

MS1000
Corrosion Meter
Owner's Manual

Metal Samples

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I. Introduction

A. Background

The MS1000 is a portable, hand-held, battery-powered corrosion meter. This versatile instrument measures the instantaneous corrosion rate with the Linear Polarization Resistance (LPR) technique. It also measures the current flowing between electrodes in the short-circuited condition with a high precision zero resistance ammeter (ZRA). The MS1000 can analyze two-electrode linear polarization resistance or galvanic type probes.

The principle use of this instrument is to measure corrosion rates under various conditions in the plant, field, or lab. In addition to using this instrument to monitor corrosion rates, corrosion engineers can also use the MS1000 to monitor inhibitor effectiveness, identify process upsets, identify localized corrosion events, and evaluate corrective actions in real time. These measurements are very important since a change in the process conditions can lead to dramatic changes in the observed corrosion rate.

B. Instrument Capabilities

Instantaneous Corrosion Rate Measurements

Instantaneous corrosion rate measurements are made with the linear polarization resistance (LPR) technique. This technique is a reliable electrochemical procedure based on principles outlined in ASTM G59 Standard Practice for Conducting Potentiodynamic Polarization Resistance Measurements.¹ An excellent technical review of this technique is given elsewhere by Mansfeld.^{2,3}

The determination of a corrosion rate from the parameters measured with corrosion probes depends on Faraday's law. The mass loss, current, potential, and changes in these variables are converted into a corrosion rate. ASTM G102 Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements provides all necessary information for the direct calculation of the corrosion rate.⁴

The method used by the MS1000 for calculating the corrosion rate is as follows. A low amplitude dc voltage is applied across the electrodes and then the resulting current, normalized to current density, is measured. The voltage is held constant for thirty seconds before measuring the current so that any capacitance in the oxide layer will be fully charged. The polarity of the applied voltage is then changed and the measurement cycle is repeated. Polarity is reversed to minimize potential errors due to possible electrode dissimilarities or changes in the open circuit potential of the electrodes during the measurement.

The polarization resistance, R_p , of the corroding electrodes is calculated from the slope of the potential-current density plot. R_p is defined as:

$$R_p = \frac{\Delta E}{i}$$

where ΔE is the polarization from the open circuit potential of the electrodes and i is the measured current density at ΔE . Stern and Geary showed that there is a linear relationship between potential and applied current at potentials only slightly removed from the corrosion potential.¹ Based on the kinetics of electrochemical reactions and concepts of mixed potential theory, as discussed by Wagner and Traud, an equation was derived which related the polarization resistance to the corrosion current density, i_{corr} .⁶ The corrosion current density is calculated as:

$$i_{corr} = \frac{\beta_a \beta_c}{2.303R_p(\beta_a + \beta_c)}$$

where β_a and β_c are the anodic and cathodic Tafel constants (ie., the slopes of the anodic and cathodic polarization curves in the Tafel region).

The instantaneous corrosion rate in mils per year (mpy) is determined from i_{corr} with the following equation:

$$COR(mpy) = \frac{i_{corr} \cdot EW \cdot K}{\rho}$$

where **EW** is the equivalent weight, **K** is a constant for units conversion, and ρ is the density. The equivalent weight depends upon the composition of the alloy. Guidelines for determining the equivalent weight are given in ASTM G102.⁴

Note that this instrument has been designed to calculate the corrosion rate of carbon steel and common grades of stainless steel in mils per year. In other words, the programmed values of the Tafel slopes, equivalent weight, and density are typical for carbon steel and common grades of stainless steel. Multiplication factors for copper, admiralty brass, and lead are included on the front panel of the instrument.

The instrument is programmed for electrodes with surface areas of five cm². Multiplication factors are also included for flush mount electrodes with surface areas of 0.5 cm².

Zero Resistance Ammeter (ZRA) and Equivalent Pitting Rate

A high precision zero resistance ammeter is used for monitoring the short-circuit current between electrodes. This total current flowing between the electrodes in the short-circuited condition is monitored. The current is displayed in microamps. The zero resistance ammeter (ZRA) function may also be used to monitor the galvanic current between electrodes of different alloys or the area effect of galvanic corrosion.

Generally, if the magnitude of the ZRA reading divided by 2 is less than the corrosion rate, then pitting may be occurring but the pits will probably be shallow and wide; however, pitting may be a serious concern if the ZRA/2 is greater than the corrosion rate.

Faraday's law may be used to calculate the mass of material lost as a result of the localized corrosion as follows:

$$W = \frac{[(\sum ZRA)/n] \cdot t \cdot EW}{F}$$

where **W** is the mass of the corroded metal in grams, **($\sum ZRA$)/n** is the time-integrated ZRA divided by **n**, the number of days of exposure, **t** is the time the current is flowing in seconds, **EW** is the equivalent weight as previously defined, and **F** is the Faraday constant, 96480 Coulombs/mol. The mass of the corroded material may be used to calculate a

corrosion rate, designated as the equivalent pitting rate, based on the ZRA. This equivalent pitting rate is defined as:

$$EPR = \frac{K' \cdot W}{A \cdot t \cdot \rho}$$

where **EPR** is the equivalent pitting rate in mpy, **K'** is a constant for units conversion, **A** is the surface area in cm², **W** is the mass loss in grams, **t** is the time of exposure in seconds, and **ρ** is the density of the alloy in grams/cm³.

Additional technical information on this instrument has been published in the Proceedings of the 1994 International Water Conference.⁷

C. Applications for the MS1000

- Measure the instantaneous corrosion rate in aqueous solutions. For example, the content and dosage of inhibitors in water treatment facilities and chemical process plants can be monitored and optimized.
- Monitor the actual lifetime of plant equipment. Corrosion monitoring provides data that may be combined with other forms of data to estimate the lifetime of equipment in the plant.
- Detection of localized corrosion due to process conditions or upsets.
- Evaluate alternate materials for a specific purpose. Option for other alloys, heat treatments, or finishes may be evaluated and compared to the performance of the specific alloy considered.
- Analyze galvanic probes and measure the galvanic current between electrodes. Area effects in galvanic corrosion can also be investigated.

C. MS1000 Specifications and Features

Model

MS1000 - LPR Corrosion Meter (Ordering # IN1000)

Physical Data

Instrument Weight:	0.84 lb. (0.38 Kg)
Total Weight w/ Carrying Case and Accessories:	5.20 lb. (2.36 Kg) Instrument
Dimensions:	7.63"H x 4.15"W x 1.3"D (19.38cm x 10.54cm x 3.30cm)
Carrying Case Dimensions:	10"H x 11.75"W x 5.4"D (25.40cm x 29.85cm x 13.72cm)
Operating Temperature:	32° to 122°F (0° to 50°C)
Storage Temperature:	-4° to 158°F (-20° to 70°C)

Performance Data

Measurement Type:	2-Electrode LPR, Galvanic
Range:	2-Electrode: 0-40 mpy Galvanic: 0-80 μ A
Resolution:	2-Electrode: 0.02 mpy Galvanic: 0.04 μ A
Cycle Time:	Corrosion Rate: 60 sec ZRA: 30 sec

Electrical Data

Power Requirements:	One 9V Rechargeable Battery
Maximum Probe Cable Distance:	2000 ft (609.6 m)

Special Features

- Microprocessor-based electronics
- Function key interface using 4-key keypad and 4-line LCD display
- Low-battery detection
- Portable

Accessory Items

Carrying Case, 10' Probe Cable, Battery Charger, Lightweight Protective Case, Meter Prover, Operation Manual

III. MS1000 Operation

A. Test Readings

The MS1000 is supplied with a test probe to check proper functioning of the cable and instrument. In order to guarantee the accuracy of your data, check the instrument readings **at room temperature** with the test probe prior to taking measurements.

The test probe is used to verify correct instrument operation as follows:

1. Insert test probe into cable.
2. Press ON.
3. Press COR to measure the instantaneous corrosion rate. After 60 seconds the display should read:

$$\text{CORROSION RATE} = 5.00 \pm 0.05 \text{ mpy}$$

4. Press ZRA to measure the current imbalance. After 30 seconds the display should read:

$$\text{ZRA} = 0.00 \pm 0.12 \mu\text{A}$$

B. Data Acquisition

1. Instantaneous Corrosion Rate Measurements

Corrosion rate measurements may be collected as follows:

- a. Connect the instrument cable to the desired probe.
- b. Press ON to turn the MS1000 on.
- c. Press COR to measure the instantaneous corrosion rate.
- d. A short beep will sound after 60 seconds to indicate that the measurement is complete and the measured corrosion rate will be displayed on the screen.
- e. The measured rate is calculated for carbon steel. If another

electrode material was used, the result should be multiplied by the appropriate alloy multiplier. Four common alloys are listed on the MS1000 keypad. A more comprehensive list is provided on page 14.

2. ZRA and EPR Measurements

Electrochemical current noise and equivalent pitting rate measurements may be collected as follows:

- a. Connect the instrument cable to the desired probe.
- b. Press ON to turn the MS1000 on.
- c. Press ZRA to measure the current imbalance between the electrodes.
- d. A short beep will sound after 30 seconds to indicate that the measurement is complete and the measured ZRA and EPR will be displayed on the screen.

C. Electrode Installation, Replacement, and Care

The electrodes supplied from Metal Samples have a 600 grit (ground) surface finish. The electrodes are also degreased and shipped in volatile corrosion inhibitor (vci) bags for protection. Additional cleaning of the elements prior to use is not required. However, it is recommended that the electrodes be pretreated in the test solution of interest in order to bring the electrode surfaces to equilibrium. Pretreatment may be conducted in a full strength mixture of the solution in the system. Typical pretreatment times are at least 24 hours.

The resulting data generated from the pretreated electrodes will indicate the corrosion trends of the system much more rapidly, usually within a day, as opposed to as much as a week for untreated electrodes.

New electrodes are 1.250" (31.75 mm) in length and 0.188" (4.76 mm) in diameter. As corrosion occurs, the electrode diameter decreases. As a result, the electrode surface area decreases and the distance between the electrodes increases. These two factors are sources of error and may diminish the accuracy of the measured corrosion rate. Therefore, it is recommended that the electrodes be replaced when their diameter has decreased by 17%. In other words, the electrodes should be replaced when their diameter has decreased to 0.156" (3.97 mm).

If the probe and electrodes are to be moved, or if the electrodes become fouled with corrosion products or system contaminants, remove the electrodes from the probe and polish them to a dull shine with wet 600 grit abrasive paper. After polishing, rinse and degrease the electrodes prior to reinstallation.

Note: When handling electrodes, use clean latex gloves and paper towels. This will keep the electrodes clean and free from contaminating oily deposits.

D. Correcting for Low Solution Conductivity Effects

Low solution conductivity effects increase the apparent polarization resistance, thus yielding an underestimation of the corrosion rate. The effect of solution resistance is a function of the cell geometry. Since the cell geometry (in this case, the electrode configuration of the corrosion probe) remains constant, analytical correction may be performed to compensate for this apparent increase in the polarization resistance. The following equation may be used to approximate the magnitude of this effect.

$$R_p = R_a - \frac{l}{\sigma}$$

where R_p is the true polarization resistance, R_a is the apparent polarization resistance as measured by the instrument, l is the distance between

the two electrodes in cm, and σ is the solution conductivity in ohms⁻¹/cm. Specific guidelines for this correction technique are detailed in ASTM G102.⁴

The above equation has been used to analytically derive a correction curve for low solution conductivity effects. The curve is plotted as a function of the corrosion rate, as measured by the instrument, and the solution conductivity. This correction curve is given in Figure 3.

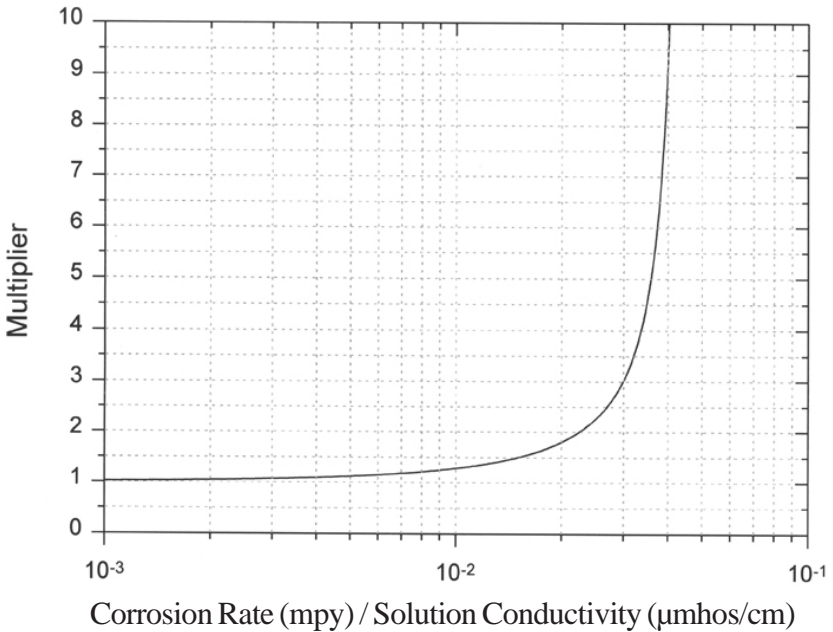


Figure 3 - Multipliers for IR correction.

An example of how to use the correction curve is given below.
If the

$$\text{Corrosion Rate (Instrument Reading)} = 1.00 \text{ mpy}$$

and the

$$\text{Solution Conductivity} = 100 \text{ } \mu\text{mhos/cm}$$

then the value on the x-axis of the graph may be calculated as

$$\frac{\text{Corrosion Rate (mpy)}}{\text{Solution Conductivity (}\mu\text{mhos/cm)}} = 10^{-2}$$

Referring to figure 3, a value of 10^{-2} on the x-axis corresponds to a multiplier of 1.3.

Therefore, the corrosion rate, as corrected for IR drop in the electrolyte, is the product of 1.3 and the measured corrosion rate. In other words,

$$\text{Corrected Corrosion Rate} = 1.3 \cdot 1.00 = 1.30 \text{ mpy}$$

IV. UNS Constant Table

The following lists many of the common constructional metals/ alloys with their appropriate alloy constants.

<u>UNS#</u>	<u>Alloy Const.</u>	<u>Alternate Designation</u>	<u>Major Constituents (or common names)</u>
F12101	1.0	-	Gray Cast Iron
F13502	1.0	-	Gray Cast Iron
G10100	1.0	AISI 1010	0.1% Carbon Steel
G10180	1.0	AISI 1018	0.18% Carbon Steel
G10200	1.0	AISI 1020	0.20% Carbon Steel
K03504	1.0	ASTMA105	0.35% Carbon Steel
K03006	1.0	ASTMA106	0.3% Carbon Steel
K02504	1.0	ASTMA53	0.25% Carbon Steel
K03011	1.0	ASTMA350LF2	0.3% Carbon Steel
K01800	1.0	ASTMA516	0.18% Carbon Steel
G41300	1.0	AISI4130	1% Cr 0.2% Mo Steel
K41545	1.0	ASTMA199	5% Cr 0.5% Mo. Steel
S50400	1.0	ASTMA199 (T9)	9% Cr 1.0% Mo. Steel
S30400	1.0	AISI 304	18% Cr 8% Ni S.S.
S30403	1.0	AISI 304L	18% Cr 8% Ni (Low Carbon) S.S.
S31600	1.0	AISI 316	18/Cr 10/Ni/ 3/Mo S.S.
S31603	1.0	AISI 316L	(Low Carbon) S.S.
S32100	1.0	AISI 321	Ti Stabilized 18/8 S.S.
S41000	1.0	AISI 410	12% Cr. S.S.
S43000	1.0	AISI 430	17% Cr. S.S.
S31200	1.0	ASTMA182	26 Cr 6 Ni Duplex SS
S31803	1.0	ASTMA276	22 Cr 5 Ni 3 Mo. Duplex S.S.
C11000	2.0	AMS 4500	99.90 Copper
C26000	1.8	AMS 4505	70-30 Brass
C28000	1.8	ASME SB111	Muntz Metal (60% Cu)

<u>UNS#</u>	<u>Alloy Const.</u>	<u>Alternate Designation</u>	<u>Major Constituents (or common names)</u>
C23000	1.9	ASME B16.22	85-15 Brass
C63000	1.9	AMS 4640	Aluminum Bronze
C68700	1.9	ASME SB111	Aluminum Brass (Arsenical)
C44300	1.8	ASME B111	Admiralty Brass
C70690	1.9	ASTM F96	90-10 Copper Nickel
C71590	1.6	ASTM F96	70-30 Copper Nickel
N04400	1.2	AMS 4544	Monel 400
N08825	1.0	ASME B163	Incoloy 825
N06600	1.0	AMS 5540	Inconel 600
N06625	1.0	AMS 5401	Inconel 625
N10001	1.0	AMS 5396	Hastelloy B
N10002	1.0	AMS 5388	Hastelloy C
N10276	1.0	ASME B366	Hastelloy C-276
N02201	0.9	AMS 5553	Nickel 201
N08904	1.0	ASME B625	23-1-4-25 Cr-Cu-Mo-Ni
Z13001	1.3	ASTM B6	99.990 Zinc
R05200	0.6	ASTM B364/365	Tantalum
R50250	0.7	ASTM F67	Titanium
R60701	1.0	ASTM B493	Zirconium
A96061	0.9	AA6061	Aluminum

V. Maintenance

The only maintenance item in the MS1000 is the 9 volt rechargeable battery. A battery charger is included with the instrument to facilitate recharging. The battery will recharge to full capacity in a few hours. The LED indicator on the battery charger will turn red while the battery is charging, and will turn green when the battery is fully charged. Over time the rechargeable battery may require replacement. It should be replaced with a rechargeable battery of the same type. Alternately, a standard alkaline battery can be installed, but you should NOT attempt to recharge it. Attempting to recharge an alkaline battery may cause it to leak and cause damage to the instrument.

VI. Troubleshooting

If the corrosion rate $\neq 5.00 \pm 0.05$ mpy when the calibration probe is connected

Check the following items:

1. Is the calibration probe completely plugged into the cable assembly?
2. Is the cable assembly plugged into the “Probe” port on the instrument?

If the above methods do not cause the corrosion rate to be 5.00 ± 0.05 mpy, it is possible that the cable assembly has been damaged. You may check the cable assembly for proper operation as follows:

1. Unplug the instrument from the power outlet and turn the power switch on the inside front panel to the “off” position.
2. Unplug the cable assembly from the “probe” connection on the instrument.
3. Place a 1000 Ohm resistor across the bottom two pins of the probe connector on the instrument **OR** use jumper wires and

connect pins A and D on the calibration probe directly to the lower two pins of the probe connector on the instrument.

You may plug the instrument into a power outlet, turn the instrument on, and then the measured corrosion rate should be 5.00 ± 0.05 mpy. If the instrument does not calibrate properly, please contact Metal Samples.

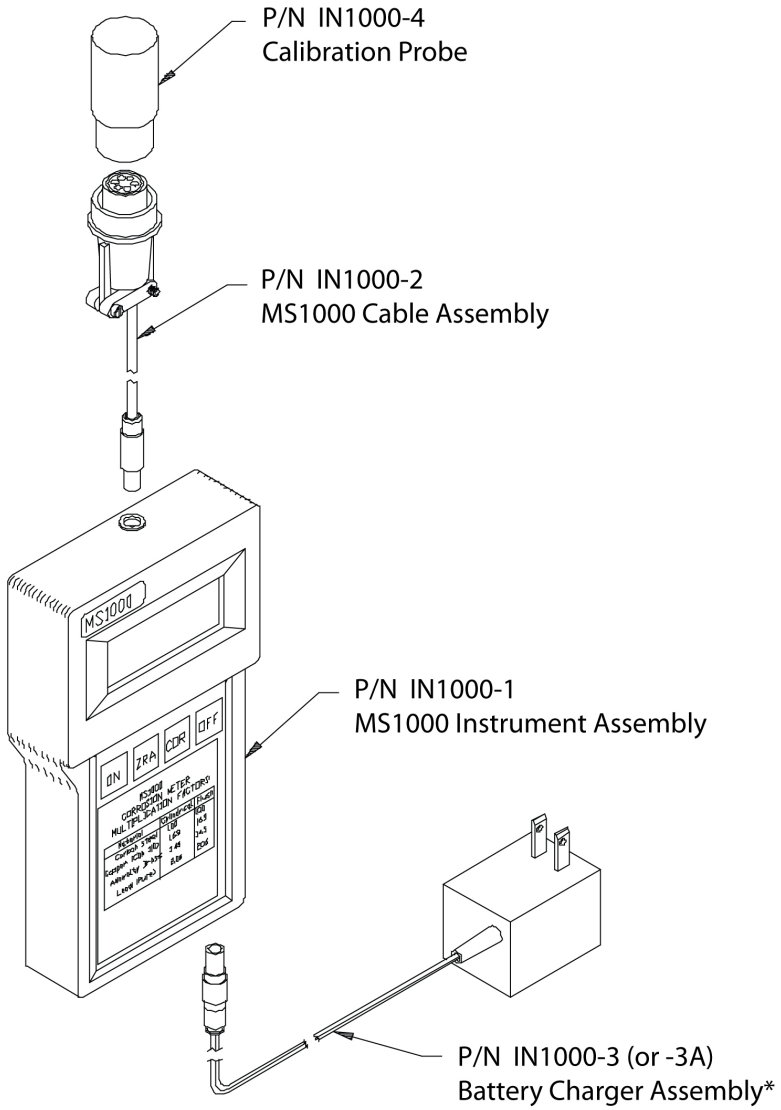
VII. Replacement Parts

Replacement parts for the MS1000 as well as replacement electrodes and probes are available from Metal Samples. Replacement items and part numbers are listed below:

<u>Item Description</u>	<u>Part Number</u>
MS1000	IN1000
Probe Cable	IN1000-2
Rechargeable battery (NiCad)*	ET0007
Rechargeable battery (Lithium-Ion)*	ET1142
Recharger (NiCad)*	IN1000-3
Recharger (Lithium-Ion)*	IN1000-3A
Calibration Probe	IN1000-4

A complete line of LPR probes and electrodes are available. Please consult a sales representative at Metal Samples for part numbers and pricing.

** In 2010 the rechargeable battery technology was changed from Nickel-Cadmium (NiCad) to Lithium-Ion (Li-Ion). If you are ordering a replacement battery or charger, you must make sure you order the correct style (NiCad or Li-Ion), or you must replace both parts (the battery and the charger). If you are uncertain which one you need, consult Metal Samples for further assistance.*



VIII. Warranty

Metal Samples will correct, either by repair or replacement, any defect of material or workmanship which develops within ninety (90) days after startup, or six (6) months from the date of shipment to the original purchaser, whichever comes first, provided that an inspection by Metal Samples discloses that such a defect developed under normal and proper use.

IX. References

¹ “G-59: Standard Practice for Conducting Potentio-dynamic Polarization Resistance Measurements”, 1993 Annual Book of ASTM Standards, Vol. 3.02, Wear and Erosion: Metal Corrosion, ASTM, p. 219, (1993).

² F. Mansfeld, Electrochemical Techniques for Corrosion Engineers, NACE, Houston, TX, p. 67-73 (1986).

³ F. Mansfeld, ASTM STP 727: Electrochemical Corrosion Testing, F. Mansfeld and U. Bertocci, Editors, ASTM, Philadelphia, PA, p. 163-262 (1981).

⁴ ASTM G102 Standard Practice for Calculation of Corrosion Rates & Related Information from Electrochemical Measurements, Annual Book of ASTM Standards, Vol. 3.02, Wear and Erosion; Metal Corrosion, ASTM, Philadelphia, PA, p. 406-412, (1993).

⁵ M. Stern and A.L. Geary, J. Electrochem. Soc., 104, p. 57 (1957).

⁶ C.W. Wagner and W. Trand, Z. Electrochem., 44, p. 391 (1938).

⁷ J. Orth, Presented at the 1994 International Water Conference, Paper #IWC-94-10, (1994).