Designation: G106 – 89 (Reapproved 2023)

Standard Practice for Verification of Algorithm and Equipment for Electrochemical Impedance Measurements[1]

This standard is issued under the fixed designation G106; 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 practice covers an experimental procedure which can be used to check one's instrumentation and technique for collecting and presenting electrochemical impedance data. If followed, this practice provides a standard material, electrolyte, and procedure for collecting electrochemical impedance data at the open circuit or corrosion potential that should reproduce data determined by others at different times and in different laboratories. This practice may not be appropriate for collecting impedance information for all materials or in all environments.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *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.*

1.4 *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]

D1193 Specification for Reagent Water

G3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing

G5 Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements

G15 Terminology Relating to Corrosion and Corrosion Testing (Withdrawn 2010)[3]

G59 Test Method for Conducting Potentiodynamic Polarization Resistance Measurements

3. Terminology

3.1 *Definitions*—For definitions of corrosion related terms, see Terminology G15.

3.2 *Symbols:*

C = capacitance (farad-cm^{-2})
E' = real component of voltage (volts)
E'' = imaginary component of voltage (volts)
E = complex voltage (volts)
f = frequency (s^{-1})
I' = real component of current (amp-cm^{-2})
I'' = imaginary component of current (amp-cm^{-2})
I = complex current (amp-cm^{-2})
j = $\sqrt{-1}$
L = inductance (henry – cm^2)
R_s = solution resistance (ohm-cm^2)
R_p = polarization resistance (ohm-cm^2)
R_t = charge transfer resistance (ohm-cm^2)
Z' = real component of impedance (ohm-cm^2)
Z'' = imaginary component of impedance (ohm-cm^2)
Z = complex impedance (ohm-cm^2)
α = phenomenological coefficients caused by depression of the Nyquist plot below the real axis, α is the exponent and τ is the time constant(s).
θ = phase angle (deg)
ω = frequency (radians-s^{-1})

3.3 *Subscripts:*

x = in-phase component
y = out-of-phase component

[1] This practice is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.11 on Electrochemical Measurements in Corrosion Testing.

Current edition approved June 1, 2023. Published June 2023. Originally approved in 1989. Last previous edition approved in 2015 as G106 – 89 (2015). DOI: 10.1520/G0106-89R23.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

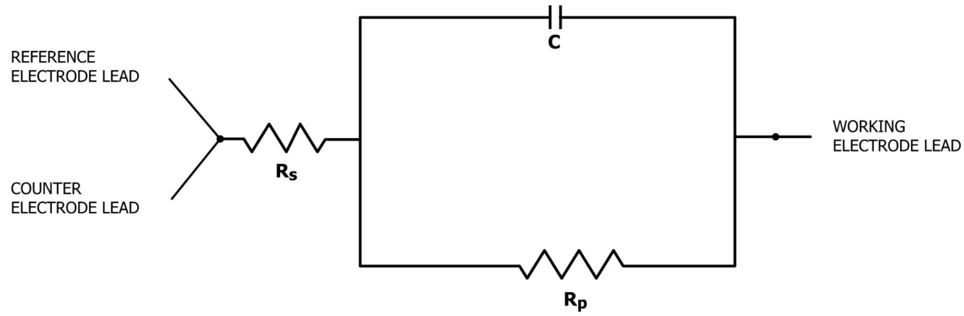

FIG. 1 Circuit Diagram for Dummy Cell Showing Positions for Hook-Up to Potentiostat

4. Summary of Practice

4.1 Reference impedance plots in both Nyquist and Bode format are included. These reference plots are derived from the results from nine different laboratories that used a standard dummy cell and followed the standard procedure using a specific ferritic type alloy UNS-S43000[4] in 0.005 M H_2SO_4 and 0.495 M Na_2SO_4. The plots for the reference material are presented as an envelope that surrounds all of the data with and without inclusion of the uncompensated resistance. Plots for one data set from one laboratory are presented as well. Since the results from the dummy cell are independent of laboratory, only one set of results is presented.

4.2 A discussion of the electrochemical impedance technique, the physics that underlies it, and some methods of interpreting the data are given in the Appendix X1 – Appendix X6. These sections are included to aid the individual in understanding the electrochemical impedance technique and some of its capabilities. The information is not intended to be all inclusive.

5. Significance and Use

5.1 The availability of a standard procedure, standard material, and standard plots should allow the investigator to check his laboratory technique. This practice should lead to electrochemical impedance curves in the literature which can be compared easily and with confidence.

5.2 Samples of a standard ferritic type 430 stainless steel (UNS 430000) used to obtain the reference plots are available for those who wish to check their equipment. Suitable resistors and capacitors can be obtained from electronics supply houses.

5.3 This test method may not be appropriate for electrochemical impedance measurements of all materials or in all environments.

6. Apparatus

6.1 *Dummy Cell*—The dummy cell used to check the equipment and method for generating electrochemical impedance data is composed of a 10 Ω precision resistor placed in series with a circuit element composed of a 100 Ω precision resistor in parallel with a 100 µF capacitor. The resistors should have a stated precision of ±0.1 %. The capacitor can have a precision of ±20 %. The cell can be constructed from readily available circuit elements by following the circuit diagram shown in Fig. 1.

6.2 *Test Cell*—The test cell should be constructed to allow the following items to be inserted into the solution chamber: the test electrode, two counter electrodes or a symmetrically arranged counter electrode around the working electrode, a Luggin-Haber capillary with salt bridge connection to the reference electrode, an inlet and an outlet for an inert gas, and a thermometer or thermocouple holder. The test cell must be constructed of materials that will not corrode, deteriorate, or otherwise contaminate the solution.

6.2.1 One type of suitable cell is described in Reference Test Method G5. Cells are not limited to that design. For example, a 1 L round-bottom flask can be modified for the addition of various necks to permit the introduction of electrodes, gas inlet and outlet tubes, and the thermometer holder. A Luggin-Haber capillary probe could be used to separate the bulk solution from the saturated calomel electrode. The capillary tip can be easily adjusted to bring it into close proximity to the working electrode. The minimum distance should be no less than two capillary diameters from the working electrode.

6.3 *Electrode Holder*—The auxiliary and working electrodes can be mounted in the manner shown in Reference Test Method G5. Precautions described in Reference Test Method G5 about assembly should be followed.

6.4 *Potentiostat*—The potentiostat must be of the kind that allows for the application of a potential sweep as described in Reference Test Method G5 and Reference Practice G59. The potentiostat must have outputs in the form of voltage versus ground for both potential and current. The potentiostat must have sufficient bandwidth for minimal phase shift up to at least 1000 Hz and preferably to 10 000 Hz. The potentiostat must be capable of accepting an external excitation signal. Many commercial potentiostats meet the specification requirements for these types of measurements.

6.5 *Collection and Analysis of Current-Voltage Response*—The potential and current measuring circuits must have the characteristics described in Reference Test Method G5 along with sufficient band-width as described above. The impedance can be calculated in several ways, for example, by means of a transfer function analyzer, Lissajous figures on an oscilloscope,

[4] These standard samples are available from ASTM Headquarters. Generally, one sample can be repolished and reused for many runs. This procedure is suggested to conserve the available material.