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# Corrosion of metals and alloys — Multielectrode arrays for corrosion measurement

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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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# Introduction

The multielectrode array technology has been used to study electrochemical behaviours and localized corrosion of metals and alloys since the 1990s 1-2. It has been demonstrated that the multielectrode arrays are highly powerful tools for studying the spatiotemporal behaviour of metals in laboratories3-13 and for monitoring non-uniform corrosion, especially localized corrosion in laboratories and plants 14. Multielectrode arrays are also used as high-throughput probes for studying the statistical behaviour of metal corrosion15 and evaluation of inhibitors16. The goal of this standard is designed to outline the requirements and procedures for conducting corrosion measurements using multielectrode arrays.

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# Corrosion of metals and alloys — Multielectrode arrays for corrosion measurement

### **1** Scope

This standard specifies the methodology of using multielectrode arrays for measurement of the corrosion, especially localized corrosion, of metals and alloys. It can be used as a powerful tool for studying the initiation and propagation processes of localized corrosion. It is also a useful tool for long-term corrosion monitoring in the field, especially for localized corrosion, and for obtaining high throughput results for the evaluation of metals with different compositions and/or physical properties in different environments and the screening of a large number of inhibitors. Additionally, the galvanic coupling current and potential distribution of dissimilar metal parings can be assessed by multielectrode arrays. Multielectrode arrays can be implemented in full-immersion, thin-film, spray, and alternating wet-dry cycle exposures.

This standard is not intended to be used for measurements of corrosion caused by non-electrochemical mechanism.

#### 2 Normative references

dsisteriot The following documents, in whole or in parts are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document applies.

ASTM G199, Standard Guide for Electrochemical Noise Measurement

ASTM G217, Standard Guide for Corrosion Monitoring in Laboratories and Plants with Coupled Multielectrode Array Sensor (CMAS) Technique

ISO 8407, Corrosion of metals and allows  $\leftrightarrow$  Removal of corrosion products from corrosion test specimens

ISO 8044, Corrosion of metals and alloys — Basic terms and definitions

ISO 11463, Corrosion of metals and alloys — Evaluation of pitting corrosion

ISO 11845, Corrosion of metals and alloys — General principles for corrosion testing

ISO 14802, Corrosion of metals and alloys — Guidelines for applying statistics to analysis of corrosion data

ISO 17474, Corrosion of metals and alloys — Conventions applicable to electrochemical measurements in corrosion testing

ISO 17093, Corrosion of metals and alloys — Guidelines for corrosion test by electrochemical noise measurements

ASTM-G1, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

#### 3 **Terms and definitions**

For the purposes of this document, the terms and definitions given in ISO 8044 apply except as noted below.

**3.1** Uneven general corrosion—corrosion that occurs over the whole exposed area of a metal at different rates across the exposed area. It is a type of general corrosion as defined in ISO 8044 that produces uneven surface or wave-like surface<sup>17, 18</sup> where the thickness reduction at the more corroded areas is significantly larger than the thickness reduction at the less corroded areas or the average corroded areas.

**3.2 Non-uniform corrosion**—corrosion that occurs at different rates over a metal surface where there is a localized surplus of net anodic or net cathodic rates such that a localized area does not exhibit charge neutrality and electrons flow within the metal from the anodic-dominant areas to the cathodic-dominant areas. Non-uniform corrosion includes both localized corrosion as defined in ISO 8044 and uneven general corrosion (as defined in <u>3.1</u>). Non-uniform corrosion also includes the type of general corrosion that produces even surfaces at the end of a large time interval, but uneven surfaces within small time intervals.

**3.3 Multielectrode Array**—A device with multiple electrodes that have similar surface area and are made of a same metal for corrosion studies and corrosion monitoring.

### 4 Principle

### 4.1 Multielectrode arrays

One of the characteristics of non-uniform corrosion, especially localized corrosion, on a metal surface is that there are some small areas that are more anodic and some small areas that are less anodic or that are cathodic. Multielectrode arrays as shown in Figure 1 are highly effective tools for studying non-uniform corrosion. In Figure 1(A), the electrodes of the multielectrode array were closely packed to simulate the metal surface for studying the spatiotemporal behaviour of localized corrosion.<sup>5</sup> In Figure 1(B), the multielectrode array was buried under sands in a cup to evaluate under deposit corrosion.<sup>19</sup> In general, the electrodes in a multielectrode array are arranged in regular patterns such as those shown in Figures 1 and 2, but they may also be arranged in a randomly packed pattern.<sup>15</sup>



# Figure 1 — Typical multielectrode arrays with closely-packed electrodes for spatial-temporal studies of localized corrosion (A) <sup>5</sup> and a sand cup for evaluation of under deposit corrosion (B)<sup>19</sup>

The currents of the electrodes composing the array can be measured individually. It is possible to measure the potentials of each individual electrode, of a selected group of electrodes, or the totality of the electrodes if they are coupled (see below). It is at times technically feasible to polarize one or more electrodes using a single-channel potentiostat or a multi-channel potentiostat in order to evaluate the effects of polarization on the neighbouring electrodes.<sup>5</sup> Because of the small size of the electrodes in the array, the polarization currents are usually very small (less than 1  $\mu$ A) and their effects on the measurements of the potential of the neighboring electrodes due to the IR drop can be ignored.

### 4.2 Coupled multielectrode array (CMA)

If all the electrodes or a selected number of electrodes in a multielectrode array are coupled together by wires or through the use of multichannel ammeters that impose near-zero voltages between the electrodes and the coupling joint so that all the electrodes connected to the coupling joint are essentially at the same potential, such multielectrode array is called a coupled multielectrode array (CMA). The ammeters that impose near zero voltage are called zero-voltage ammeters (ZVA) and will be described in <u>Section 5.2</u>. Figure 2 shows a typical CMA system where all the electrodes are controlled at the same potential by the potentiostat through a multichannel ZVA box<sup>1</sup>.



Figure 2 — A Typical CMA system for electrochemical studies under polarization conditions<sup>1</sup>. Note that the counter electrode is electrically separated from the multielectrode array.

# 4.3 Multielectrode array with closely packed electrodes for studying spatiotemporal behaviour of localized corrosion

**4.3.1** If the electrodes are arranged in an organized pattern such as 4x4, 5x20, or 10x10 and the electrodes are closely packed and their size are small (typically < 1 mm in diameter), such multielectrode array may be used to study the spatial and temporal behaviour of corrosion on a metal surface, e.g., when and where localized corrosion first initiate and how the localized corrosion propagate on the metal surface. Annex A shows a typical use of the CMA as shown in Figure 1(A) for studying the spatial and temporal behaviour of corrosion.

**4.3.2** The CMA may also be used at its corrosion potential without any polarization. In a typical case of localized corrosion where there is clear separation of anodes and cathodes, the array simulates one-piece metal and the electrodes that have net anodic currents simulate the anodic areas and the electrodes that have net cathodic currents simulate the cathodic areas on the metal surface as shown in Figure 3. By measuring the electron flow from the anodic electrodes to the cathodic electrodes on the array as a

function of time, the information of the initiation and propagation of localized corrosion that takes place naturally on the metal can be obtained.



Figure 3 — Typical characteristics of localized corrosion on a metal surface at its corrosion potential--Electrons flow from anodic areas to the cathodic areas within the metal<sup>2</sup>

In a typical non-uniform general corrosion case, there is no clear separation of anodes and cathodes, but some areas corrode more and some areas corrodeless and all areas are anodic, at least for short a duration during corrosion process. The electrodes on the array that have net anodic currents simulate the more corroding areas and the electrodes that have net cathodic currents simulate the less corroding areas.

### 4.4 Coupled multielectrode array sensor (CMAS)

### 4.4.1 CMAS for corrosion monitoring

If a CMA is used as a sensor for corrosion monitoring, such a CMA is called a coupled multielectrode array sensor (CMAS). Figure 4 shows some typical CMASs. There is no need for a plant operator to know all the individual currents and create a corrosion map for a sensor in the fields. It often suffices for the operator to know the maximum corrosion rate, at the worst corroding area, and the associated maximum penetration depth, without needing to know where exactly these worst areas are. The outputs of the CMAS probes are often those two simple parameters: maximum corrosion rate (calculated from the most anodic current which is from the worst or most corroding electrode), and maximum penetration depth (calculated from the most corroded electrode). The operators can apply their corrosion mitigation measures (e.g., by adding a corrosion inhibitor) based on the maximum corrosion rate. On the other hand, the engineers may decide how often the plant equipment should be inspected based on the maximum penetration depth [See ASTM G217-16 for additional information].