Methodology for Evaluation of a.c. Corrosion Risk Using Coupon d.c. and a.c. Current Densities

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Abstract

In 1986, corrosion failure on a pipeline caused by induced a.c. interference currents was first reported in Europe despite satisfying the protection potential criterion. The pipeline was installed in 1980 paralleling a 15 kV a.c. traction system which operated at frequency of 16-2/3 Hz. Since the mid 1980's, pipeline failures caused by a.c. corrosion have been reported not only in Europe but in North America. A.c. interference currents with frequencies of 16-2/3, 50 or 60 Hz originating from high voltage electric power lines and/or a.c. traction systems can cause corrosion. Today it is acknowledged that, the a.c. corrosion risk of cathodically protected pipelines with high coating resistance values must be evaluated by installing steel coupons at pipe depth and measuring the coupon d.c. and a.c. current densities when the coupon is connected to the pipe.

The author has developed an innovative instrumentation for assessing the a.c. corrosion risk of cathodically protected pipelines caused by frequencies of 16-2/3, 50 or 60 Hz by using coupon d.c. and a.c. current densities. Immediately after obtaining the average coupon d.c. and a.c. current densities over a period of measurement time, the results can be evaluated by referring to prEN 15280.

Methodik zur Beurteilung des Risikos der Wechselstromkorrosion unter Verwendung von Probeplatten für Gleich- und Wechsel-Stromdichten

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Zusammenfassung

Trotz Erfüllung des Schutzpotential-Kriteriums wurde in Europa im Jahr 1986 erstmals über verursachte Korrosionsschäden an einer Rohrleitung durch induzierte Wechselstrominterferenzen berichtet. Die Rohrleitung wurde 1980 parallel zu einer 15-kV-Bahnlinie mit einer Frequenz von 16-2/3 Hz verlegt. Seit Mitte der 1980er Jahre wurden Rohrbrüche durch Wechselstromkorrosion nicht nur in Europa, sondern auch in Nordamerika gemeldet. Wechselstrominterferenzen mit Frequenzen von 16-2/3, 50 order 60 Hz von Wechselstrom-Hochspannungsleitungen order Straßen- und Stadtbahnsystemen mit Wechselspannung können Korrosion verursachen. Es ist heute unbestritten, dass das Wechselstromkorrosionsrisiko für Rohrleitungen mit sehr widerstandsfähigen Beschichtungen durch die Installation von Probeplatten aus Stahl in Rohrtiefe und die Messung der Gleichstrom- und Wechselstromdichte der an das Rohr angeschlossenen Probeplatten bewertet werden muss.

Der Autor hat ein innovatives Gerät entwickelt, das der Beurteilung des Wechselstromkorrosionsriskos für erdverlegte Rohrleitungen bei Frequenzen von 16-2/3, 50 order 60 Hz unter Verwendung von Gleichstrom- und Wechselstromdichten für die Probeplatten bezogen auf prEN 15280 dient.

Méthodologie d’évaluation du risque de corrosion C.A. utilisant des densités de courant C.A. et C.C. de coupons

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Résumé

En 1986, une défaillance due à la corrosion sur une canalisation, causée par des

courants d’interférence C.A. induits, fut signalée pour la première fois en Europe, malgré un critère de potential de protection satisfaisant. La canalisation avait été installée en 1980 parallèlement à des voies de chemin de fer électrifiées de 15 kV exploitées à la fréquence de 16-2/3 Hz. Depuis le milieu des années 1980, des défaillances de canalisations causées par la corrosion C.A. ont été signalées non seulement en Europe, mais aussi en Amérique du Nord. Les courants d’interférence C.A. aux fréquences de 16-2/3, 50 ou 60 Hz provenant de lignes de transport électrique C.A. haute tension ou de systèmes de transport ferroviaire alimentés par C.A. peuvent causer de la corrosion. Aujourd’hui, il est admis que le risque de corrosion C.A. de canalisations à revêtement haute résistivité doit être évalué en installant des coupons d’acier à la profondeur de la canalisation et en mesurant les densités de courant C.C. et C.A. du coupon lorsqu’il est relié à la canalisation.

L’auteur a mis au point une instrumentation innovante pour évaluer le risque de corrosion C.A. de canalisations enterrées causée par des fréquences de 16-2/3, 50 ou 60 Hz en utilisant des densités de courant C.C. et C.A. de coupons, en référence à prEN 15280.

1 Occurrence of a.c. corrosion

In 1986, corrosion failure on a pipeline caused by induced a.c. interference currents was first reported in Europe despite satisfying the protection potential criterion [1]. The pipeline was installed in 1980 paralleling a 15 kV a.c. traction system which operated at frequency of 16-2/3 Hz. Since the mid 1980’s, pipeline failures caused by a.c. corrosion have been reported not only in Europe but in North America [2-6].

Cathodic protection (CP) personnel have gained widespread recognition that at prevailing commercial current frequencies such as 16-2/3, 50 or 60 Hz corrosion is possible, even on cathodically protected pipelines.

The a.c. corrosion risk of modern pipelines (post-1980) is increasing, due to the technological advancements in pipe coating materials which provide very high coating resistance values and further the increased tendency to locate pipelines paralleling high voltage a.c. electric power lines and/or a.c. traction systems.

2 Lessons learned from a.c. corrosion

Lessons learned from a.c. corrosion are as follows:

- At prevailing commercial current frequencies (such as 16-2/3, 50 or 60 Hz) corrosion is possible, even on cathodically protected pipelines.

- At very small coating defects the a.c. corrosion rate would be very high even with very modest a.c. voltage. Therefore assessment of a.c. corrosion threat on the basis of a.c. voltage can be misleading.

- The a.c. current density within a coating defect is the primary determining factor in assessing the a.c. corrosion risk.

- If the a.c. current density is too high, the a.c. corrosion cannot be prevented by CP [7].

- To determine the a.c. corrosion risk, coupons should be installed. Measurements for coupon d.c. and a.c. current densities provide information on the risk of a.c. corrosion [8].

3 Concepts for the design of an innovative instrumentation

At present, no single measuring technique or criterion for the evaluation of a.c. corrosion risk is recognized to assess a.c. corrosion [7].

The author has developed an innovative instrumentation for assessing the a.c. corrosion risk of buried pipelines [9]. The instrumentation can measure coupon on-potential and d.c. and a.c. current densities continuously with high data sampling rate; store a large number of these time- and data-stamped readings; and perform mathematical calculation of coupon a.c. current density as well as statistical values such as average and standard deviation. Average coupon d.c. current density $I_{d.c.}$ and coupon a.c. current density $I_{a.c.}$ are used to provide an indication as to whether or not the results meet the acceptable interference levels offered by prEN 15280 [10].

Concepts for the design of an innovative instrumentation are described as below.

3.1 Installation of a coupon at pipe depth

Literature suggests that the most severe corrosion occurs at holiday surface area of 1 cm^2 [11], then a 1 cm^2 coupon is recommended to be installed at the pipe depth for the purpose of measuring a.c. current density. In the present field observations, however, conical shaped coupons having a surface area of 10 cm^2 were used in order to ensure full contact between the coupon surface and the surrounding electrolyte. From the extensive field observations, no possibility of significant non-uniformity of the current distribution (i.e., the current density is higher at the edge of the coupon where current lines emerge or arrive from a greater range than at the middle of the coupon) was confirmed. Steel coupons permitting accurate weighing to judge whether or not CP level is acceptable were installed in monitoring stations. The monitoring stations shall be installed above the pipeline at intervals not greater than 250 m along the pipeline. Figure 1 shows the measuring system for coupon on-potential and coupon current.

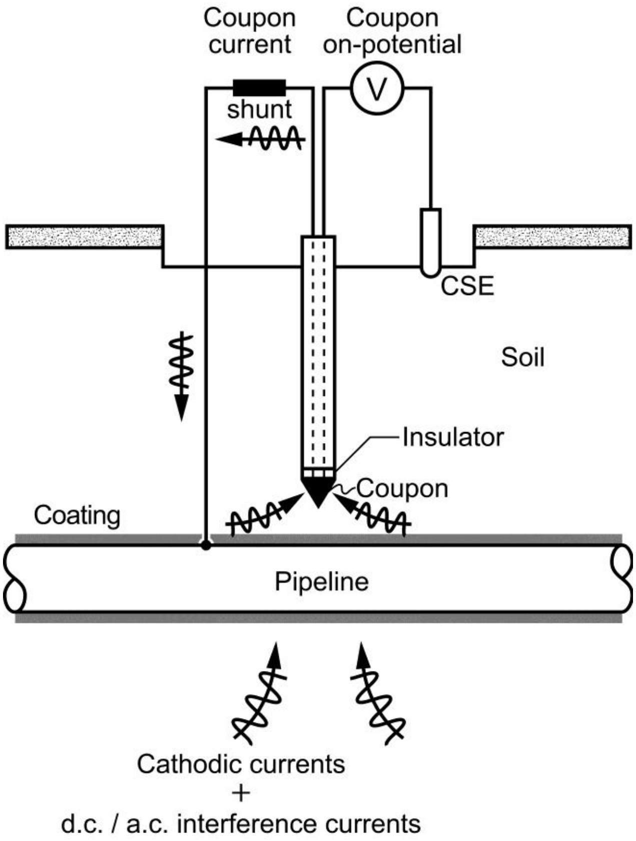

Figure 1 ─ Measuring system for coupon on-potential and coupon current

3.2 Measurement parameters

The evaluation of a.c. corrosion risk is performed by evaluation of the following parameters:

- coupon on-potential, E_{on}
- coupon d.c. current density, $I_{d.c.}$

- coupon a.c. current density, $I_{a.c.}$
- coupon a.c. current density/coupon d.c. current density ratio, $I_{a.c.}/I_{d.c.}$

3.3 Simultaneous measurements on coupon on-potential and coupon current densities with high data sampling rate

Because of advancements in electronic technology, hand-held battery-powered digital multimeters and data loggers having the capability to measure volt, resistance, capacitance, frequency, and both d.c. and a.c. current are easily used in the field. However, it is important to ascertain that frequency of the obtained coupon a.c. current density is consistent with commercial current frequency of 16-2/3 Hz or 50 Hz or 60 Hz [9].

The data on coupon on-potentials and coupon currents are measured at intervals of 0.1 ms in each monitoring station while the CP system is continuously operating. Coupon on-potential measurement with respect to a saturated copper/copper sulfate reference electrode (CSE) is taken through the voltmeter. The voltmeter has an accuracy of ±1 mV in the range of −30 V to 30 V with an input impedance of 10 megohm. In this paper, coupon current is defined as current flowing between the coupon and the pipe and measured by the voltage drop across a shunt resistor with 0,1 ohm for a 10 cm^2 coupon. In areas where d.c./a.c. interference currents induced by the passing of high speed d.c./a.c. trains are suspected, this measuring technique with high data sampling rate of 0,1 ms enables an engineer to assess the corrosion risk.

3.4 Calculation of coupon on-potentials and coupon d.c. and a.c. current densities

Coupon on-potential E_{on}, coupon d.c. current density $I_{d.c.}$ and coupon a.c. current density $I_{a.c.}$ are obtained every subunits according to commercial frequency of 16-2/3 Hz or 50 Hz or 60 Hz, from equations (1), (2) and (3), respectively, using a low pass filter with a cut-off frequency of 73 Hz to avoid abnormal electrical spikes and harmonic currents.

$$E_{on} = \frac{1}{T}\sum_{t=1}^{T} E_{on}(t) \tag{1}$$

$$I_{d.c.} = \frac{1}{A} \cdot \frac{1}{T} \sum_{t=1}^{T} I(t) \tag{2}$$

$$I_{a.c.} = \frac{1}{A} \cdot \sqrt{\frac{1}{T}\sum_{t=1}^{T} \{I(t) - I_{d.c}\}^2} \qquad (3)$$

where: A = surface area of a coupon

E_{on} (t) = instantaneous coupon on-potential at t ms in each subunit

I(t) = instantaneous coupon current at t ms in each subunit

$I_{d.c.}$ = coupon d.c. current density

$I_{a.c.}$ = coupon a.c. current density

T: 600（for 16-2/3Hz）, 200（for 50Hz）, 167（for 60Hz）

Table 1 shows measuring time of 1 subunit and 1 unit for respective frequencies of 16-2/3, 50 and 60 Hz.

Table 1 ─ Measuring time of 1 subunit and 1 unit for respective frequencies of 16-2/3, 50 and 60 Hz

Frequency	1 subunit	1 unit	
	Measuring time	Total of subunits	Measuring time
16-2/3 Hz	60 ms	200	12 s
50 Hz	20 ms	500	10 s
60 Hz	16,7 ms	500	8,35 s

To evaluate whether or not a.c. corrosion at frequency of 50 Hz will occur, measurements are taken according to Figure 2.

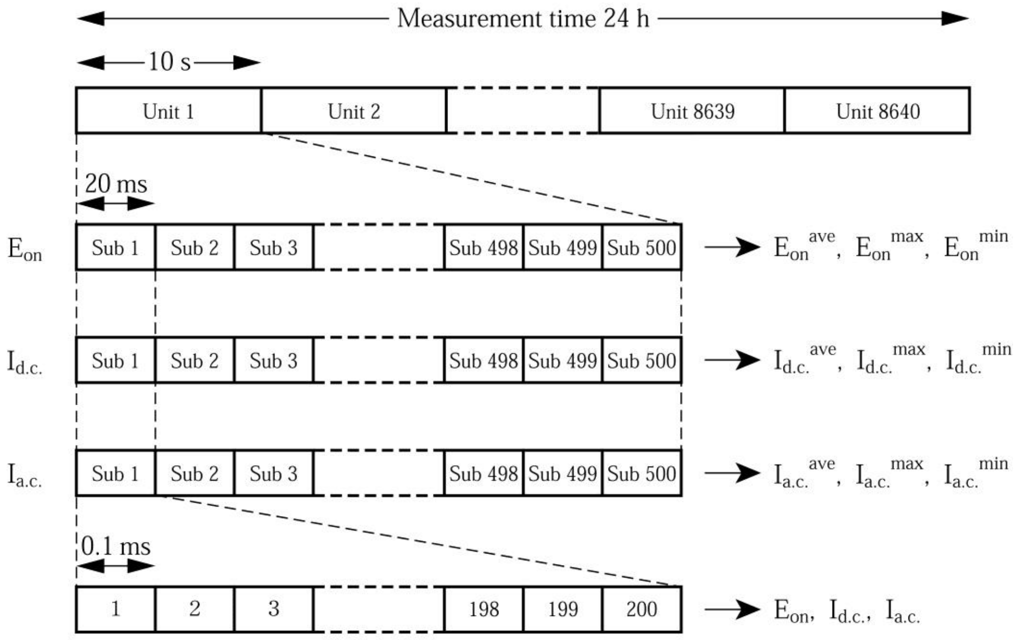

Figure 2 ─ The schematic representation of measurements on coupon on-potential E_{on}, coupon d.c. current density $I_{d.c.}$, and coupon a.c. current density $I_{a.c.}$ at frequency of 50 Hz

3.5 Identification of commercial current frequency

When coupon current density exhibits the difference within half of a period ±0,5 ms in appearance time between the maximum and minimum values in a subunit, frequency of the coupon current is considered to be commercial current frequency (16-2/3, 50 or 60 Hz).

3.6 Display of the waveform in a subunit

After the measurement, the original waveforms in a subunit are displayed. Thereby frequency, potential and current levels can be confirmed visually.

The original waveforms include

— waveform when the maximum coupon a.c. current density in a subunit was obtained,

— waveform when the minimum coupon d.c. current density in a subunit was obtained, and

- waveform when the most positive coupon on-potential in a subunit was obtained.

4 prEN 15280:2011 (E) [10]

Preliminary European Standard 15280 (prEN 15280:2011) offers the acceptable interference levels as below:

- As a first step, the a.c. voltage on the pipeline should be decreased to a target value, which should be 15 V rms or less. This value is measured as an average over a representative period of time (e.g. 24 h).

  and

- As a second step, effective a.c. corrosion mitigation can be achieved by meeting the cathodic protection potentials defined in EN 12954:2001, Table 1,

- and

  - maintaining the a.c. current density (rms) over a representative period of time (e.g. 24 h) to be lower than 30 A/m^2 on a 1 cm^2 coupon or probe,

    or

- maintaining the average cathodic current density over a representative period of time (e.g. 24 h) lower than 1 A/m^2 on a coupon or probe if average a.c. current density (rms) is more than 30 A/m^2,

or

maintaining the ratio between a.c. current density ($J_{a.c.}$) and d.c. current density ($J_{d.c.}$) less than 5 over a representative period of time (e.g. 24 h).

Note current density ratios between 3 and 5 indicate a small risk of a.c. corrosion. However, in order to reduce the corrosion risk to a minimum value, smaller ratios of current density than 3 would be preferable.

5 Example of the determination of the a.c. corrosion risk by the use of a developed instrumentation

An example of the determination of the a.c. corrosion risk by the use of a developed instrumentation was demonstrated for the coupon connected to the polyethylene coated 400 mm diameter gas pipeline paralleling a 25 kV a.c. traction system which operated at frequency of 50 Hz with great accelerations, high speed and long trains (250 m). The steel coupon was installed in the monitoring station where the a.c. current density reached its maximum. The a.c. traction system did not operate after midnight until early morning (0:00 – 6:00). High speed a.c. trains passed the monitoring station every several minutes at the rate of 150 to 200 kilometers per hour. Coupon on-potentials, coupon d.c. and a.c. current densities were recorded over 24 hours.

Figure 3 shows the data on coupon on-potentials, coupon d.c. current densities and coupon a.c. current densities over 24 hours in February 2013.

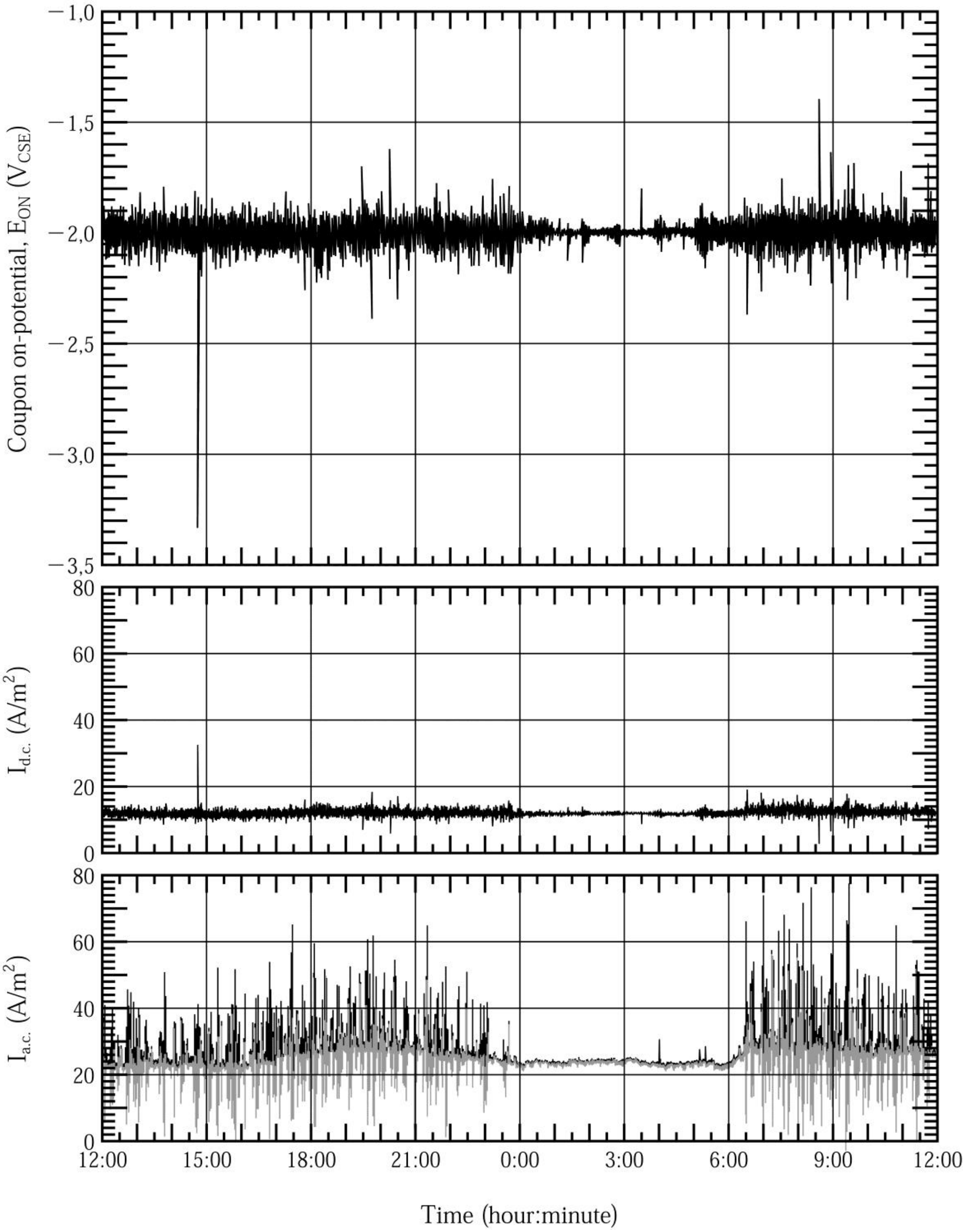

Figure 3 ─ The data on on-potentials E_{on}, d.c. current densities $I_{d.c.}$ and a.c. current densities $I_{a.c.}$ on the steel coupon connected to the polyethylene coated 400 mm diameter pipeline paralleling a 25 kV a.c. traction system which operated at frequency of 50 Hz, measured over 24 hours in February 2013

Summary data are shown in Table 2.

Table 2 — Results of coupon on-potential E_{on}, coupon d.c. current density $I_{d.c.}$, and coupon a.c. current density $I_{a.c.}$

		E_{on} (V_{CSE})	$I_{d.c.}$ (A/m^2)	$I_{a.c.}$ (A/m^2)
Average	average	−2,003	12,3	25,4
	maximum	−1,923	15,2	62,4
	minimum	−2,120	10,5	4,6
	standard deviation	0,021	0,051	0,513
Maximum	average	−1,976	12,7	27,1
	maximum	−1,395	32,9	77,5
	minimum	−2,109	10,8	7,1
	standard deviation	0,031	0,074	0,618
Minimum	average	−2,030	11,8	23,6
	maximum	−1,952	14.5	56,2
	minimum	−3,333	3,0	0,3
	standard deviation	0,034	0,057	0,536

The evaluation of a.c. corrosion likelihood was done on the basis of prEN 15280.

The results obtained from the measurement over 24 hours were as follows:

1) Very marked and quick coupon a.c. current density variations were observed when the a.c. traction system was in operation. This indicated that a.c. interference caused by the operation of a.c. traction system affected the pipeline. Variations in coupon a.c. current density between 0,3 – 77,5 A/m^2 were measured, the most severe effect occurring at 9:28.

2) The a.c. voltage on the pipeline was 1,60 V rms when the most positive coupon on-potential of −1,395 V_{CSE} was measured in a subunit. The difference in appearance time between the maximum and minimum values exhibited 10,2 ms (8,9 ms – 19,1 ms), therefore the coupon on-potential was consistent with the a.c. traction system frequency of 50 Hz. The a.c. voltage was decreased by achieving effective a.c. corrosion mitigation such as installation of d.c. decoupling devices.

3) The value of −1,395 V_{CSE} including IR drop was not polarized potential. However, it was considered to have met the cathodic protection potentials defined in EN 12954:2001, Table 1.

4) Average coupon a.c. current density was 25,4 A/m^2 lower than 30 A/m^2.

5) The ratio between average coupon a.c. current density $I_{a.c.}$ and average coupon d.c. current density $I_{d.c.}$, $I_{a.c}$. /$I_{d.c.}$, was 2,1(=25,4/12,3) less than 5.

6) The above-mentioned results were thought to be satisfied with acceptable interference levels established by prEN 15280:2011 (E).

7) Frequency of the displayed waveforms in a subunit was consistent with the a.c. traction system frequency of 50 Hz.

Figure 4 shows the waveform of coupon current density when the maximum coupon a.c. current density 77.5 A/m^2 in a subunit was obtained. Appearance time between the maximum (8,7 ms) and minimum values (18,7 ms) in Figure 4 exhibited 10,0 ms that was half of a period of 50 Hz. Therefore frequency of the coupon current density in Figure 4 was consistent with the a.c. traction system frequency of 50 Hz.

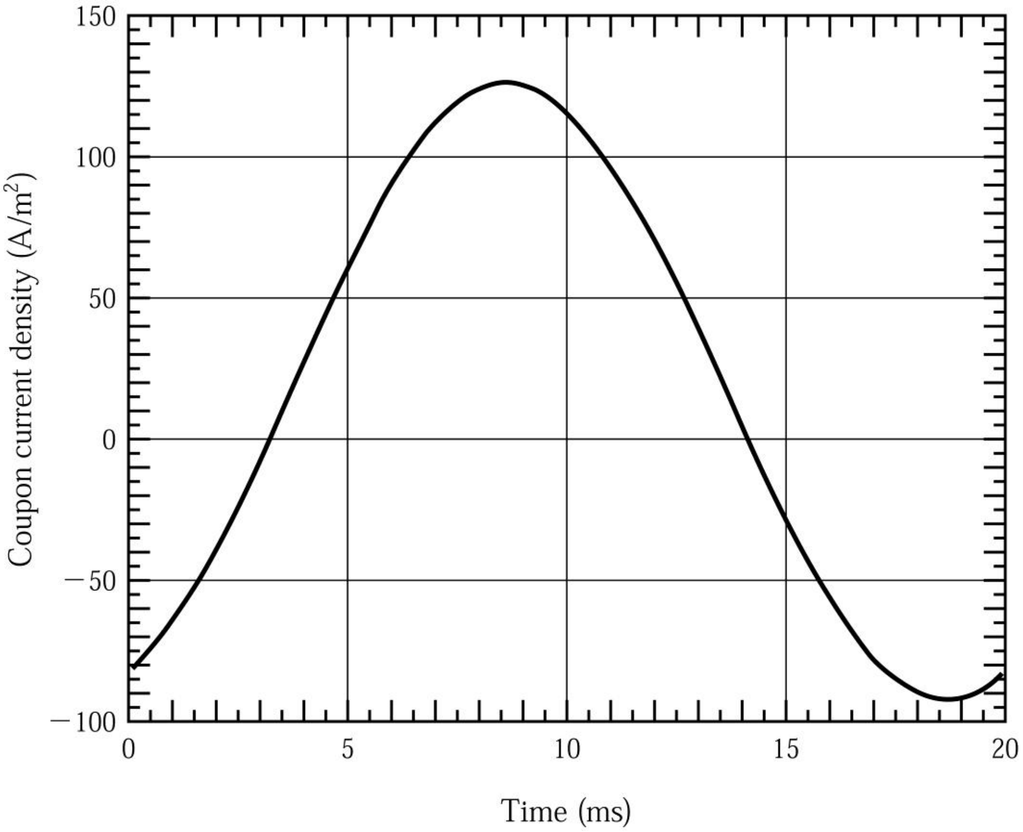

Figure 4 ─ The waveform of coupon current density when the maximum coupon a.c. current density in a subunit was obtained

Figure 5 shows the waveform of coupon current density when the minimum coupon d.c. current density 3.0 A/m^2 in a subunit was obtained. Appearance time between the maximum (8,6 ms) and minimum values (19,0 ms) in Figure 5 exhibited 10,4 ms that was half of a period of 50 Hz. Therefore frequency of the coupon current density in Figure 5 was consistent with the a.c. traction frequency of 50 Hz.

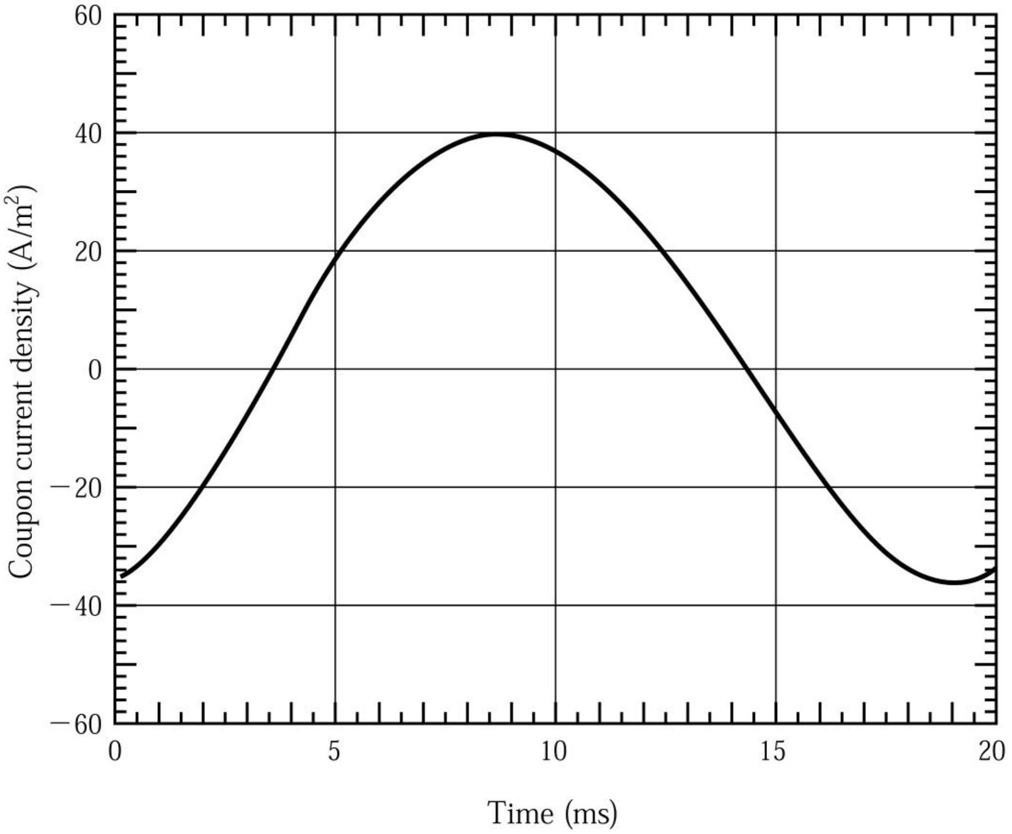

Figure 5 ─ The waveform when the minimum coupon d.c. current density in a subunit was obtained

Figure 6 shows the waveform of coupon on-potential when the most positive coupon potential of −1,395 V_{CSE} in a subunit was obtained. Appearance time between the maximum (19,1 ms) and minimum values (8,9 ms) in Figure 6 exhibited 10,2 ms that was half of a period of 50 Hz. Therefore frequency of the coupon on-potential in Figure 6 was consistent with the a.c. traction system frequency of 50 Hz.

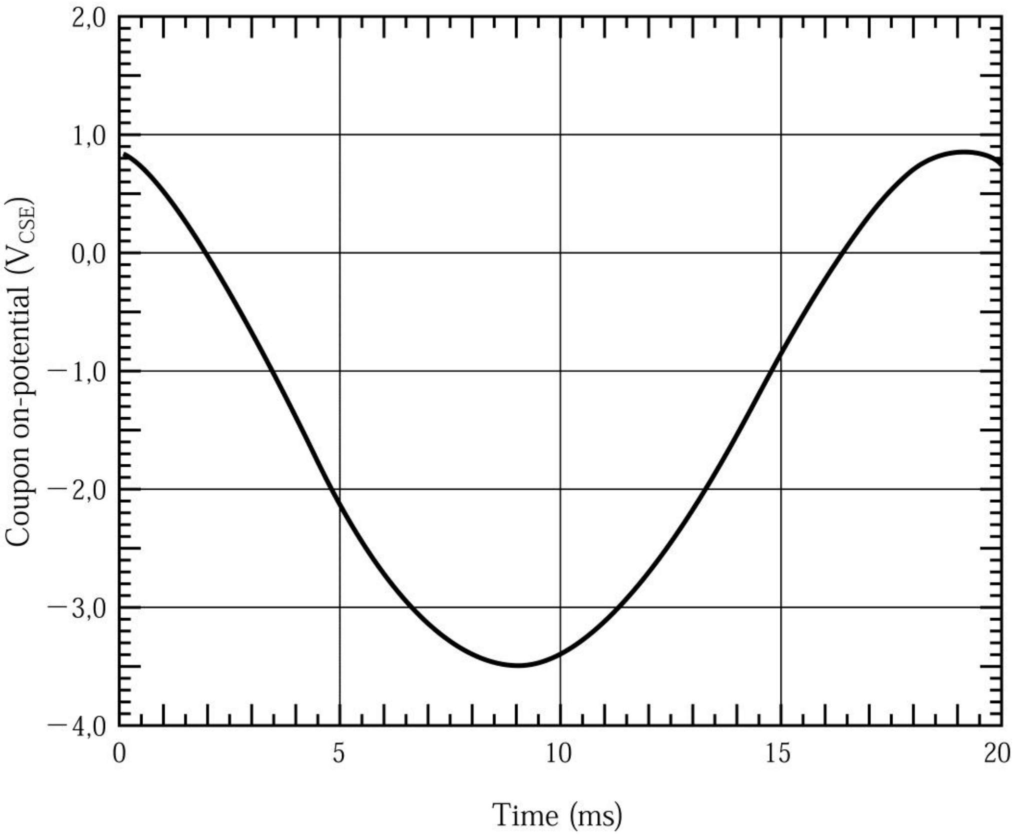

Figure 6 ─ The waveform of coupon on-potential when the most positive coupon on-potential in a subunit was obtained

6 Conclusions

─ In order to assess the a.c. corrosion risk of cathodically protected pipelines in the field, the author has developed an innovative hand-held instrumentation having capability to obtain coupon d.c. and a.c. current densities simultaneously from coupon currents with high data sampling rate.

─ The most distinguished feature of the instrumentation is to provide coupon a.c. current density at commercial current frequencies such as 16-2/3 Hz or 50 Hz or 60 Hz.

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