STRATEGY FOR ELIMINATING RISKS OF CORROSION AND OVERPROTECTION FOR BURIED MODERN PIPELINES

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JAPAN

The main point of the presentation

1) Establishment of a new cathodic protection criterion in consideration of the elimination of all corrosion risks including AC corrosion and overprotection.

2) Development of an advanced instrumentation for assessing the AC corrosion risk in the field.

Contents

Cathodic protection

and

the protection potential criterion

Applicalion of cathodic protection (CP)

to reduce or eliminate the corrosion of a pipeline

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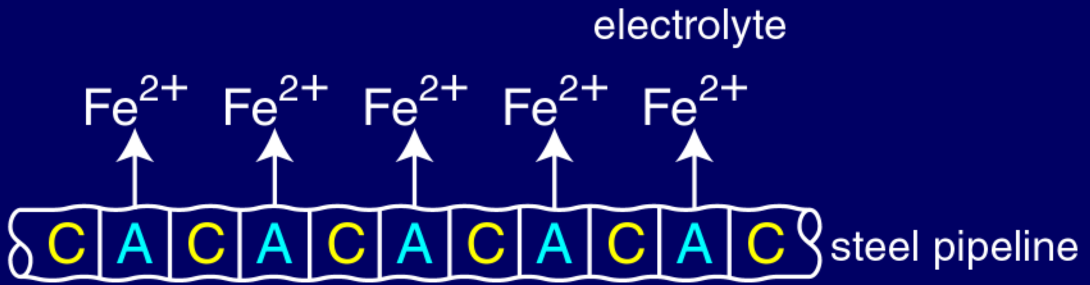
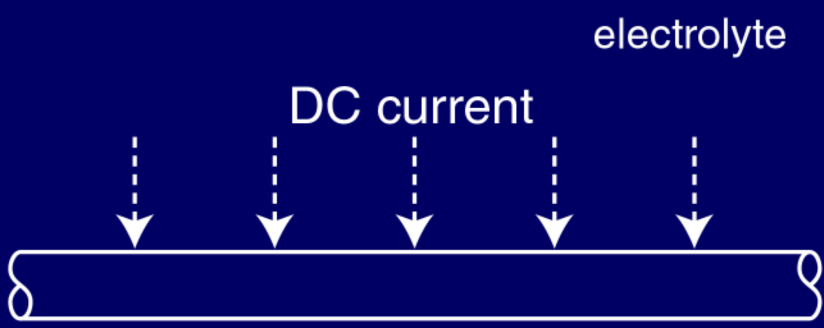
No protection



A : anodic area

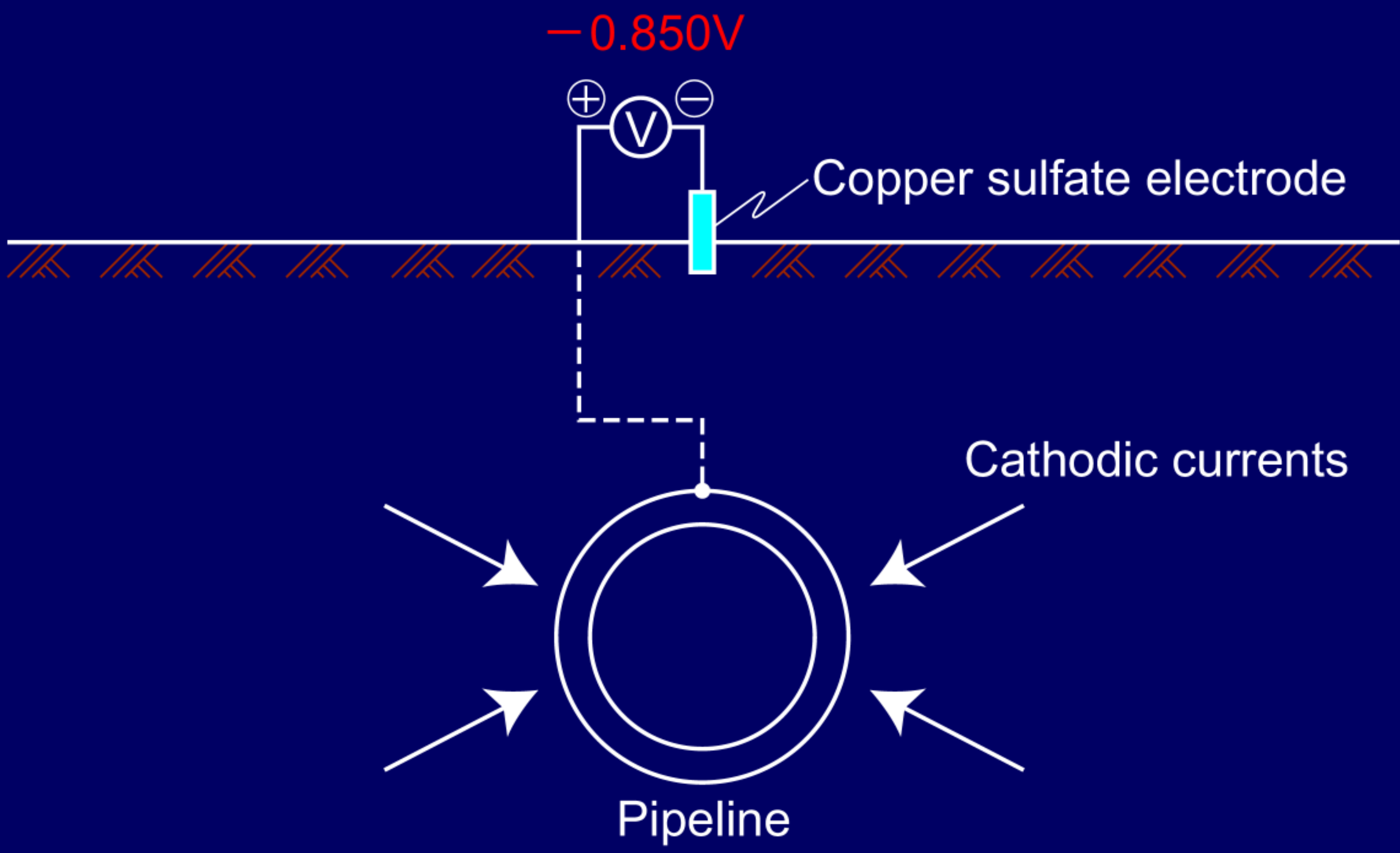
C : cathodic area

With the cathodic protection (CP) applied



CP reduces or eliminates the corrosion of a pipe surface by making that surface the cathode of an electrochemical cell, with a DC current flowing through electrolyte to the pipe surface.

The protection potential criterion proposed by Kuhn in 1933



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The latest tendency in the natural gas industry

and

new threats to modern natural gas transmission pipelines

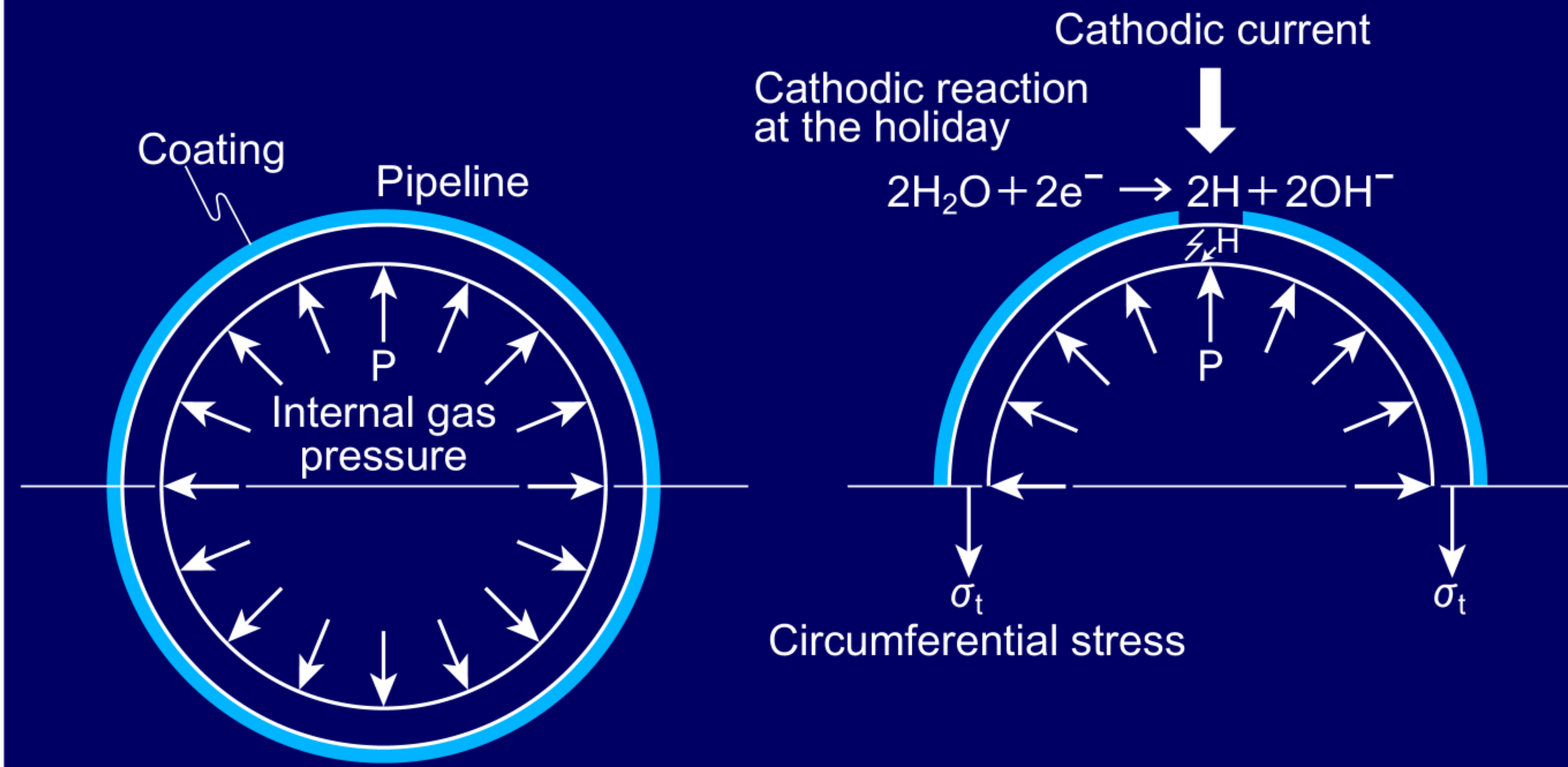
The latest tendency in the natural gas industry

Natural gas transmission pipelines (modern pipelines) with thinner, high strength steel-walls and high resistivity coating, are being constructed in parallel with:

— HV (high voltage) AC electric power lines and/or

— AC powered rail transit systems

Hydrogen embrittlement of a natural gas transmisson pipeline



A possible problem
in cathodically protected modern pipelines (natural gas transmission pipelines)

A sustained tensile stress in the circumferential directions by the internal gas pressure

Continuous deposition of H on the pipe surface by cathodic reaction
($2H_2O + 2e^- \rightarrow 2H + 2OH^-$)

→ **The risk of hydrogen embrittlement**

Modern natural gas transmission pipeline with cathodic protection (CP) applied under induced AC voltage

Materials

〈Pipe〉

High strength steel

under circumferential stress

by the intenal gas pressure

〈Coating〉

High resistivity coating

such as polyethylene

Risks

Hydrogen embrittlement

by high level of

cathodic protection

$(2H_2O + 2e^- \rightarrow 2H + 2OH^-)$

AC corrosion at a coating defect

even at high pH as a result of

accumulation of OH^-

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New threats to modern pipelines

〈 Change in pipeline and coating materials 〉
- Thinner, high strength walls
- High resistivity coating

〈 Change in burial conditions 〉
- Parallel with HVAC electric power lines and/or AC powered rail transit systems

⇩

Occurrence of new threats to pipeline integrity

- Overprotection
- AC corrosion

AC corrosion

Recognition of AC corrosion

The phenomenon of AC corrosion has been considered by many authors since the early 1900s.
(Hayden's paper (1906), AGA corrosion committee survey (1955), etc.)

However,

→ up to the mid 1980s, corrosion failure on a pipeline was not attributed to AC corrosion.

Probably because the pipelines were bare or less well coated having sufficient grounding, such that induced voltages were not a practical problem.

The first AC corrosion failure of a natural gas transmission pipeline

Incident : perforation
Installed time : 6 yeas (installation data 1980, perforation date 1986)
Corrosion rate : 0.8 mm/y

Steel pipe
- Material : DN 150 PN 70
- Diameter : 168.4 mm
- Wall thickness : 4.5 mm

Coating : polyethylene

Environment : parallel to a 16-2/3 Hz 15 kV single phase AC powered rail transit system

Instant-off potential : $-1.0\ V_{CSE}$ (satisfied the protection potential criterion)
pH of the corrosion product : 10 (indicated satisfactory level of cathodic protection)
The maximum possible pipe-to-remote earth AC voltage : 130 V
Resistivity : 1.90 ohm m (leak location, de-icing salt)
Suface area of the holidays : 1 to 3 cm^2

The primary conclusions stemming from the literature survey on AC corrosion with the CP applied :

(1) Short-term perforation or severe corrosion has been observed.

(2) The pipeline had high resistivity coatings.

(3) The pipelines were laid paralleling HVAC electric power lines and/or AC powered transit systems for a long distance.

(4) AC corrosion protection has not been taken into account in the stage of design for cathodic protection.

Lessons from the incidents of AC corrosion

A DC potential, E_{DC}, satisfying the protection potential criterion and a high pH at the pipe surface as a result of accumulation of hydroxide ions by very high level of cathodic reaction does not necessarily mean that AC corrosion control is adequate.

I_{AC} on a circular holiday

$$I_{AC} = \frac{8V_{AC}}{\rho \pi d} \propto \frac{I \cdot L}{\rho d}$$

where :

V_{AC} = Induced AC voltage of pipeline to remote earth (V)

ρ = Electrolyte resistivity (ohm-m)

d = Diameter of a circular holiday (m)

I = Current in HVAC electric power lines of trolley wires

L = Parallel length between pipelines and HVAC electrical power lines or AC powered rail transit systems

AC corrosion rates

I_{AC}, that is, AC corrosion rates;

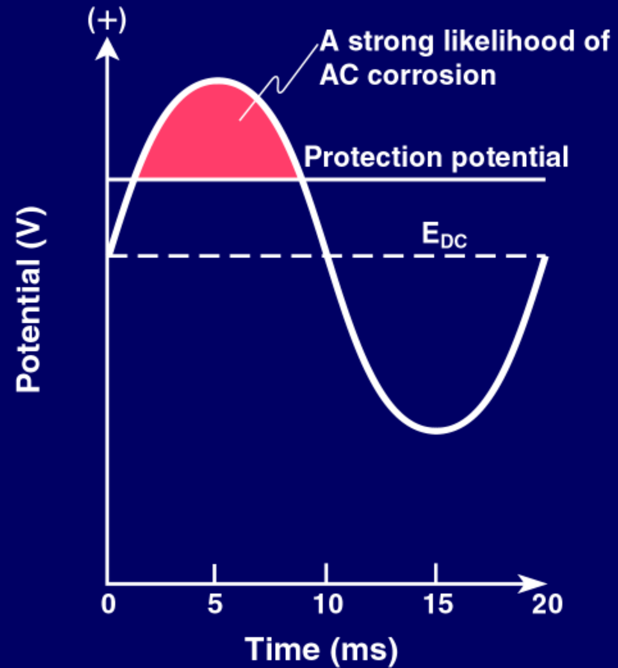
- Increase with increasing currents in HVAC electric power lines/trolley wires I;
- Increase with increasing the parallel length between pipelines and HVAC electric power lines/trolley wires;
- Increase with decreasing electrolyte resistivity; and
- Increase with decreasing holiday surface area.

Limitations of the protection potential criterion

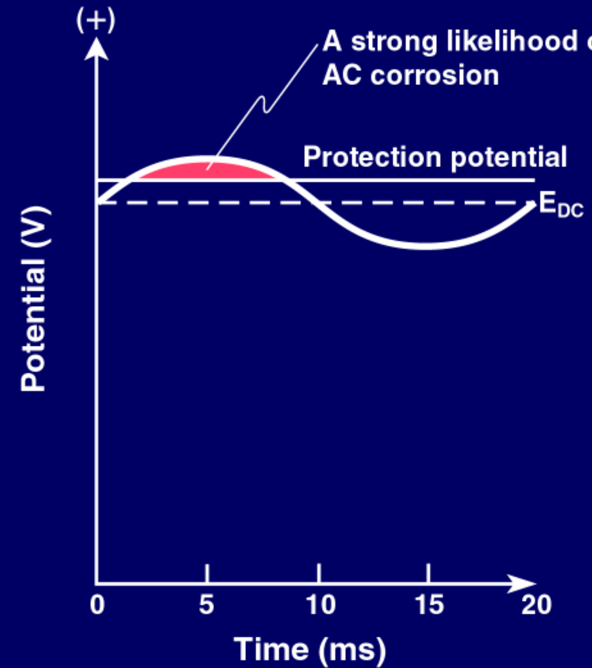
Why does “the protection potential criterion” overlook the risk of AC corrosion?

The protection potential criterion can overlook the risk of AC corrosion

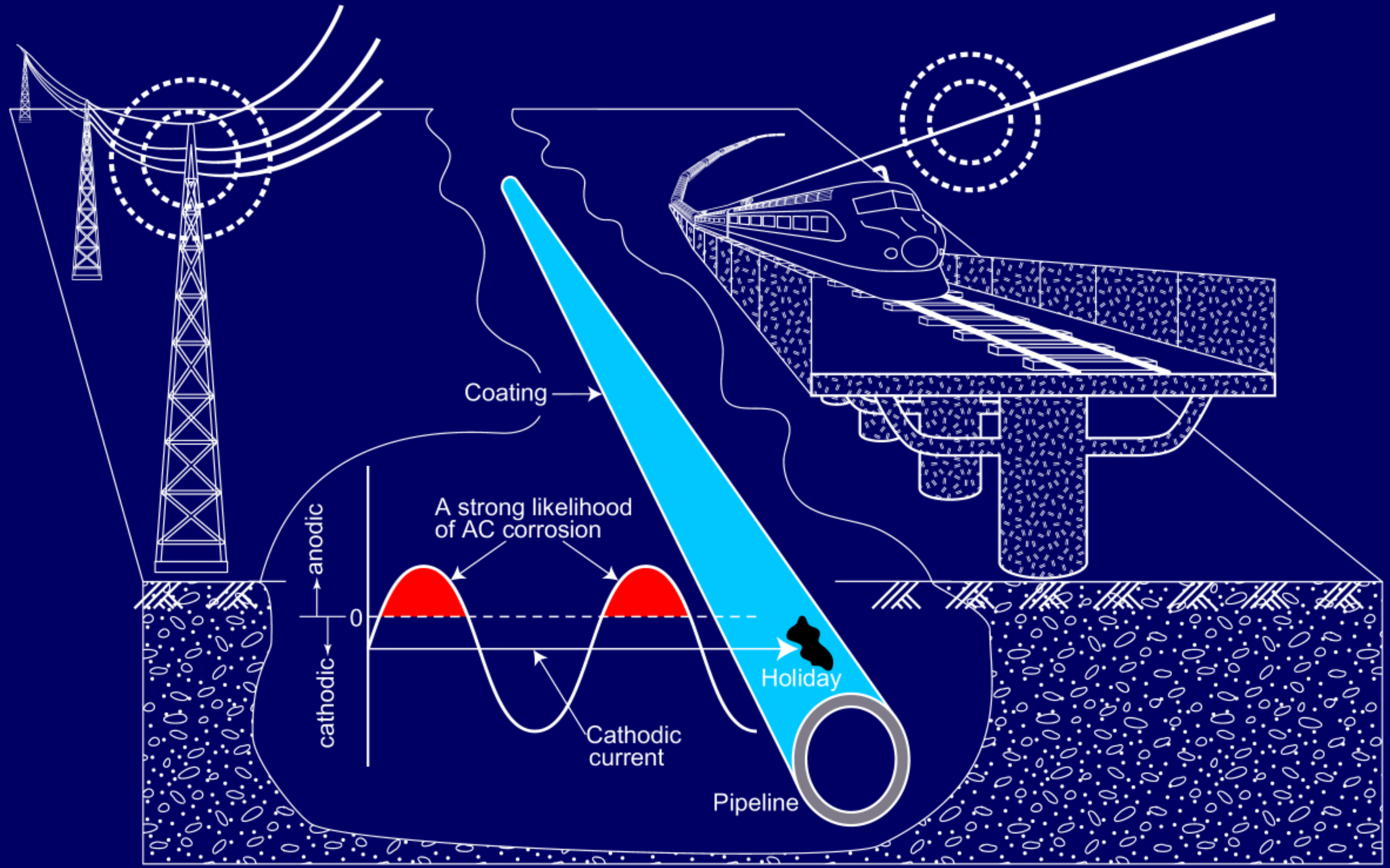
< Very high induced AC potential >



< Very modest induced AC potential >



AC corrosion
of a natural gas transmission pipeline



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Limitations of the protection potential criterion (1/3)

A 1992 report by Funk, Prinz and Schöneich

– for AC current densities greater than 30 A/m^2
the maximum corrosion rate is in excess of 0.1 mm/y despite a constant cathodic protection current density of 2 A/m^2.
In this case, the protection potential criterion is not applicable.

– for AC current densities less than 30 A/m^2
there is no AC induced corrosion at cathodic protection current density of about 1 A/m^2.

Funk et al. also reported that
measurement of AC current density on steel coupons provides information on the risk of corrosion and corrosion prevention for AC current densities greater than 30 A/m^2.

Limitations of the protection potential criterion (2/3)

A 1999 report by Kajiyama and Nakamura

Field study, with coupons in monitoring stations, on a 6.6 km length of polyethylene coated 323.9 mm outside diameter pipeline that paralleled a 66 kV, 50 Hz electric power transmission line.

– despite a substantial coupon DC (cathodic protection) current density of 10.8 A/m^2 and showing polarized of –1.12 V_{CSE}, coupon AC current density was 183 A/m^2.

This indicates that AC corrosion on a holiday is very likely to occur despite high level of cathodic polarization.

Limitations of the protection potential criterion (3/3)

ISO 15589-1 Petroleum and natural gas industries

– Cathodic protection of pipeline transportation systems
  – Part 1: On-land pipelines in the year 2003

– If the a.c. current density on a 100 mm^2 bare surface (e.g. an external test probe) is higher than 30 A/m^2 (or less, in certain conditions), there is a high risk of corrosion.
  Risk of corrosion is mainly related to the level of a.c. current density compared to the level of CP current density.

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

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Development of an advanced instrumentation for assessing the AC corrosion risk in the field

Concepts for the design of an advanced instrumentation "CP MONITOR"

1. Surface area and shape of a coupon
2. Simultaneous measurements on coupon current densities and potentials with high rate data sampling techniques
3. Controlled by the "CP Management System"
4. Identification of I_{AC} (50 Hz)
5. Display of the original waveform of the maximum coupon AC current density

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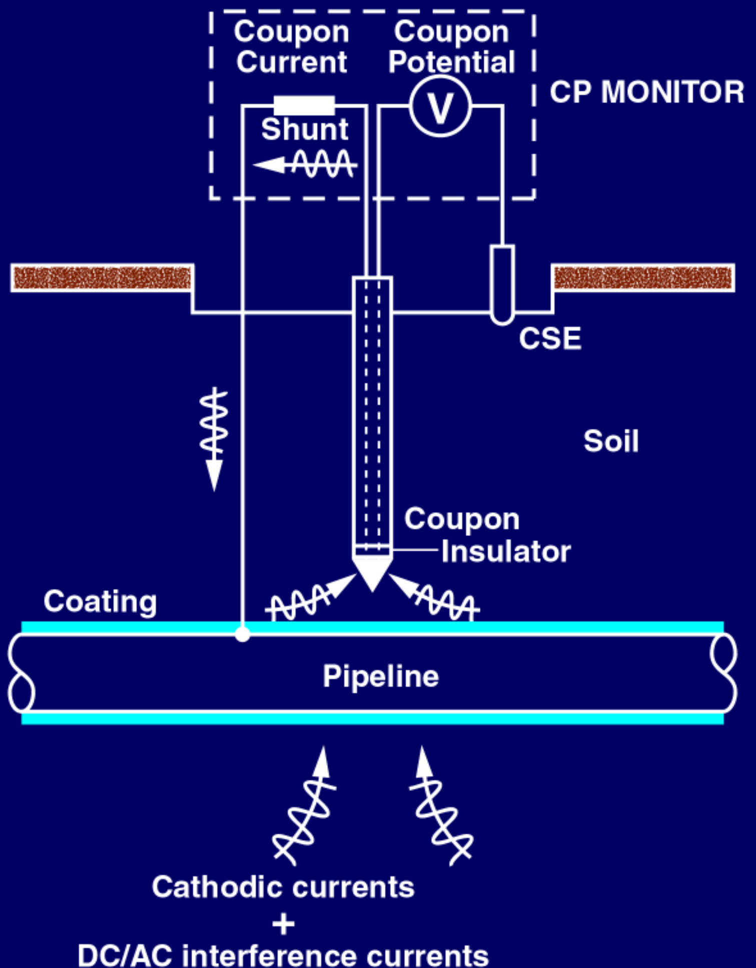
Concepts for the design of an advanced instrumentation "CP MONITOR"

1. Surface area and shape of a coupon

Measuring systems
for the coupon currents and potentials



Concepts for the design of an advanced instrumentation "CP MONITOR"

2. Simultaneous measurements on coupon current densities and potentials with high rate data sampling techniques

The most distinguished feature of an advanced instrumentation

The simultaneous computation in a measuring unit of 20 ms regarding I_{DC} and I_{AC} (50Hz) corresponding to the commercial frequency of 50 Hz.

Note : 50Hz = the predominant frequency component on AC corrosion of buried pipelines

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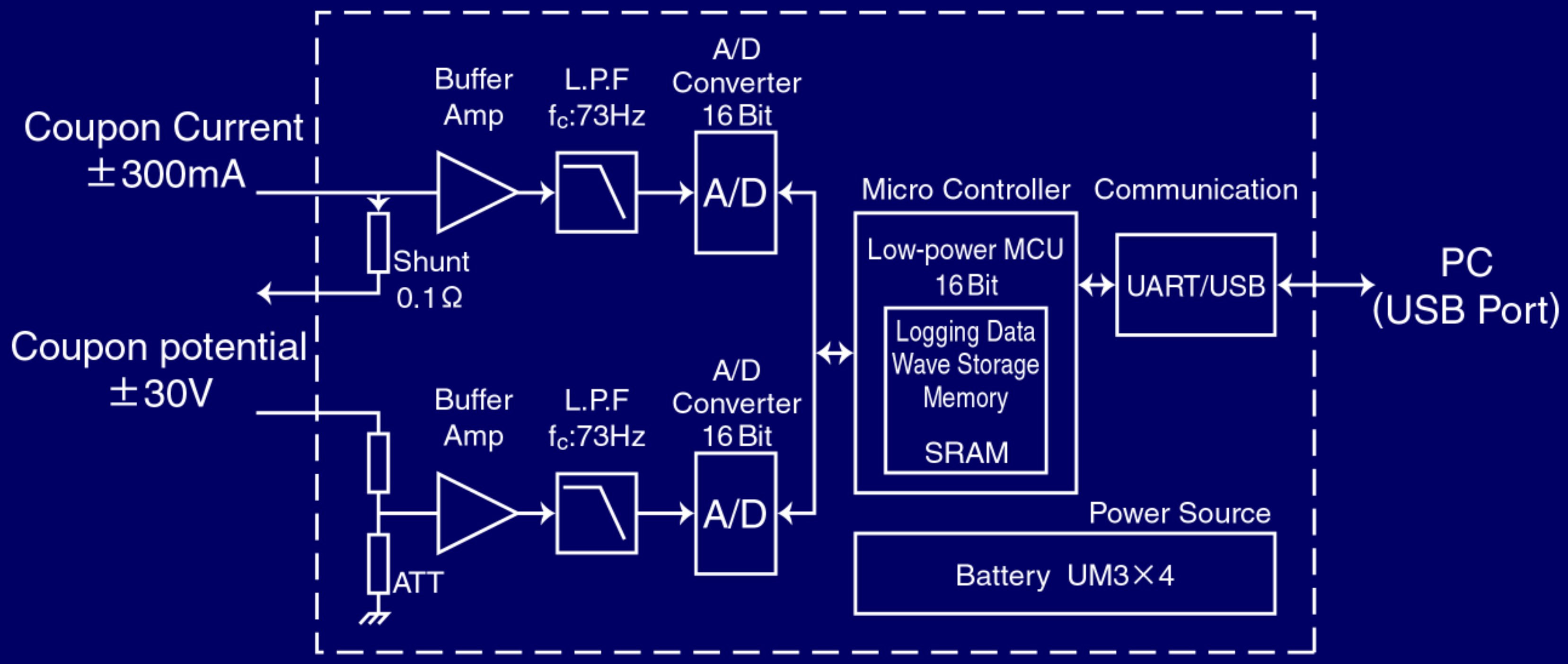
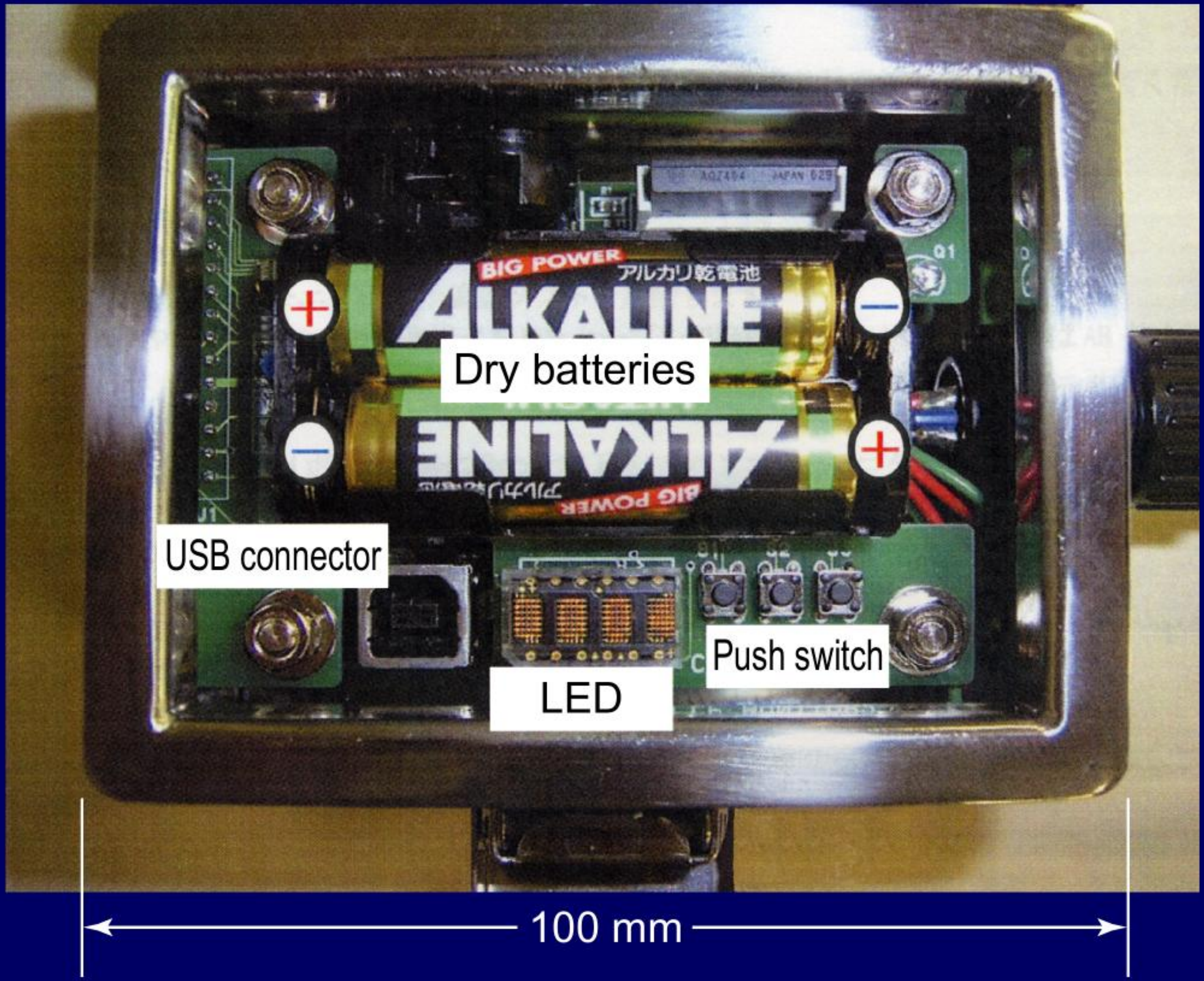
Immediately after computing the averaged I_{DC} and I_{AC} (50Hz) in measuring time, the results are referred to the coupon current density-based cathodic protection criterion established by the authors.

Block diagram for an advanced instrumentation



An Advanced instrumentation



Derivation of I_{DC}, I_{AC} and E_{DC}

$$I_{DC} = \frac{1}{A} \cdot \frac{1}{200} \sum_{t=1}^{200} I(t)$$

$$I_{AC} = \frac{1}{A} \cdot \sqrt{\frac{1}{200} \sum_{t=1}^{200} \{I(t) - I_{DC}\}^2}$$

$$E_{DC} = \frac{1}{200} \sum_{t=1}^{200} E_{DC}(t)$$

where A : surface area of a coupon (= 10 cm^2)

$I(t)$: instantaneous coupon current at t ms in each sub-unit of 20 ms

I_{DC} : time-averaged instantaneous coupon current in each sub-unit of 20 ms

I_{AC} : coupon AC current in each sub-unit of 20 ms

$E_{DC}(t)$: instantaneous coupon potential at t ms in each sub-unit of 20 ms

E_{DC} : time-averaged instantaneous coupon potential in each sub-unit of 20 ms

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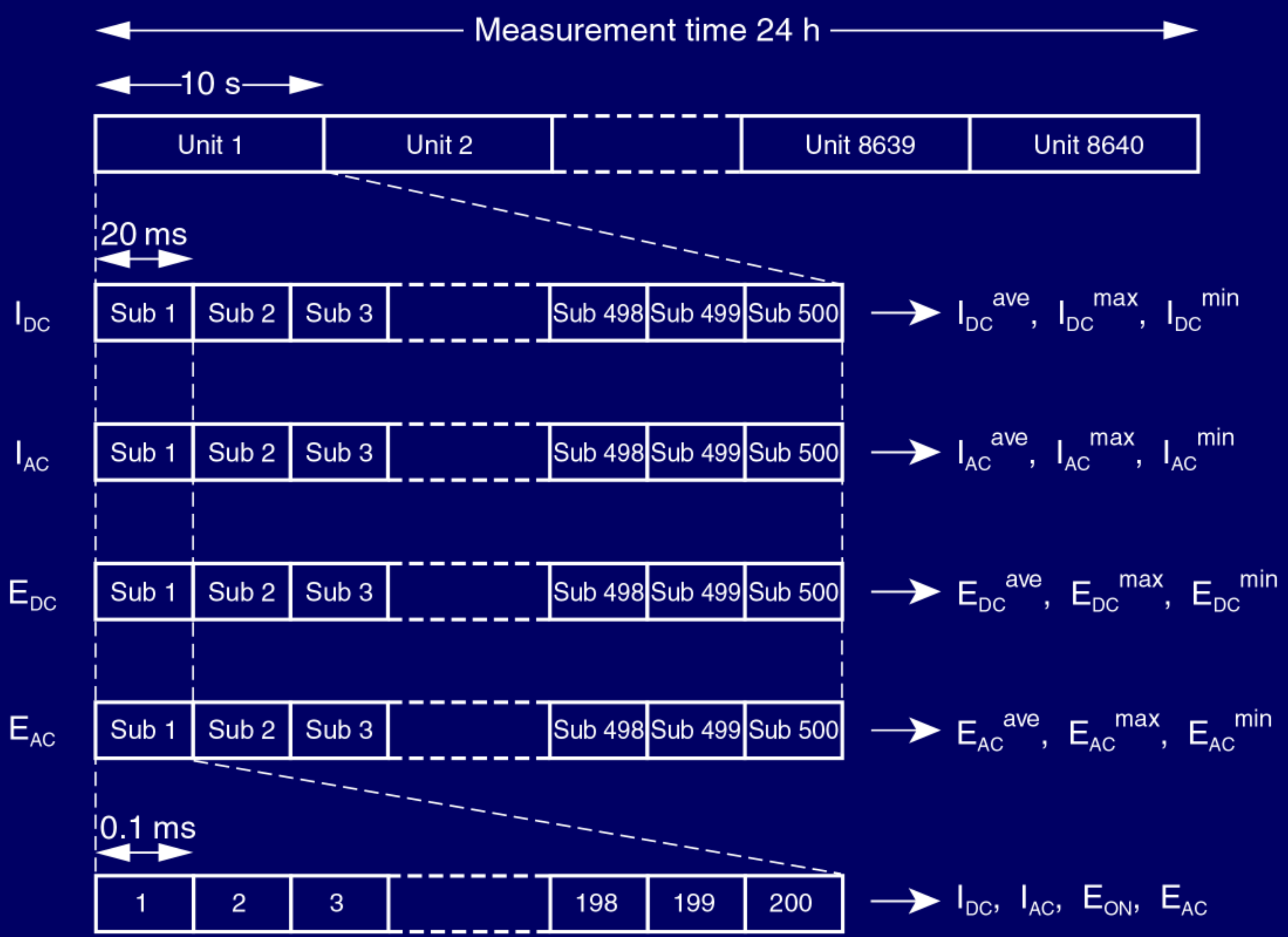
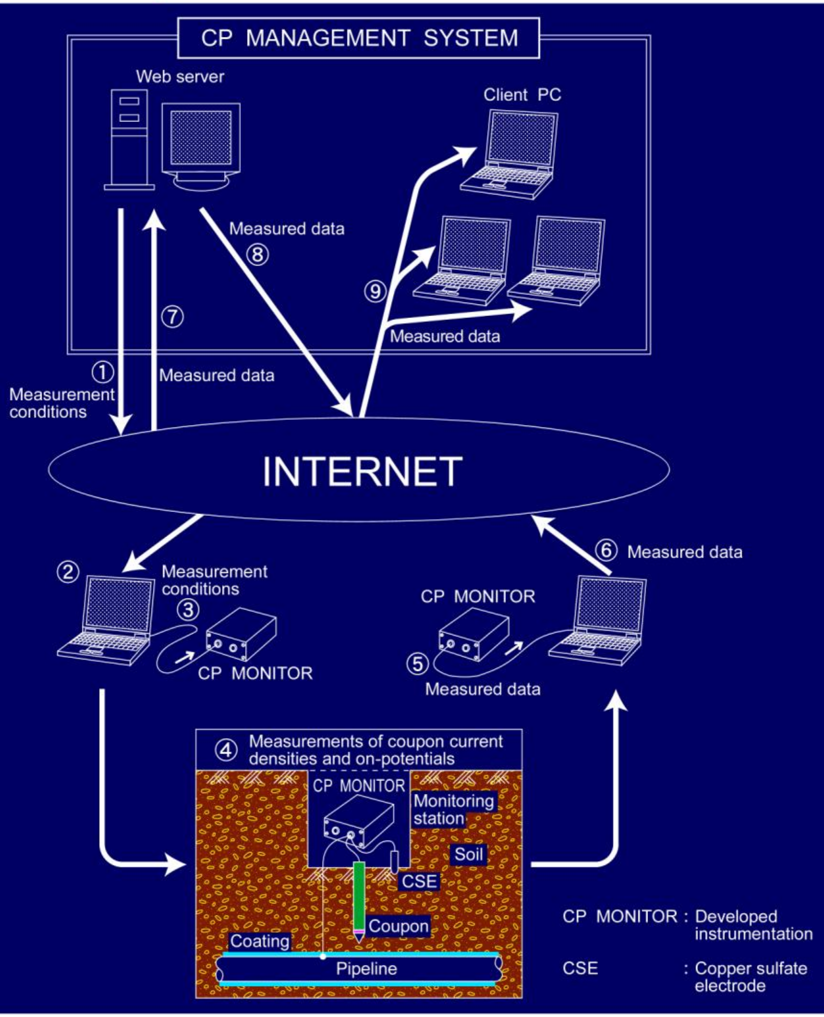
Measurement for I_{DC}, I_{AC}, E_{DC} and E_{AC}



Concepts for the design of an advanced instrumentation "CP MONITOR"

3. Controlled by the "CP Management System"

Periodic inspection using a developed instrumentation "CP MONITOR" controlled by "CP MANAGEMENT SYSTEM".



A benefit of “CP MANAGEMENT SYSTEM-based inspection”

A benefit of CP MANAGEMENT SYSTEM-based inspection is to certainly and efficiently implement periodic inspection of the CP system with large quantity information, resulting in minimizing human errors.

Concepts for the design of an advanced instrumentation "CP MONITOR"

4. Identification of I_{AC} (50 Hz)

Definition of I_{AC} (50 Hz)

In this paper I_{AC} (50 Hz) is defined as the coupon AC current densities, corresponding to the frequency of 50 Hz.

The frequency of 50 Hz is regarded as coupon AC current density having the difference within 10 ms ±1 ms (i.e. 45.5 Hz −55.6 Hz) in appearance time between the maximum and minimum values in a sub-unit.

Concepts for the design of an advanced instrumentation “CP MONITOR”

5. Display of the original waveform of the maximum coupon AC current density

Establishment of the new cathodic protection criterion for the elimination of all corrosion risks and overprotection

Two CP criteria
related to the control of AC corrosion

– DIN 50 925 (in the year 1992)
AC current densities less than about 30 A/m^2, when cathodic protection current densities shall be maintained at about 1 A/m^2.

– ISO 15589-1 (in the year 2003)
AC current densities less than 30 A/m^2 (or less, in certain conditions).

The two CP criteria, however, do not document how coupon AC current density can be measured in the field, and the frequency at which AC corrosion shall be prevented.

Cathodic protection criteria ralated to AC corrosion protection and overprotection control

— There are no agreed-on criteria for AC corrosion protection.

— There are no coupon current density-based criteria for overprotection control.

Cf. ISO 15589-1:2003(E)

To prevent damage to the coating, the limiting critical potential should not be more negative than –1200 mV referred to CSE, to avoid the detrimental effects of hydrogen production and/or a high pH at the metal surface.

Points to be duly considered to establish cathodic protection criteria

— Elimination of corrosion risks

- DC stray current corrosion
  (corrosion caused by DC interference current originating from CP rectifiers and DC powered rail transit systems etc.)

- AC corrosion

- microbiologically influenced corrosion

etc.

— Elimination of overprotection risk

New CP criterion for the elimination of all corrosion risks and overprotection (1/5)

A 1981 report by Kasahara (Field Survey using coupons)

The minimum coupon DC current density of 0.1 A/m^2 should be adopted.

New CP criterion for the elimination of all corrosion risks and overprotection (2/5)

A 2010 report by Kajiyama et al. (overprotection control criterion based upon BS 7361 : Part 1)

BS 7361 : Part 1
for thick film coatings, such as reinforced coal tar enamel in high resistivity soil, an instant-off potential more negative than -3.0 V_{CSE} could be accepted.

In the case of thick polyethylene coatings (thickness ＞ 5mm) with an average coating resistance of higher than 10^5 ohms-m^2, the maximum coupon DC current density of 40 A/m^2 corresponding to instant-off potential more positive than –2.5 V_{CSE} should be adpted.

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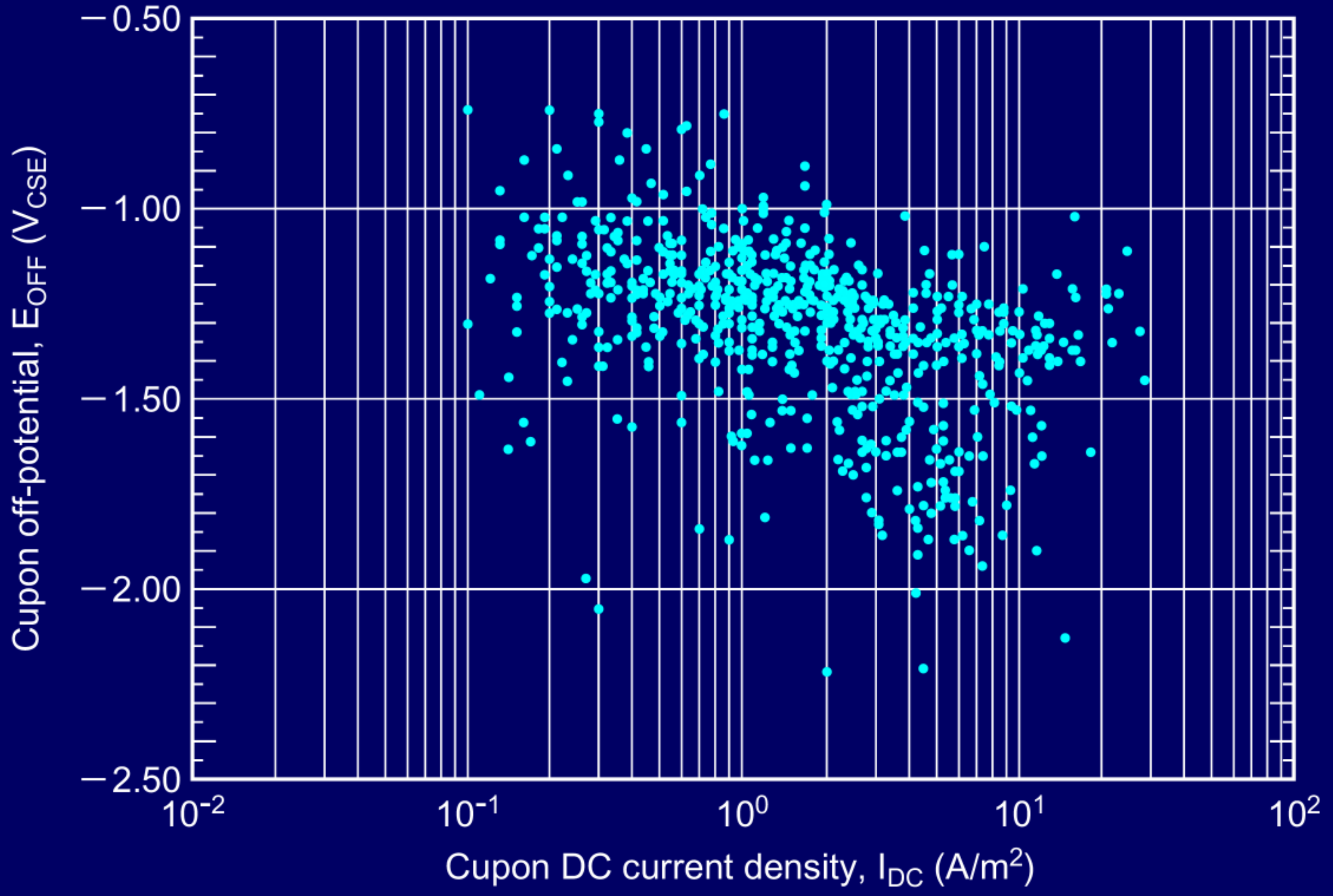
Relationship between E_{OFF} and I_{DC}



New CP criterion
for the elimination of all corrosion risks and overprotection (3/5)

A 2010 report by Nakamura and Kajiyama (laboratory studies steel specimens)

Corrosion rate obtained from weight loss was reduced to less than 0.01 mm/y as the data was plotted inside the protection area designated by thick lines.

New CP criterion
for the elimination of all corrosion risks and overprotection (4/5)

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A 1999 report by Kajiyama and Okamura
(MIC control, laboratory studies using steel specimens)

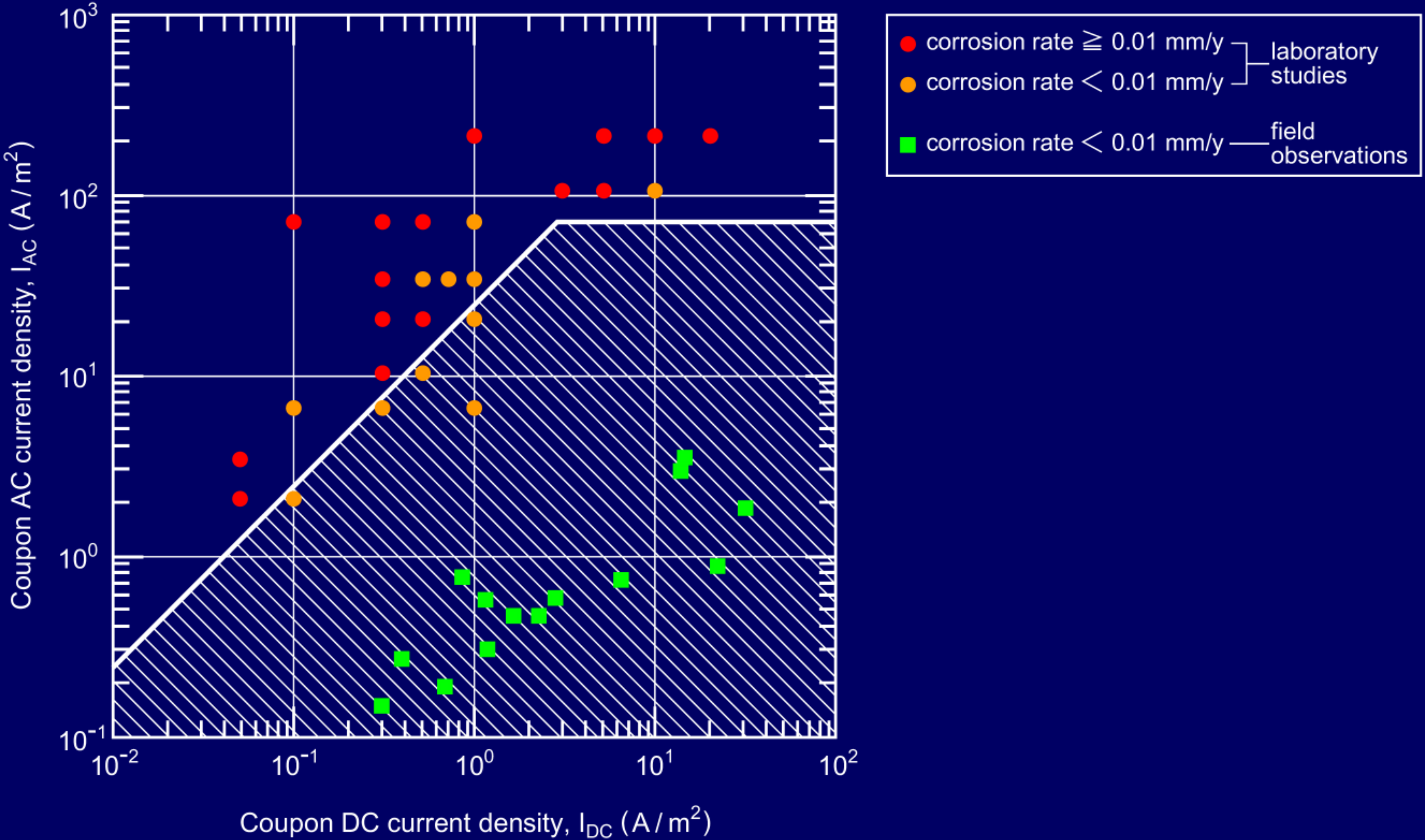
The cathodic current density, required to achieve CP of steels buried in soils containing SRB and/or IB in Japan, is grater than 0.1 A/m^2 corresponding to the residual uniform corrosion rate less than 0.1 mm/y.

New CP criterion
for the elimination of all corrosion risks and overprotection (5/5)

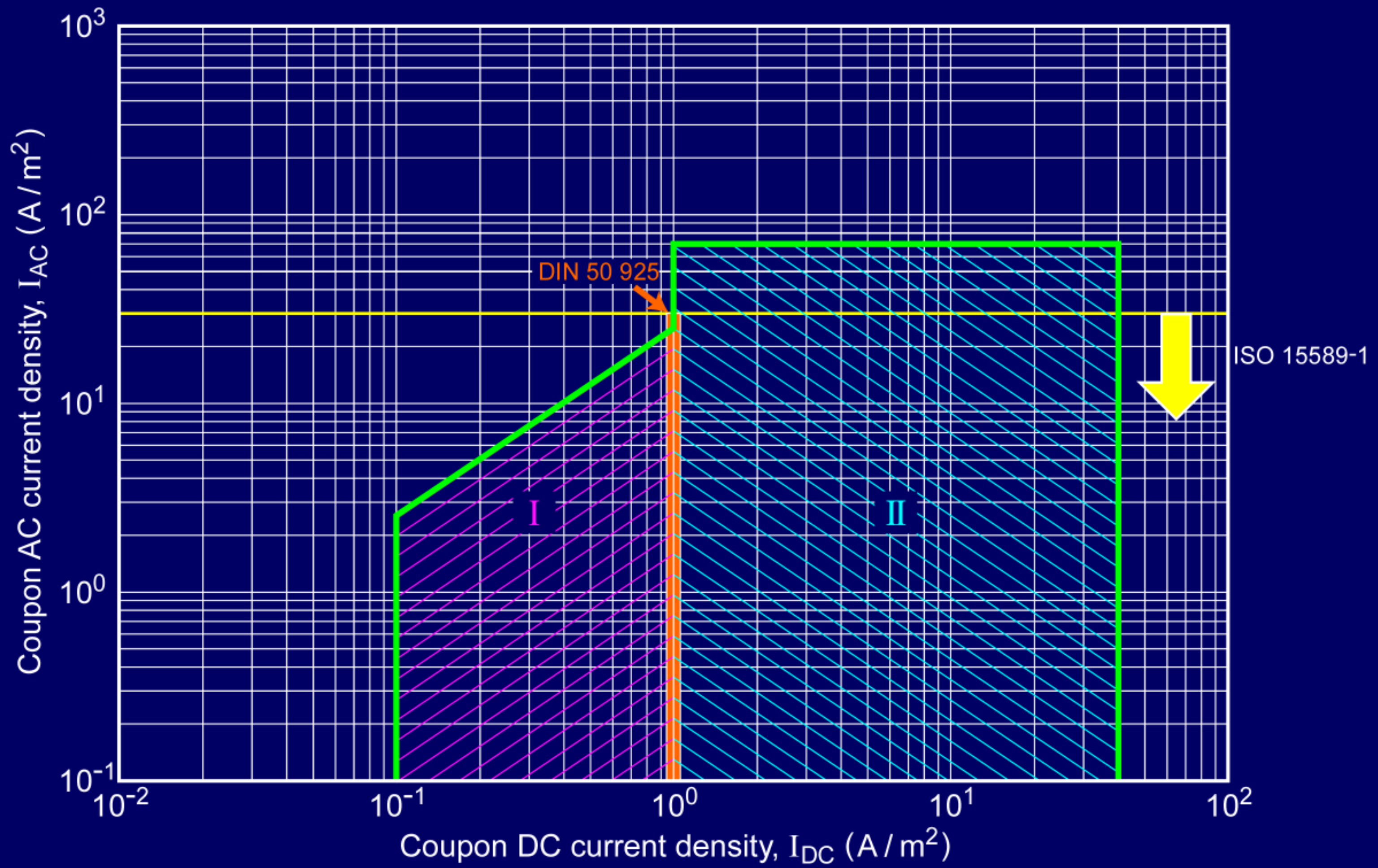
Fild observation by Kajiyama (corrosion rate of coupon)

The final values of coupon current densities are shown by square symbols.
Corrosion rates were obtained to be less than 0.01 mm/y.

Laboratory and field work



New CP criterion together with DIN 50 925 and ISO 15589-1



Protection measures against AC corrosion

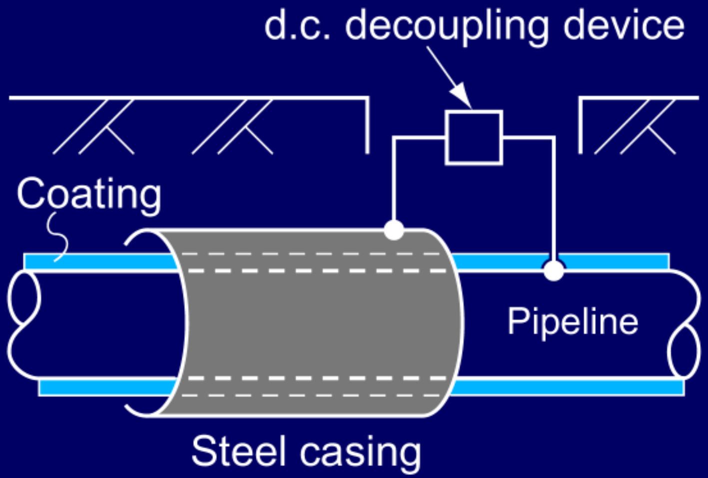
Protection measures against AC corrosion (ISO 15589-1)

— reduce the induced AC voltage;

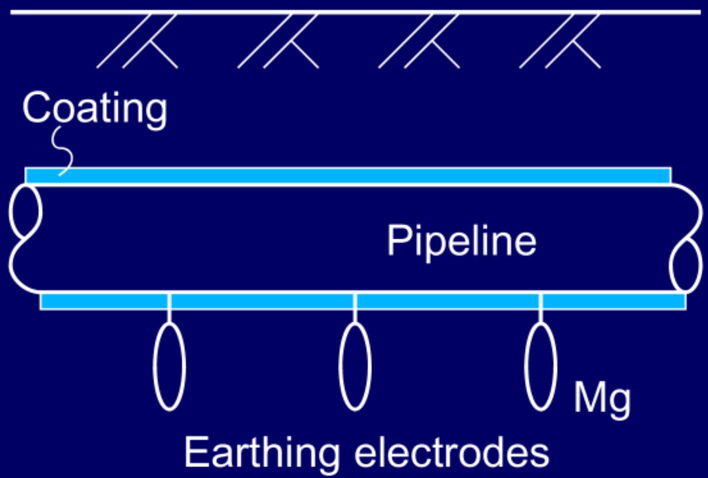
— increase the CP level so that the positive part of AC current can be neglected

Reduction of the induced a.c. voltage as protection measures against a.c. corrosion

d.c. decoupling device

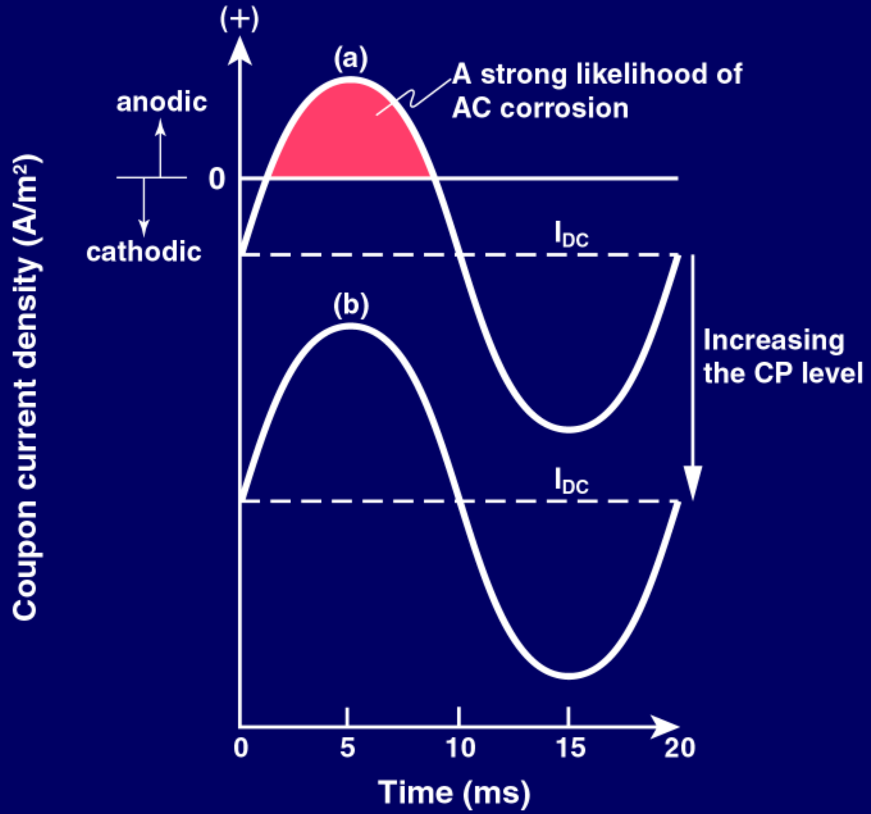


Earthing systems

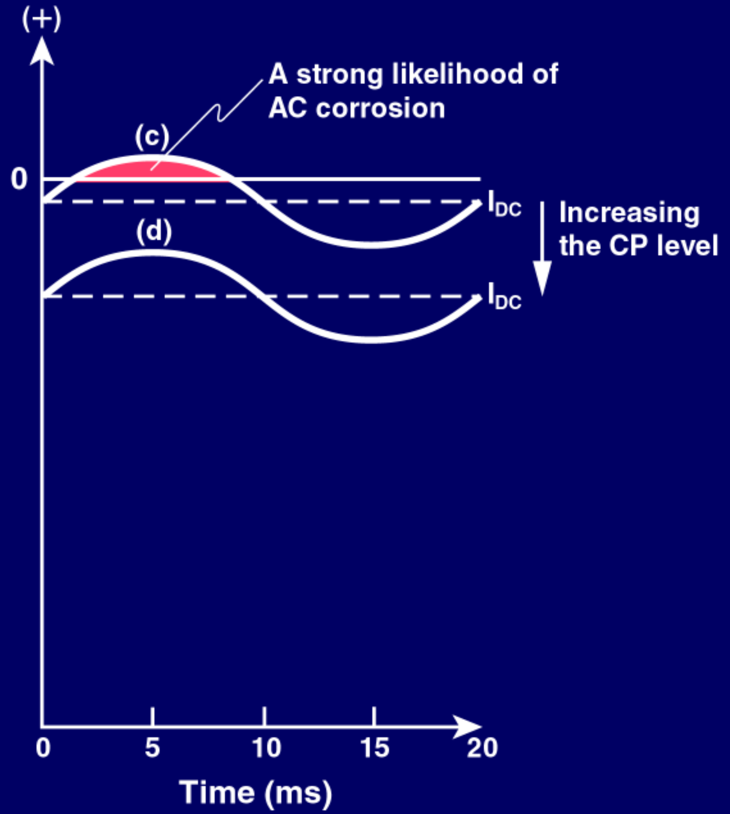


Increase the CP level so that the positive part of AC current can be neglected

< Very high induced AC current >

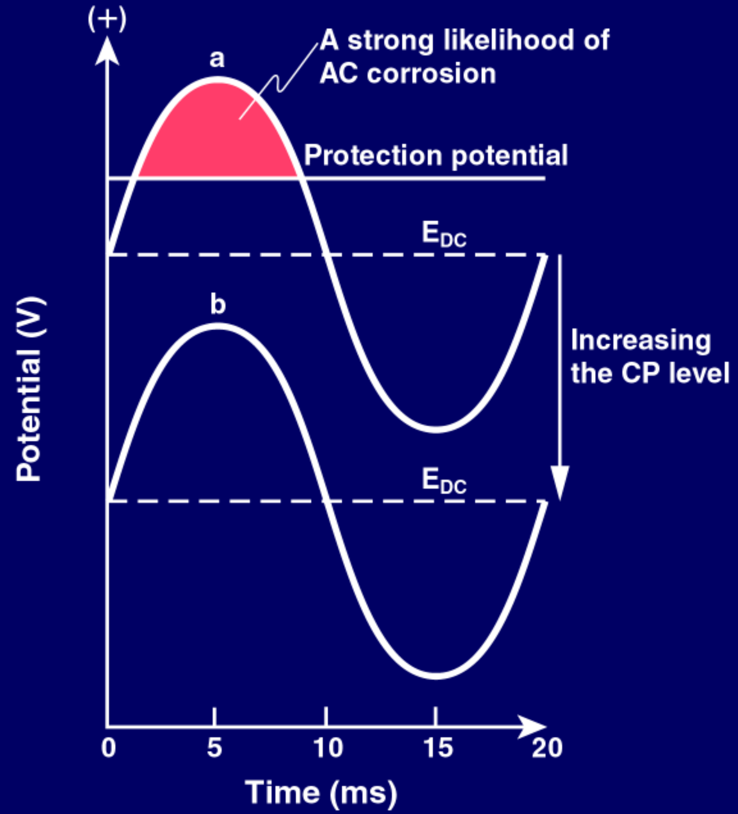


< Very modest induced AC current >

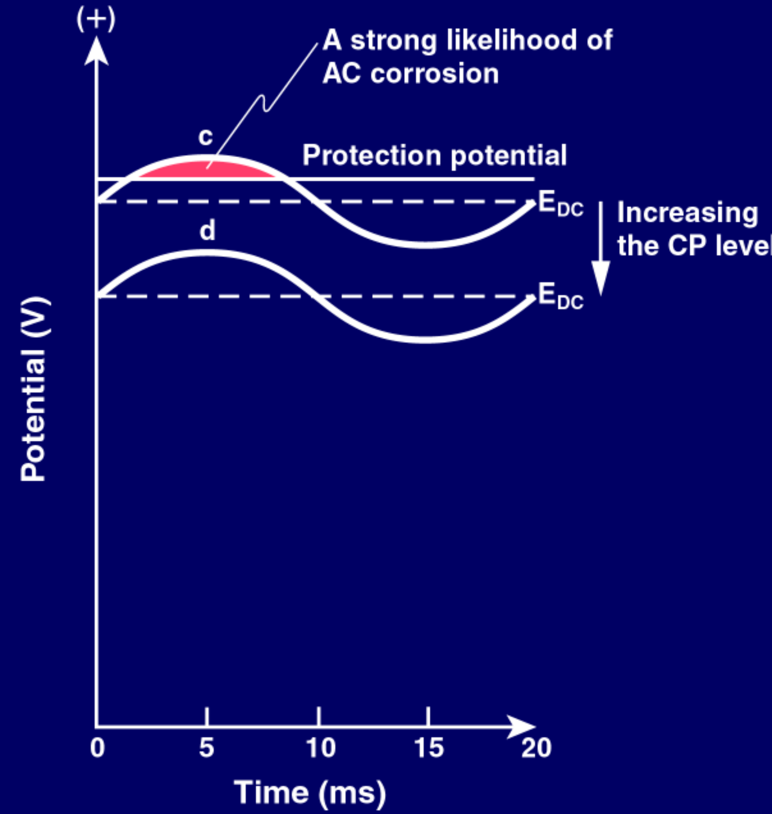


Increase the CP level so that the positive part of AC potential can be neglected

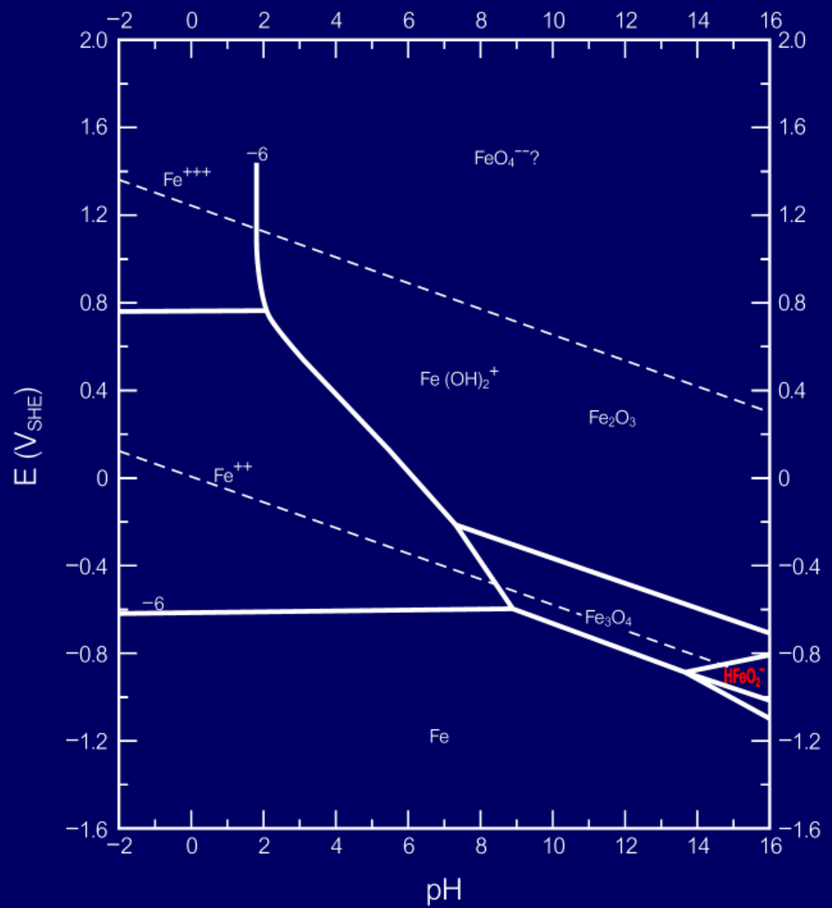
< Very high induced AC potential >



< Very modest induced AC potential >



Pourbaix diagram showing $HFeO_2^-$ region with respect to AC corrosion at very high pH



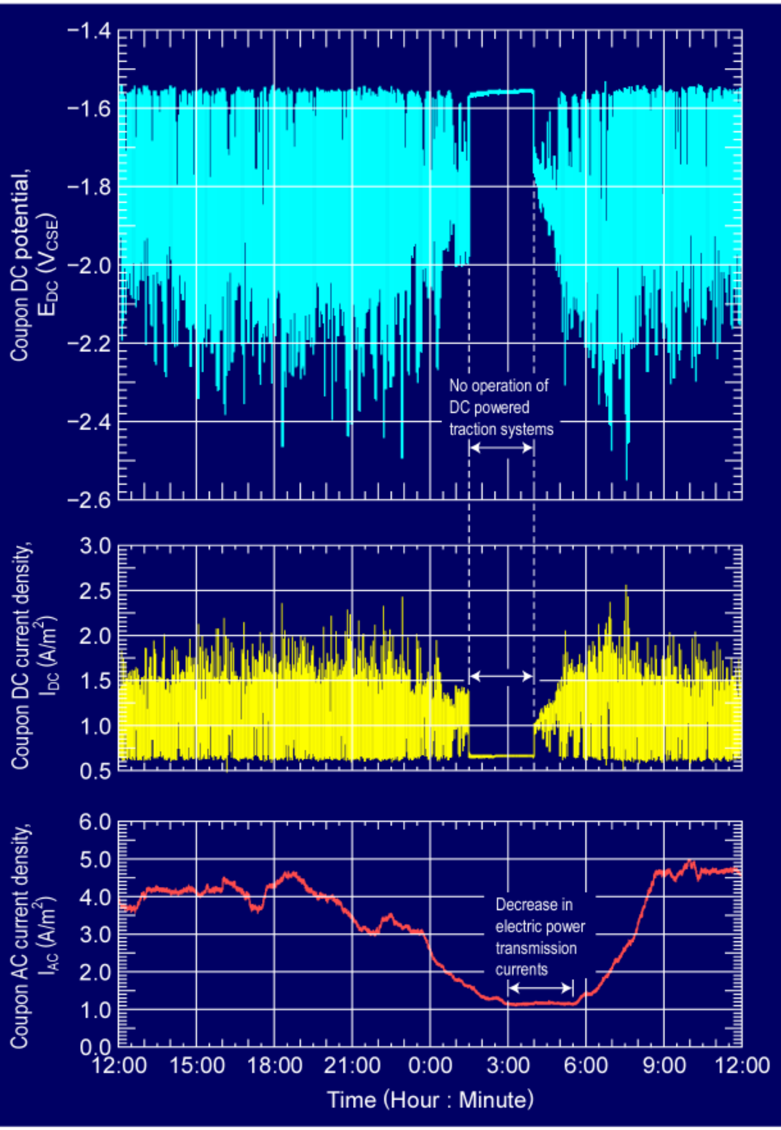
Care should be exercised to avoid increase in CP level, which can promote AC corrosion risk as well as hydrogen embrittlement risk.

An example of measured data

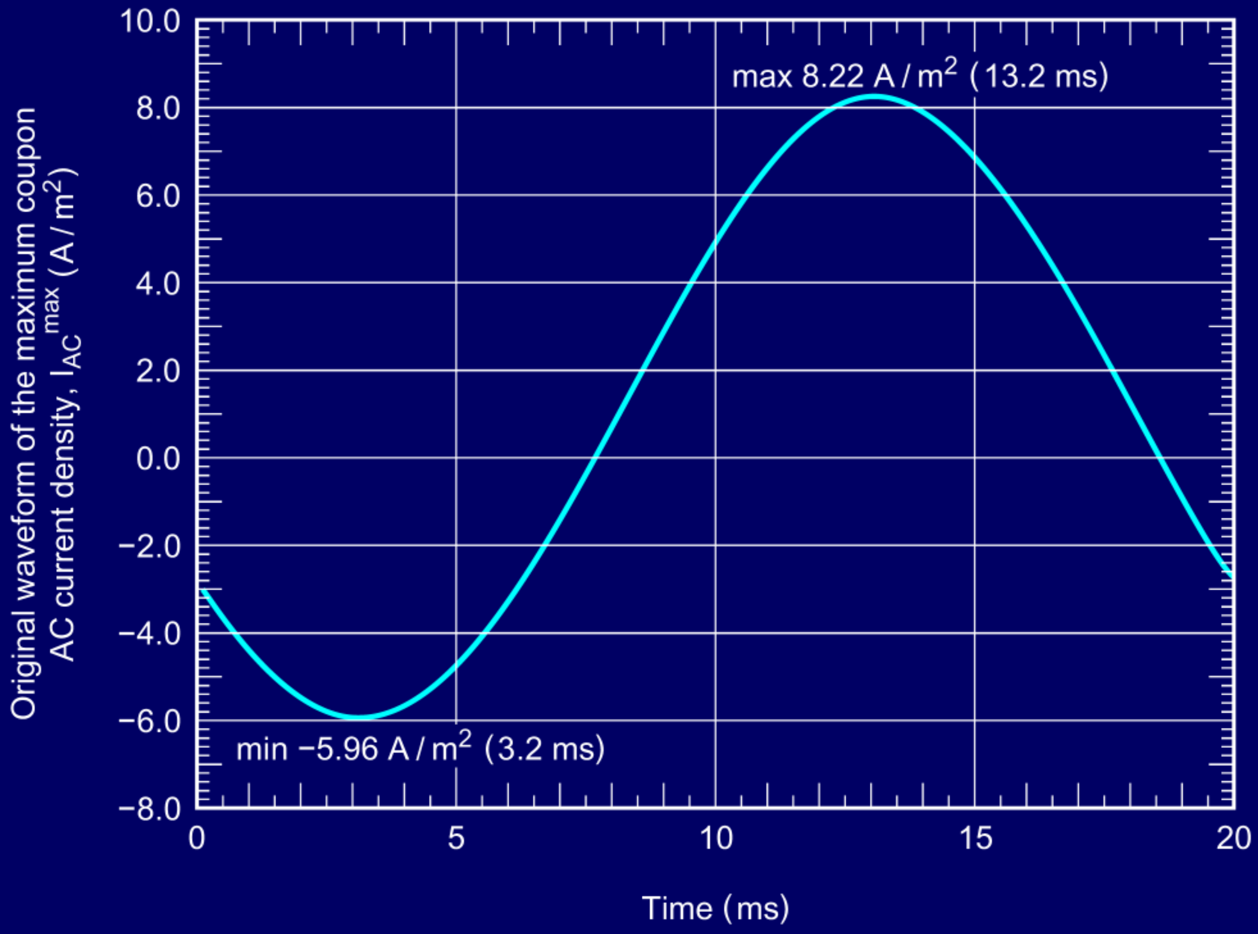
Example of measured data

Polyethylene coated 300 mm diameter pipeline paralleling two 66 kV, 50 Hz overhead electric power transmisson lines and neighboring a 1500 V DC powered rail transit systems.

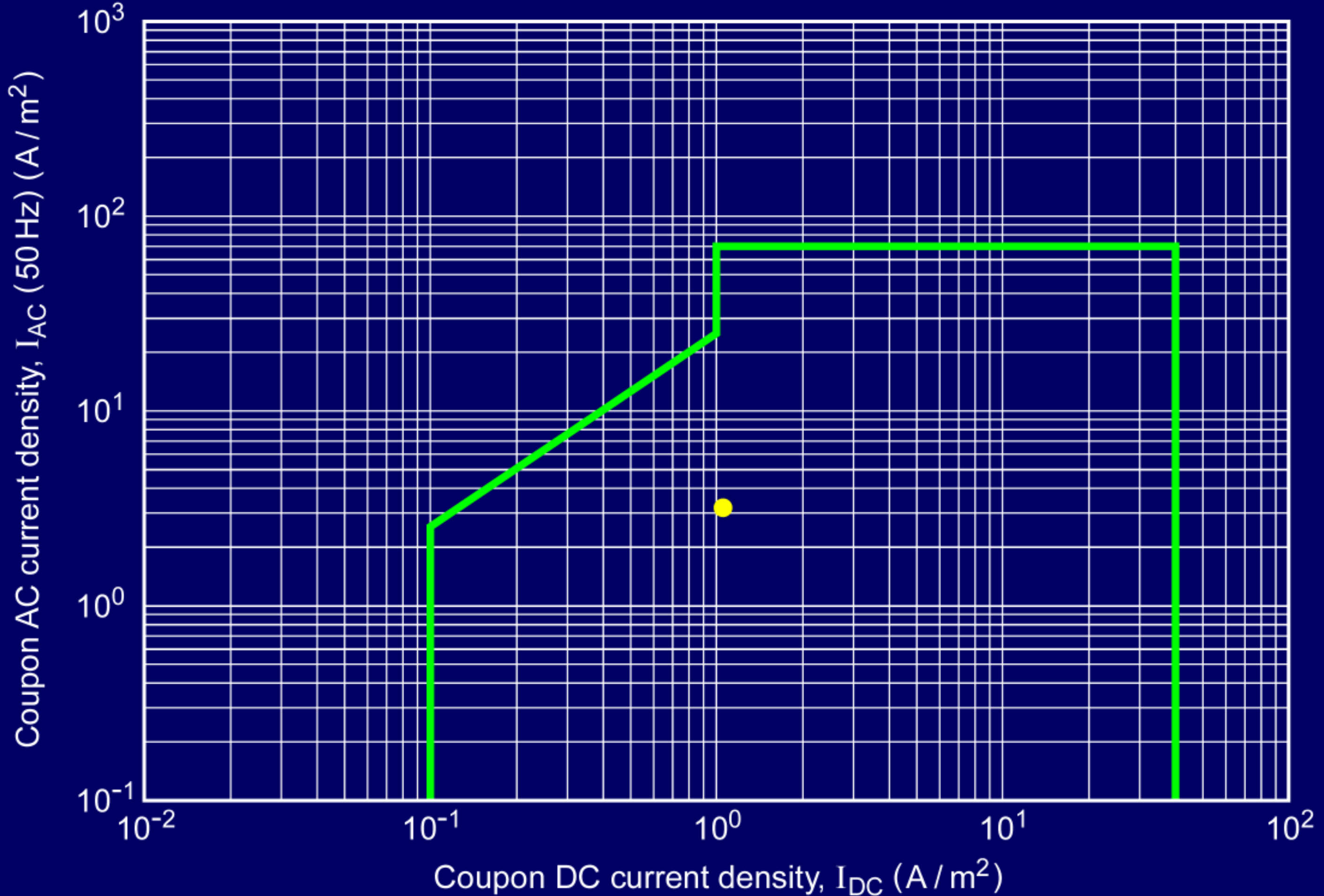
E_{DC}, I_{DC} and I_{AC}



Original waveform of maximum coupon AC current density in the measurement time



Result of the measured average values of I_{DC} and I_{AC}.



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Conclusions

Conclusions (1/6)

1. Even if coupon DC potential, E_{DC}, (polarized potential) satisfies the protection potential criterion, the positive part of AC wave form more positive than the protection potential which indicates a strong likelihood of AC corrosion cannot be recognized without high rate data sampling measurement techniques.

2. AC corrosion can occur in high alkaline environment produced by cathodic protection that is perfectly passivating if AC currents are absent.
   This is a special feature of AC corrosion.

Conclusions (2/6)

3. There is a lack of technical consensus on the mechanism and the extent of the effect of AC densities on cathodically protected underground metallic structures, particularly AC corrosion in soils.

   There are no agreed-on criteria for AC corrosion protection.

   Furthermore, the effect of hydrogen formed by cathodic protection on a modern pipeline is not well understood.

   In spite of these situations, pipeline corrosion engineers shall struggle to eliminate risks.

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Conclusions (3/6)

4. Based on accumulated-experience and knowledge for many years, the authors have developed an innovated instrumentation for assessing the AC corrosion risk of buried pipelines, and established the new CP criterion based on coupon DC and AC current densities (coupon current density-based criterion).

   The most distinguished feature is the simultaneous computation in a measuring unit of 20 ms regarding coupon DC current density and coupon AC current density corresponding to a period of the commercial frequency of 50 Hz.

Conclusions (4/6)

The criterion eliminates all corrosion risks such as AC corrosion, DC stray current corrosion, microbiologically influenced corrosion etc. and overprotection risk.

Conclusions (5/6)

5. The new CP criterion established by the authors is the second revolutionary criterion following the protection potential criterion proposed by Kuhn in 1933.

   From now on, for the case of no AC interference, the protection potential criterion continues to be accepted and used on steel pipelines and structures in various soils and water.

Conclusions (6/6)

6. Pipeline corrosion engineers shall be aware of the changes in materials (pipe and coating) and conditions of environments where the pipeline is laid (AC interference current), then, eliminate predictable risks of all corrosion including AC corrosion and overprotection to manage and maintain the integrity of their pipelines;

   thereby engineer's primary responsibility is achieved.