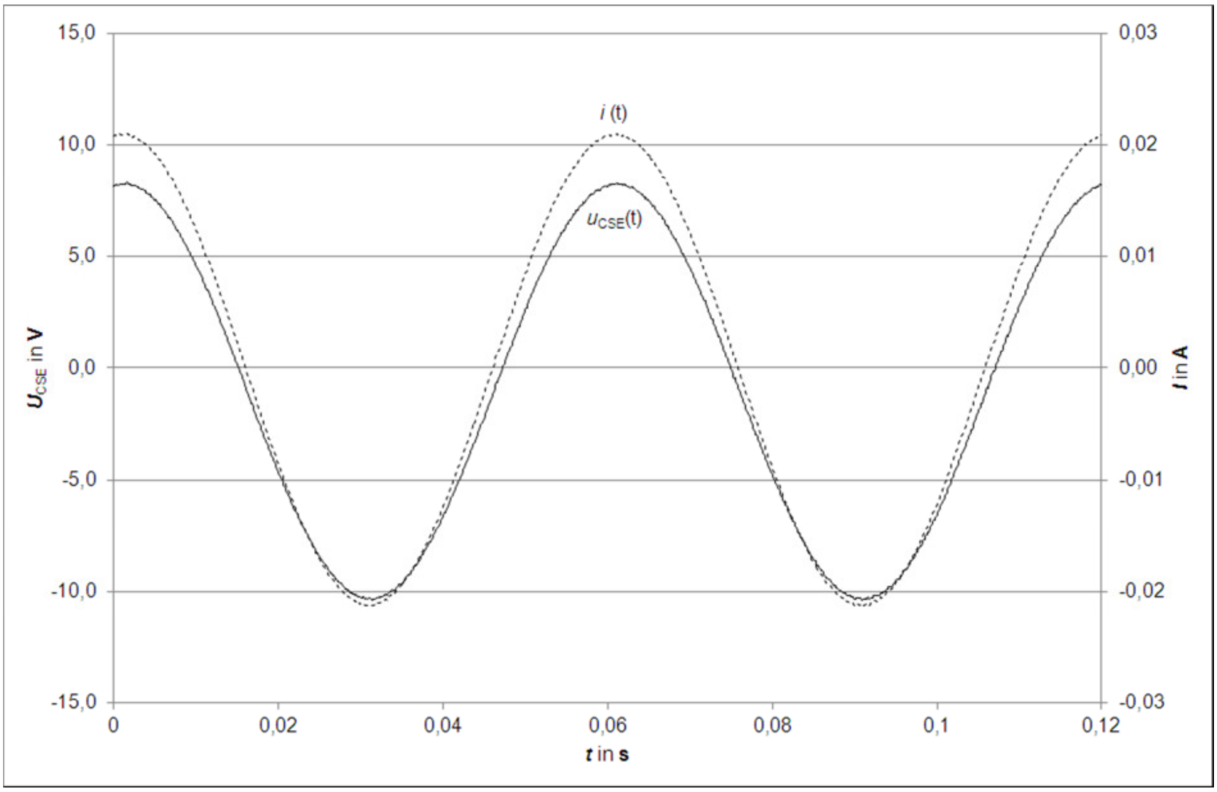

Diagram 1 – Coupon potential and current

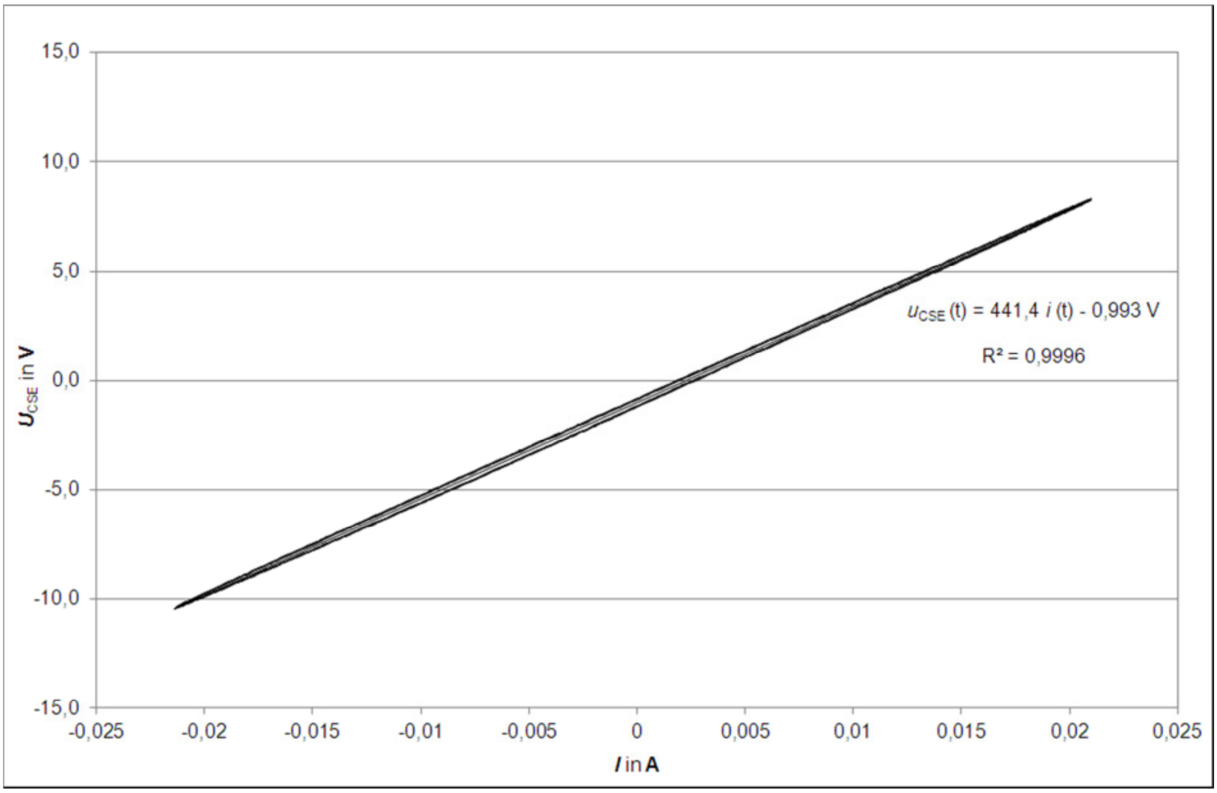

Diagram 2 – Correlation between coupon potential and current

A statistical evaluation of the values generated by the oscilloscope shows that the on-potential amounts to $U_{CSE,\ on}$ = -1.04 V, the a.c. voltage to $U_{\sim}$ = 6.6 V, the protection current density to J_{dc} = -1.2 A/m^2 and the a.c. current density to J_{ac} = 149 A/m^2.
It has to be born in mind that the statistical evaluation was made over a period that corresponds to the period of oscillation of the fundamental frequency of the superimposed alternating voltage or the multiple.
The ratio of the a.c. current density to the protection current density amounts to 124.

Moreover, it appears from diagram 2 that the instantaneous values of the coupon potential deviate from the mean off-potential at the time I = 0 and depend on whether the cathodic or the anodic half-wave of the a.c. voltage had been superimposed. Diagram 3 shows the appertaining detail of diagram 2.

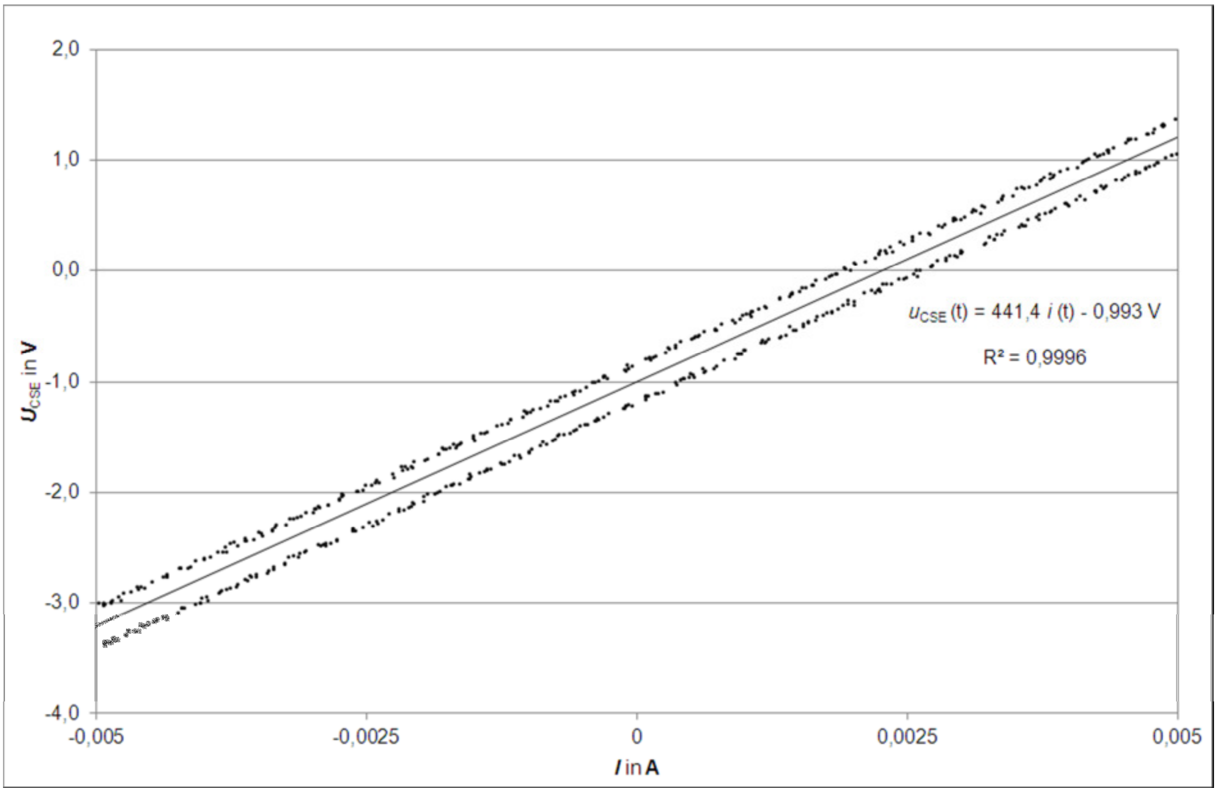

Diagram 3 – Detail of diagram 2

The IR drop coupled into the potential measurement was calculated by multiplying the current flowing through the probe with the earth resistance calculated beforehand. Afterwards, this IR drop was subtracted from the potential measured with the oscilloscope. The resulting IR-free potential is shown in diagram 4 as a function of the current. A Lissajous figure is created. The potential contains a certain noise, which was filtered out in diagram 5.
The impedance of the metal/electrolyte transition was calculated on the basis of the IR-free potential shown in diagram 4 and the flowing current; it amounts to 8.26 Ω.

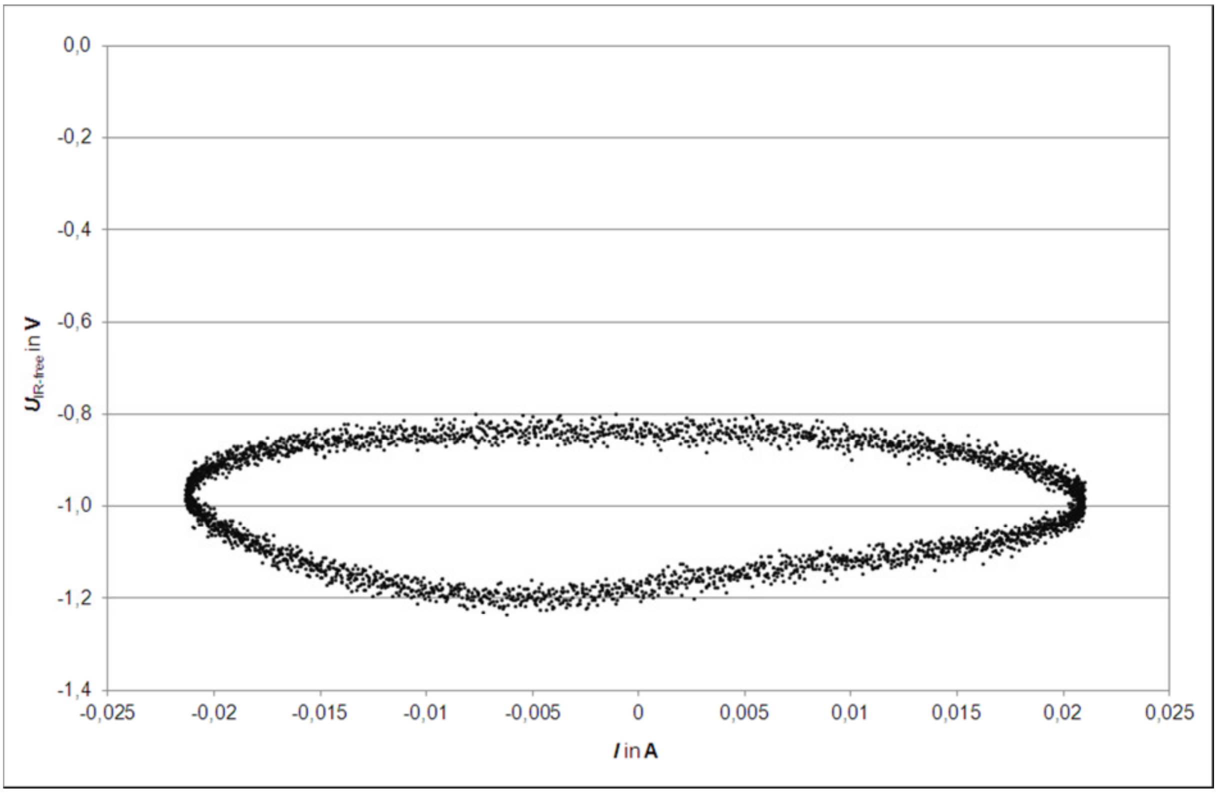

Diagram 4 – IR-free potential of the coupon and current

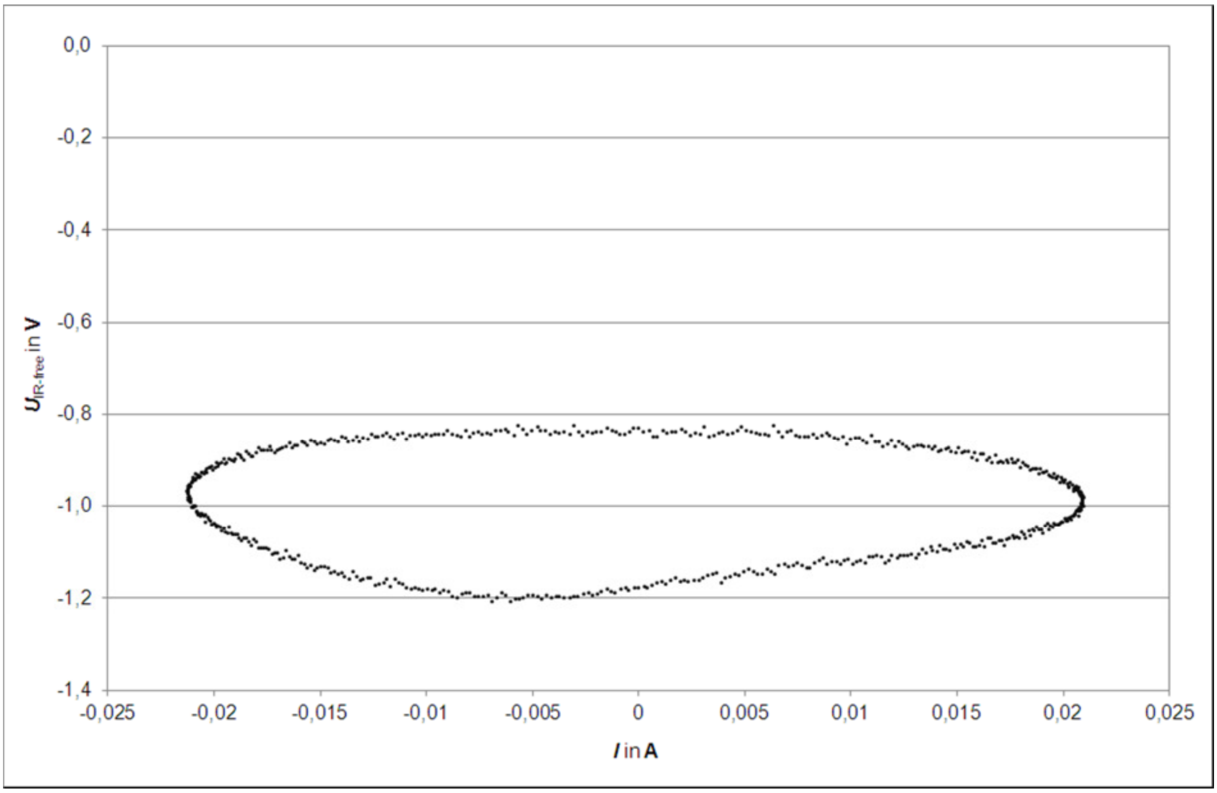

Diagram 5 – Mean IR-free potential of the coupon and current

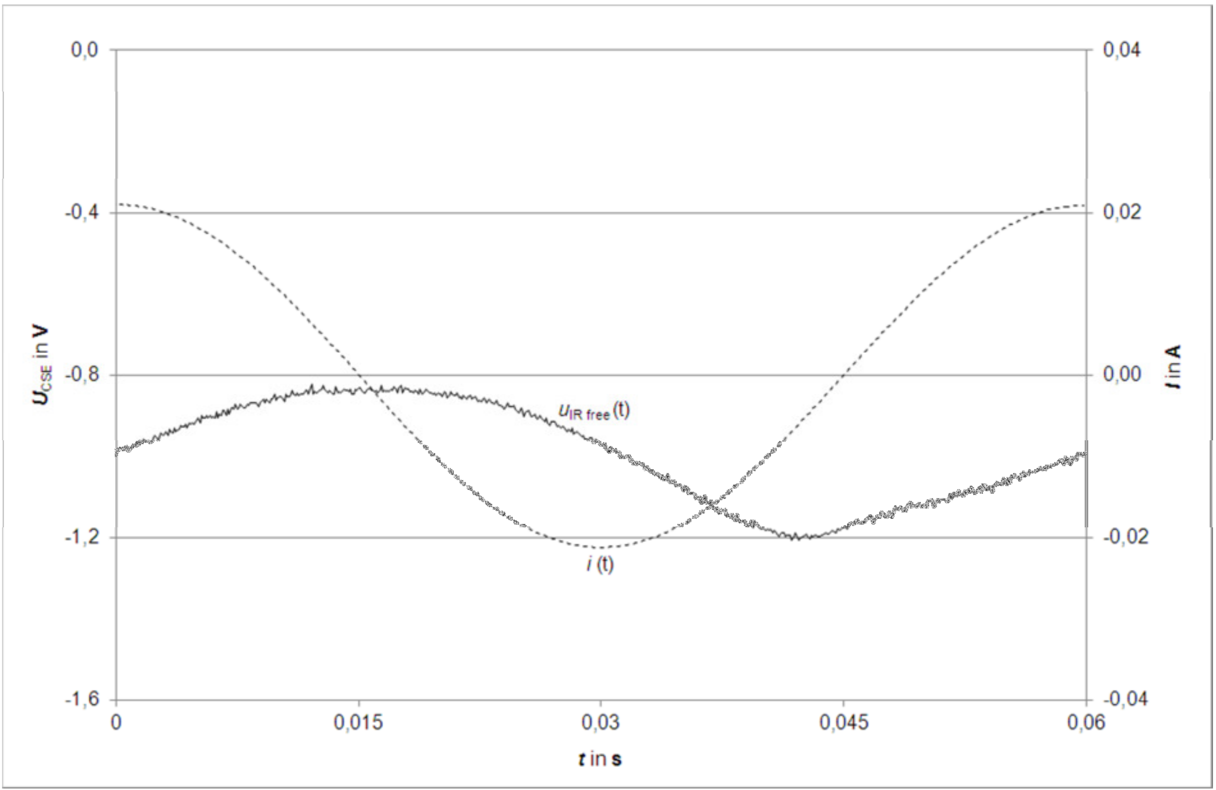

Diagram 6 – IR-free potential and current

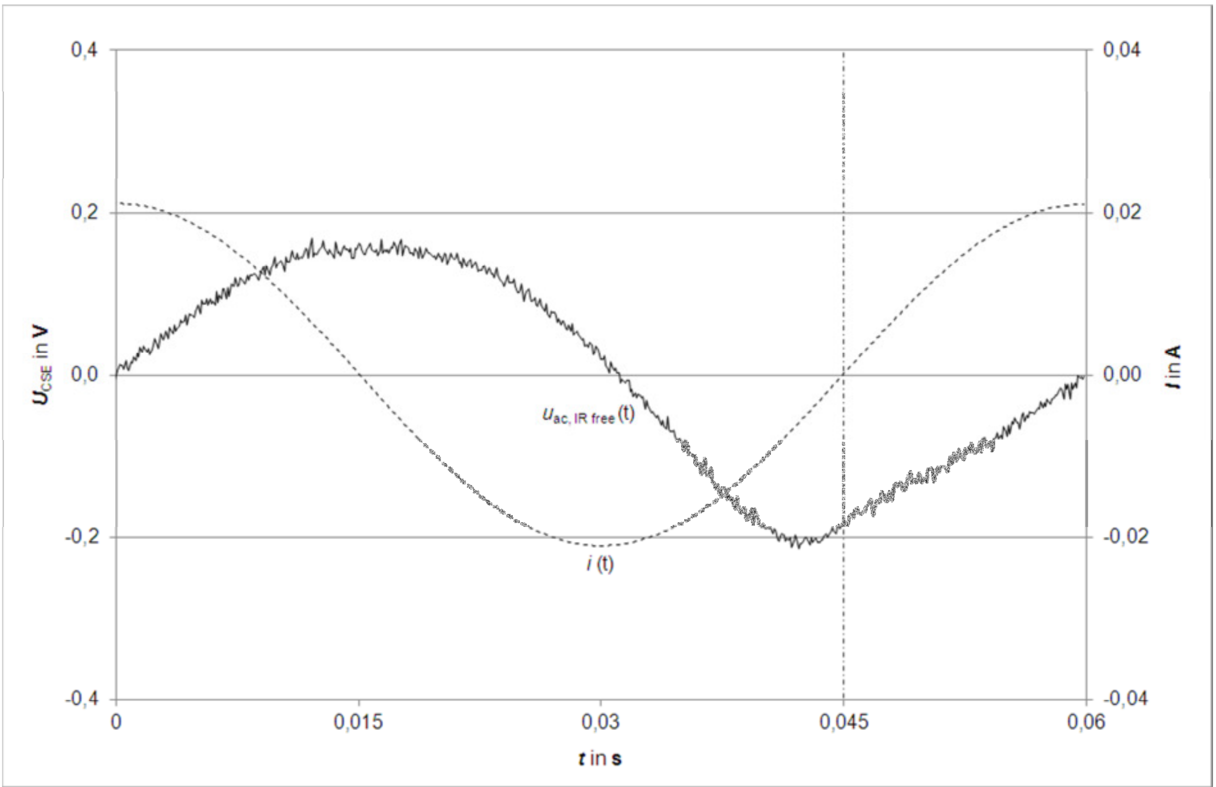

Diagram 7 – A.c. potential at the metal/electrolyte transition and current

Diagram 6 shows the time characteristics of the IR-free potential and the current. The time characteristics of the a.c. parts are calculated by subtracting the d.c. parts of the IR free potential, see diagram 7. Hence, the time lag between the zero crossings of the potential and the current was determined. In the example the current is about 15 ms ahead of the voltage. A phase shift of -90° results for the period of oscillation of the applied a.c. voltage, i.e. 60 ms. The capacity of the metal/electrolyte interface is calculated to 1 154 µF on the basis of the above mentioned impedance of 8.26 Ω and the frequency of 16.7 Hz.

Results of the Measurements with the Oscilloscope

The above described measurements were made on several ER coupons. These probes were protected cathodically with different on-potentials, and a.c. voltages of different levels were applied to them. Thereafter, the oscillograms were evaluated as described above.
The following values were determined:

on-potential,
mean off-potential,
protection current density,
a.c. voltage,
a.c. current density,
ratio of a.c. current density to protection current density,
earth resistance,
impedance of the metal/electrolyte interface and
characteristic of the IR-free potential.

In all cases there was no phase shift when the potential and the current reached their maximum values, which means that the earth resistances determined in a correlation calculation can in practice be regarded as the purely ohmic resistances. When the IR drop has been subtracted, similar Lissajous figures developed, as shown in diagrams 4 and 5. The phase shift amounted to about -90° in all cases, the corresponding impedances showed capacities of the metal/electrolyte interfaces between 1 000 µF and 4 000 µF.
Thus, under a.c. influence the metal/electrolyte interface shows to be an accumulator, the ohmic internal resistance of which can be neglected.
Therefore, a holiday in the outer coating of an a.c. influenced, cathodically protected pipe can be regarded as a series connection of an accumulator and an ohmic earth resistance. The usual representation of a holiday as a parallel circuit of the polarization capacity and the polarization resistance (metal/electrolyte interface) in series with the earth resistance could not be ascertained in the tests. Furthermore it was found that the capacity of the metal/electrolyte interface is substantially larger than the polarization capacity.

Moreover, the evaluation of the measurements showed that the impedances of the metal/electrolyte interfaces are much smaller than the ohmic earth resistances. Usually, they are less than 2 % of the ohmic earth resistance. As the distance between the copper/copper-sulfate electrode placed on the earth and the holiday is much bigger in practice than in laboratory tests, the ratio of impedance of the metal/electrolyte interface to the ground resistance might be even smaller.

In addition, no corrosion was found on the ER coupons if the characteristic of the IR-free potential, as shown in diagrams 4 and 5, is not more negative than -1.2 V.

Outlook

The realisation that there is no corrosion if the instantaneous values of the IR-free potential are usually not more negative than -1.2 V is to be examined in further tests on pipes by way of probes. If the present laboratory test results are confirmed by field tests, further examinations will be made to determine the IR-free potential characteristic of real holidays in the outer coating of pipes. The examinations will be based on the intensive measurement techniques. The pipe-to-soil potential and the potential gradient are recorded with an USB oscilloscope and evaluated. By analogy with the above described measurements the characteristic of the IR-free potential will then be determined as both the potential gradient and the voltage drop on the 10 Ω series resistance are proportional to the IR drop. Within the scope of these examinations a measuring method is to be developed that makes it possible to assess the risk of a.c. corrosion at holidays in the outer coating of pipes.