ASTM INTERNATIONAL

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Standard Guide for
Corrosion Monitoring in Laboratories and Plants with Coupled Multielectrode Array Sensor Method[1]

This standard is issued under the fixed designation G217; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide outlines the procedure for conducting corrosion monitoring in laboratories and plants by use of the coupled multielectrode array sensor (CMAS) technique.

1.2 For plant applications, this technique can be used to assess the instantaneous non-uniform corrosion rate, including localized corrosion rate, on a continuous basis, without removal of the monitoring probes, from the plant.

1.3 For laboratory applications, this technique can be used to study the effects of various testing conditions and inhibitors on non-uniform corrosion, including pitting corrosion and crevice corrosion.

1.4 *Units*—The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

G4 Guide for Conducting Corrosion Tests in Field Applications
G16 Guide for Applying Statistics to Analysis of Corrosion Data
G46 Guide for Examination and Evaluation of Pitting Corrosion
G48 Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution
G96 Guide for Online Monitoring of Corrosion in Plant Equipment (Electrical and Electrochemical Methods)
G102 Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements
G193 Terminology and Acronyms Relating to Corrosion
G199 Guide for Electrochemical Noise Measurement

3. Terminology

3.1 *Definitions*—The terminology used herein, if not specifically defined otherwise, shall be in accordance with Terminology G193. Definitions provided herein and not given in Terminology G193 are limited only to this guide.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *coupled multielectrode array sensor, CMAS, n*—device with multiple working electrodes that are coupled through an external circuit such that all the electrodes operate at the same electrode potential to simulate the electrochemical behavior of a single-piece metal.

3.2.2 *non-uniform corrosion, n*—corrosion that occurs at various rates across the metal surface, with some locations exhibiting higher anodic rates while others have higher cathodic rates, thereby requiring that the electron transfer occurs between these sites within the metal.

3.2.2.1 *Discussion*—Non-uniform corrosion includes both localized corrosion and uneven general corrosion (**1**).[3] 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 during small time intervals.

3.2.3 *uneven general corrosion, n*—corrosion that occurs over the whole exposed surface or a large area at different rates.

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[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

3.2.3.1 *Discussion*—In this guide, general corrosion is further divided into even general corrosion, or uniform corrosion, which is defined as the corrosion that proceeds at exactly the same rate over the surface of a material (see Terminology G193) and uneven general corrosion. Uneven general corrosion is defined as the general corrosion that produces uneven surface or wave-like surface on a metal that has an even surface before the corrosion (**2, 3**).

3.2.4 *zero-voltage ammeter, ZVA, n*—device that imposes a negligibly low voltage drop when inserted into a circuit for measurement of current.

3.2.4.1 *Discussion*—The ZVA defined in this guide also meets the definition of the zero-resistance ammeter (ZRA) in Guide G199. A typical ZRA is built with inverting operational amplifiers to limit the voltage drop in the current-measuring circuit to a low value. Both ZRA and a simple device formed with a shunt resistor and a voltmeter can be used as a ZVA as long as they do not impose a significant voltage drop (<1 mV) in the current-measuring circuit (see Annex A2 for more information).

4. Significance and Use

4.1 Guide G96 describes a linear-polarization method and an electrical resistance method for online monitoring of corrosion in plant equipment without the need to enter the system physically to withdraw coupons. These two online monitoring techniques are useful in systems in which process upsets or other problems can create corrosive conditions. An early

warning of corrosive attack can permit remedial action before significant damage occurs to process equipment. The two methods described in Guide G96 are suitable for uniform corrosion, but may not be sensitive enough for non-uniform corrosion, especially localized corrosion. This guide describes a new method for monitoring non-uniform corrosion, especially localized corrosion.

4.2 The CMAS technique measures the net anodic current or net cathodic current from each of the individual electrodes (I^a_{ex} or I^c_{ex} in Fig. 1), which is the characteristic of non-uniform corrosion such as localized corrosion and uneven general corrosion. Therefore, the CMAS technique can be used to estimate the rate of uneven general corrosion and localized corrosion (see Section 5).

4.3 Unlike uniform corrosion, the rate of non-uniform corrosion, especially localized corrosion, can vary significantly from one area to another area of the same metal exposed to the same environment. Allowance shall be made for such variations when the measured non-uniform corrosion rate is used to estimate the penetration of the actual metal structure or the actual wall of process equipment. This variability is less critical when relative changes in corrosion rate are to be detected, for example, to track the effectiveness of corrosion inhibitors in an inhibited system.

4.4 The same as the method described in Guide G96, the CMAS technique described in this guide provides a technique for determining corrosion rates without the need to enter the
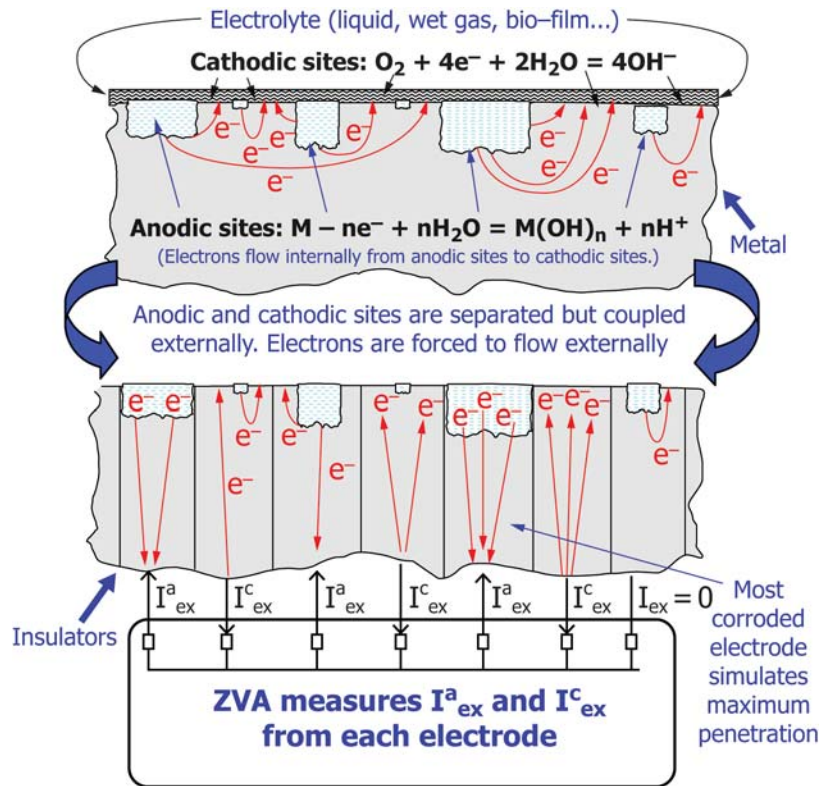
NOTE 1—The upper section shows the electron flows from the corroding area to the less corroding areas inside a metal when localized corrosion takes place; the lower section shows the electron flows after the anodic and cathodic areas are separated into individual small electrodes and coupled through an external circuit that measures the anodic current (I^a_{ex}) and cathodic current (I^c_{ex}) through each of the individual electrodes (**4**).

FIG. 1 Principle of CMAS Probe

system physically to withdraw coupons as required by the methods described in Guide G4.

4.5 The same as the methods described in Guide G96, the CMAS technique is useful in systems in which process upsets or other problems can create corrosive conditions. An early warning of corrosive attack can permit remedial action before significant damage occurs to process equipment.

4.6 The CMAS technique provides the instantaneous corrosion rate within 10 s to 40 s making it suitable for automatic corrosion inhibitor dosing control.

4.7 The CMAS technique is an online technique and may be used to provide real-time measurements for internal corrosion of pipelines and process vessels, external corrosion of buried pipes and structures, and atmospheric corrosion of metal structures.

5. Description of Guide

5.1 *Coupled Multielectrode Array Sensor (CMAS) Principle:*

5.1.1 Coupled multielectrode array is a system with multiple working electrodes that are electrically coupled through an external circuit so that all of the electrodes operate at the same potential to simulate the electrochemical behavior of a single-piece metal. The coupled multielectrode arrays have been used for studying the spatial and temporal electrochemical behaviors of metals during corrosion processes (5-7). The CMAS is a coupled multielectrode array used as a sensor for monitoring corrosion. The outputs from a coupled multielectrode array are the addressable individual currents from all electrodes. The outputs from a typical CMAS probe are usually the maximum corrosion rate and maximum penetration depth derived from the individual currents from the multiple electrodes without the need to know the spatial location of the particular electrodes (4, 8).

5.1.2 When a metal undergoes non-uniform corrosion, particularly localized corrosion such as pitting corrosion or crevice corrosion in a corrosive environment, electrons are released from the anodic sites where the metal corrodes and travel within the metal to the cathodic sites where the metal corrodes less or does not corrode (see upper section of Fig. 1) (4). Such phenomenon occurs because of local variations in the microstructure of the metal surface and in the environment or the development of scale layers on the metal surface. If the metal is separated into multiple small pieces (or mini-electrodes), some of the mini-electrodes have properties that are close to the anodic sites and others have properties that are close to the cathodic sites of the corroding metal. When these mini-electrodes are coupled by connecting each of them to a common joint through a multichannel zero-voltage ammeter (ZVA), the electrodes that exhibit anodic properties simulate the anodic areas, and the electrodes that exhibit the cathodic properties simulate the cathodic areas of the corroding metal (see lower section of Fig. 1). The electrons released from the anodic electrodes are forced to flow through the coupling joint to the cathodic electrodes. Thus, the ZVA measures the anodic currents (I^a_{ex}) to the more corroding electrodes and cathodic currents (I^c_{ex}) from the less corroding or noncorroding elec-

trodes. The quantitative localized or non-uniform corrosion rates from the individual electrodes may be determined from the anodic currents (4, 5, 8). The reason to use a ZVA to measure the current for each electrode is that the ZVA does not impose a potential drop between the electrode under measurement and the coupling joint, which ensures that all the electrodes are at the same electrode potential so that the multiple electrodes simulate the behavior of a one-piece metal. A zero-resistance ammeter (ZRA) is one type of ZVA and can be used for the current measurements in a CMAS probe. A resistor inserted in the circuit and a voltmeter can also be used as the ZVA for the measurements of the current in a CMAS probe because the current from a CMAS electrode is extremely small (typically <1 μA) and produces negligibly low-voltage drop across the resistor (<0.1 mV if the resistor is 100 Ω).

5.1.3 On an anodic electrode, the corrosion current (total dissolution current), I_{corr}, is equal to the sum of the externally flowing anodic current, I^a_{ex} (see Fig. 1) and the internally flowing anodic currents, I^a_{in} (see Annex A1 for more information). Therefore,

$$I_{corr} = I^a_{ex} + I^a_{in} \qquad (1)$$

5.1.4 Because the I^a_{in} for the anodic electrode, especially when the anodic electrode is the most anodic electrode among all the anodic electrodes of the CMAS probe, is often much smaller than its I^a_{ex} at the coupling potential in a non-uniform corrosion or localized corrosion environment, the externally flowing current from such anodic electrode of the probe is often used to estimate the non-uniform or localized corrosion current:

$$I_{corr} \approx I^a_{ex} \qquad (2)$$

5.1.5 In the case of uniform corrosion, however, there would be no physical separation between the anodic electrodes and the cathodic electrodes. The behavior of the most anodic electrode would be similar to the other electrodes in the CMAS probe. In this case, the I^a_{in} on the anodic electrode would be large and I^a_{ex} would be zero, and Eq 2 may not be used to calculate the corrosion rate. Therefore, CMAS technique is not suitable for monitoring the rate of corrosion where the corrosion is uniformly progressing at all times. The CMAS probe is suitable for monitoring non-uniform corrosion, including uneven general corrosion such as the case for carbon steel in seawater and localized corrosion (see Annex A1 for theoretical basis). In cases of general corrosion in which the corrosion is characterized as both uniform corrosion and uneven general corrosion, the CMAS probe measures the uneven portion of the corrosion. For example, the CMAS probe measures more than 56 % of the corrosion rate for carbon steel in a 0.2 % hydrochloric acid (HCl) solution and more than 22 % of the corrosion rate for carbon steel in a 2 % HCl solution (see Annex A1 for more information).

5.2 *Determination of Corrosion Rate (5, 8):*

5.2.1 In a corrosion management program for engineering structures, field facilities, or plant equipment, the most important parameter is the remaining life (often the remaining wall thickness) of the systems. If localized corrosion is of concern, the remaining wall thickness in the most corroded area is often used to evaluate the remaining life. Therefore, the maximum