

AC Corrosion at Other Frequencies Part B: Laboratory Investigations

Andreas Junker Olesen
MetriCorr Aps.
Toerringvej 7
2610 Roedovre
Denmark

Wolfgang Fieltsch
Stantec Consulting Ltd.
300W-675 Cochrane Drive
Markham, ON L3R 0B8
Canada

Lars Vendelbo Nielsen
MetriCorr Aps.
Toerringvej 7
2610 Roedovre
Denmark

Fation Shahinas
Stantec Consulting Ltd.
300W-675 Cochrane Drive
Markham, ON L3R 0B8
Canada

ABSTRACT

AC corrosion on cathodically protected pipelines is commonly experienced due to interference from high voltage transmission lines at a frequency of 50 or 60 Hz. In some cases, the source of interference may be low frequency AC transit systems (1/3 of the fundamental frequency) and in other cases higher harmonics of the fundamental frequency can be detected on pipelines. In part A of this paper a field investigation of a 120 Hz rectifier ripple, suspected to lead to AC corrosion, is investigated. In this part B of the present investigation, AC corrosion of cathodically protected steel is investigated using electrical resistance (ER) probes at various frequencies and different CP levels in an artificial soil solution. The effect of frequency on basic aspects and understanding of AC corrosion, specifically in terms of alkalization mechanisms and related time constants for involved processes, is discussed.

Key words: Alternating current, AC interference, Cathodic protection, Electrical Resistance Probes, AC corrosion, AC frequency

INTRODUCTION

The existing NACE¹ SP21424-2018 standard on AC corrosion addresses typical power frequencies up to 60 Hz, and the studies undertaken to sustain criteria for risk assessment, mitigation and monitoring have been based on 50 or 60 Hz¹. Other frequencies such as 16 2/3 Hz, and 2nd and 3rd harmonics of the 60 Hz (i.e. 120 and 180Hz) may interfere with the CP system on buried pipelines as well, and it is necessary to address this. Already, some research has been performed on the effect of frequency on AC corrosion²⁻⁵, the earliest dating back to the beginning of the 20th century, where it was concluded

¹ National Association of Corrosion Engineers (NACE), 15835 Park Ten Place Houston, Texas 77084, USA.

© 2021 Association for Materials Protection and Performance (AMPP). All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means (electronic, mechanical, photocopying, recording, or otherwise), without the prior written permission of AMPP.

Positions and opinions advanced in this work are those of the author(s) and not necessarily those of AMPP. Responsibility for the content of the work lies solely with the author(s).

that low frequency AC had the highest impact on corrosion rates². Zhu and Du explain this by a negative shift of the corrosion potential with lower AC frequencies, and the damaging impact of AC on the stability, compactness and uniformity of the passive film on steel⁴. Several authors also point out another important effect from varying the frequency: At high AC frequencies, the impedance of the double layer capacitance is low, and most of the alternating current will pass via charging/discharging of the electrochemical double layer, whereas for lower frequencies, a larger portion of the AC current will pass via the polarization resistance, i.e. as electrode reactions such as corrosion^{5–8}. Using this rationale, AC corrosion can essentially be understood as DC interference corrosion (at least during the anodic cycle), if the frequency is low enough. However, if AC corrosion could simply be treated as a periodical DC corrosion phenomenon, where the fraction of current running via electrode reactions and not the double layer capacitance is increasing with lower frequencies, then a simple mitigation measure could be to increase the level of CP as it is sometimes done in DC interference cases. This conclusion is wrong, since it is well documented that increasing the CP level will in fact accelerate corrosion rates in the presence of AC interference^{9–12}. AC corrosion is, in other words, far more complex than just considering anodic dissolution during the positive half-cycle of an alternating voltage signal.

To illustrate how important it is to remember the role of the cathodic protection level on AC corrosion, this paper will be investigating the effect of three parameters; AC interference, AC frequency and CP level.

EXPERIMENTAL PROCEDURE

Laboratory experiments were conducted in 50 L soil-box setups with separate AC (frequency generator and signal amplifier) and DC (potentiostat) circuits to simulate cathodic protection and induced AC interference of varying frequency on two ER probes buried in the same environment. Separation of the two circuits was done by implementation of a capacitor and a low resistance inductor in each of the two circuits (see Figure 1). Two working electrodes (WE) were used for double verification of the corrosion rate measurements. The exposed area of each of the ER probes was 1 cm² (3.16 mm · 31.6 mm). AC and DC counter electrodes (CE) were inert mixed metal oxide (MMO) coated titanium meshes of >20 cm². An interference corrosion logger (ICL) recorded the corrosion rate (v_{corr}), ON and IR-free potentials (E_{ON} and $E_{\text{IR-free}}$), AC voltage (U_{AC}), the resulting AC and DC current densities (J_{AC} , J_{DC}) and the spread resistance (R_{S}) with 20 minute intervals and uploaded the data to a web-based monitoring service every hour via a cellular modem. The reference electrode (RE) used in the setup was a saturated copper/copper-sulphate standard electrode (CSE) and all potentials are reported with respect to this. The chemical environment was an inert sand (0.4-0.8 mm) fully wetted with a non-scaling artificial soil solution containing 5 mM Na₂SO₄, 2.5 mM NaHCO₃ and 10 mM NaCl in deionized water, having an initial pH = 8.2 and initial resistivity, $\rho_0 = 17.3 \Omega\text{m}$. The setup is described in detail elsewhere¹³.

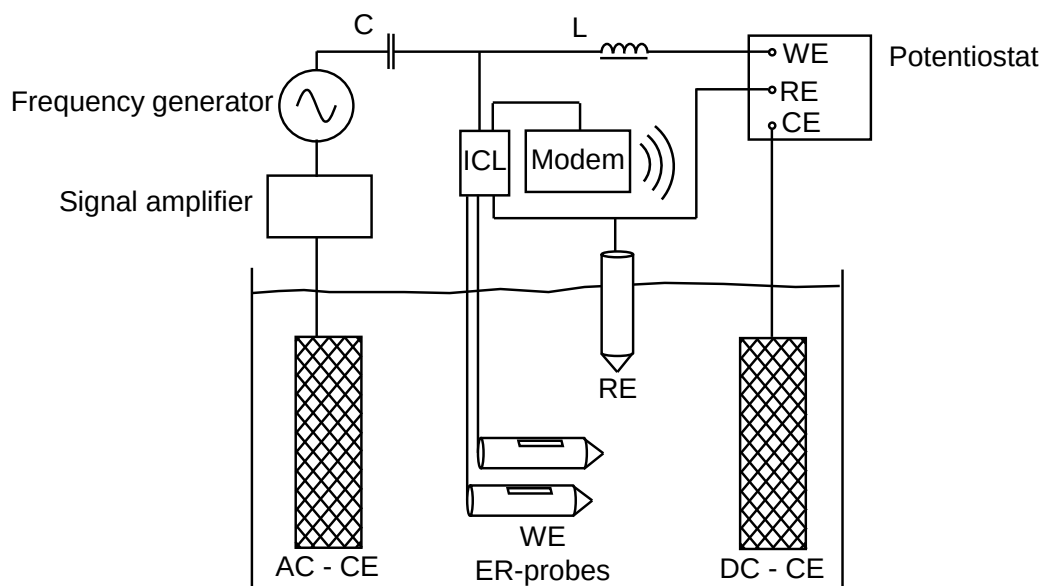


Figure 1: Schematic illustration of the experimental setup with a separate AC and DC circuit for investigation of AC corrosion under CP condition.

Using the experimental setup illustrated in Figure 1, different parameters were varied. Investigated frequencies are 16 2/3 Hz, 50 Hz, 60 Hz, 120 Hz, 180 Hz and 360 Hz. At each of these frequencies the AC interference level was varied through 0.5, 2, 5, 10 and 20 V_{rms} with >24 hrs. at each setting to be able to measure a corrosion rate on the ER probes. (For the 50 Hz investigation, data from a previous study in an identical setup was used where the AC interference levels were 0.5, 5, 10, 15 and 20 V_{rms} instead). This scan through AC frequencies and AC levels was done both at an intermediate/low level of CP ($E_{ON} = -1100 \text{ mV}_{CSE}$) and a high level of CP ($E_{ON} = -1500 \text{ mV}_{CSE}$) to assess the effect of the protection potential on AC corrosion as well.

For the 120 Hz frequency, which is of particular interest in part A of this paper¹⁴, a wider range of CP potentials was investigated ($E_{ON} = -900, -1000, -1100, -1200, -1300, -1400, -1500$ and -1600 mV_{CSE}) and this was compared to results from the 50 Hz study that similarly had data from this CP range.

Finally, a simple experiment was performed on the described setup in which the AC perturbation (60 Hz) was set for the maximum output level (34.2 V) of the frequency generator and amplifier (without cutting the peaks of the AC signal, measured with an oscilloscope), and the CP level was set at $E_{ON} = -1000 \text{ mV}_{CSE}$. This was done in order to test the theory that AC corrosion can be mitigated, even at very high AC interference levels, simply by adjusting the DC settings of the CP system.

RESULTS

Averaged data for the experiments at different AC frequencies and voltages are displayed in Table 1 and Table 2. The relatively short duration of the experiment at each setting (≥ 24 hrs.) will have an effect on the certainty of the corrosion rate measurement, but still the general picture becomes clear when observing the results. Some deviations from the design values occur, in particular for the AC voltages. Also some difference between the recorded current density values and corrosion rate measurements on the two ER probes is evident, likely due to slight variations in local soil chemistry (i.e. alkalinity, composition and density of formed oxides, etc.) in front of either coupon. Despite the controlled laboratory conditions in this study, this is a valuable reminder that field measurements on coupons are only representative of the coupon itself, and the soil in which the coupon is installed. Coupon readings merely serve as a guide for evaluating the conditions on an actual pipeline and efforts should be made to mimic the pipeline conditions as best as possible when using coupons and probes.

Table 1: Averaged data from the frequency experiments performed at $E_{ON} = -1100 \text{ mV}_{CSE}$. AC and DC readouts and measured corrosion rates.

f (Hz)	Probe 1					Probe 2				
	E_{ON} (V_{CSE})	J_{DC} (A/m^2)	U_{AC} (V)	J_{AC} (A/m^2)	v_{corr} ($\mu m/y$)	E_{ON} (V_{CSE})	J_{DC} (A/m^2)	U_{AC} (V)	J_{AC} (A/m^2)	v_{corr} ($\mu m/y$)
16.6	-1.1	-0.3	0.5	6	0	-1.1	-0.2	0.5	6	0
	-1.1	-0.3	2.0	24	0	-1.1	-0.2	2.0	20	2
	-1.1	-0.5	5.1	64	2	-1.1	-0.4	5.1	64	2
	-1.1	-2.0	9.7	199	0	-1.1	-1.9	9.7	196	0
	-1.1	-3.4	20.0	514	68	-1.1	-2.7	20.0	463	98
50*	-1.1	0.03	0.4	6	0	-1.1	0.05	0.4	6	0
	-	-	-	-	-	-	-	-	-	-
	-1.1	-0.1	5.1	65	6	-1.1	-0.1	5.1	72	3
	-1.1	-0.8	8.9	172	0	-1.1	-1.2	8.9	207	0
	-1.1	-2.8	13.9	445	66	-1.1	-3.6	13.9	524	47
60	-1.1	-0.11	0.5	5	0	-1.1	-0.12	0.5	5	0
	-1.1	-0.13	2.0	22	0	-1.1	-0.13	2.0	21	0
	-1.1	-0.17	5.0	57	0	-1.1	-0.18	5.0	54	2
	-1.1	-0.35	10.1	118	2	-1.1	-1.21	10.1	170	0
	-1.1	-3.20	19.3	504	0	-1.1	-3.05	19.3	483	0
120	-1.1	-0.1	0.5	5	0	-1.1	0.04	0.5	5	0
	-1.1	-0.1	2.0	22	5	-1.1	0.04	2.0	18	0
	-1.1	-0.2	5.1	54	0	-1.1	-0.1	5.1	47	0
	-1.1	-1.5	9.8	186	4	-1.1	-0.4	9.8	112	3
	-1.1	-2.9	19.5	484	2	-1.1	-1.9	19.5	392	7
180	-1.1	-0.2	0.5	6	0	-1.1	-0.2	0.5	6	1
	-1.1	-0.1	2.2	24	0	-1.1	-0.1	2.2	22	0
	-1.1	-0.2	5.1	62	0	-1.1	-0.2	5.1	59	1
	-1.1	-0.4	10.4	151	0	-1.1	-0.6	10.4	167	0
	-1.1	-2.8	21.1	574	0	-1.1	-3.1	21.1	621	0
360	-1.1	-0.2	0.5	7	0	-1.1	-0.1	0.5	7	2
	-1.1	-0.2	2.0	26	10	-1.1	-0.1	2.0	22	0
	-1.1	-0.2	5.0	65	3	-1.1	-0.2	5.0	55	0
	-1.1	-0.4	9.9	137	0	-1.1	-0.2	9.9	113	N/A
	-1.1	-1.0	19.4	339	12	-1.1	-0.9	19.4	321	0

* The 50 Hz data are from another study, performed under identical conditions but slightly different AC levels.