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ELECTROCHEMICAL MEASUREMENTS ON PILOT PLANT FOR THE INVESTIGATIONS OF HOT-DIP GALVANIZED PIPE CORROSIONS

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Preliminary Note - Prethodno priopćenje

A problem of the electrochemical measurement results accuracy has appeared during a performed complex long term pilot plant investigations of the hot-dip galvanized steel pipes corrosion in warm potable water. After a short introduction, the first part of the paper describes the pilot plant with pipe specimen assembly series. Specimens have been made of zinc, steel and hot-dip galvanised steel. The second part of the paper presents the performed electrochemical measurements without computer aids and displays an example of the obtained final results. The third part of the paper is devoted to the development of the system for the computer aided monitoring of the mixed electrode potentials and electric currents between short circuited specimens.

Key words: *corrosion, electrochemical measurement, pilot plant, hot dip galvanized pipes, computer aided monitoring*

Elektrokemijska mjerenja na pilot uređaju za istraživanje korozije toplo pocinčanih cijevi. Tijekom provedenog složenog dugotrajnog eksperimentalnog istraživanja korozije toplo pocinčanih čeličnih cijevi u toplim pitkim vodama pojavio se problem pouzdanosti rezultata elektrokemijskih mjerenja. Nakon kratkog uvoda, u prvom dijelu rada je opisan pilot uređaj s nizovima sklopova uzoraka. Uzorci cijevi su bili izrađeni od cinka, čelika i toplo pocinčanog čelika. U drugom dijelu rada su opisana provedena elektrokemijska mjerenja sa sustavom mehaničkih sklopki i prikazan jedan primjer dobivenih rezultata. Treći dio rada je posvećen razvoju sustava za računalom podržano praćenje mješovitih elektrodnih potencijala i električnih struja između kratko spojenih uzoraka.

Ključne riječi: *korozija, elektrokemijska mjerenja, pilot uređaj, toplo pocinčane čelične cijevi, računalom podržano praćenje*

INTRODUCTION

The corrosion of hot-dip galvanized steel pipes in warm potable waters evolves under dominant influence of the formatting scales. Therefore, the accurate prognosis of the corrosion evolution (slow uniform to fast local attack) can be made only on the basis of the long term investigations in operating conditions or on the pilot plant [1, 2].

The corrosion evolution can be monitored on the pilot plant by the electrochemical measurements. On the pilot plant, however, appears the problem of the electrochemical measurements results accuracy. The causes are:

a) electrochemical measurements in unsuitable conditions,
b) great number of the exposed specimens,
c) significant influence of the electric fields in the short circuited specimen areas,
d) the changes of the electrochemical quantity values at the disturbance of exposure conditions [3].

The electrochemical measurement results accuracy may be increased by application of a suitable computer aided monitoring system (CAMS). Development of the system (Figure 1.) is based on the experiences acquired during: a) complex long term investigations on the pilot plant [3] and b) computer aided monitoring of the arc welding pro-

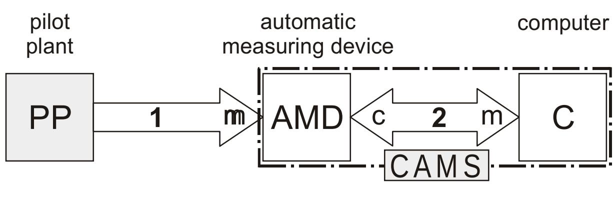

Figure 1. **Computer aided monitoring system (CAMS)**
Slika 1. **Sustav za praćenje uz podršku računala (CAMS)**

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cess [4, 5]. The developed system will be also used in the researches of the hard layers corrosion and work-pieces temperature field dynamics (welding, heat treatment).

On the basis of the preliminary considerations the following possibilities of the measurements have been adopted:

1. mixed electrode potential (potential) versus saturated calomel electrode (SCE) - 64 specimens,
2. electric current - 16 short circuited specimens and
3. water temperature - 8 positions.

An additional constraint is 2000 € available for hardware and software purchase.

PILOT PLANT AND EXPOSED SPECIMENS

Cold potable water flows into the pilot plant's tank (Figure 2., CWT) from the municipal water supply sys-

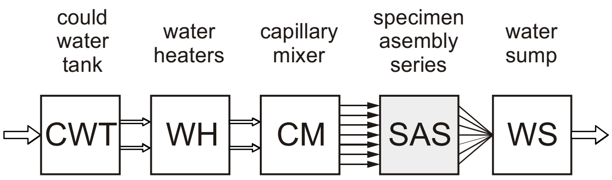

Figure 2. **Pilot plant**
Slika 2. **Pilot uređaj**

tem. The water is heated in two electrical water heaters (WH) and after that in the capillary mixer (CM) from two inflows seven outflows with water temperatures t = 40, 50, 55, 60, 65, 70 and 80 °C are being formed. The warm water streams flow through seven heat insulated specimens

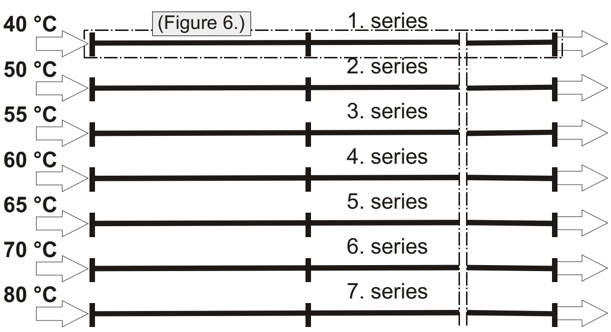

Figure 3. **Specimens assembly series (SAS - Figure 2.)**
Slika 3. **Nizovi sklopova uzorka (SAS - slika 2.)**

assembly series (SAS - Figure 3.) and flow out into water sump (Figure 2., WS). Measurements include electrochemical quantities and temperature [3].

Three kinds of pipe specimens (Figure 4.) were exposed: Z - zinc, H - hot-dip galvanized steel, and S -steel. Specimens Z were cast from zinc contained in the galvanizing kettle and specimens H were made by hot-dip galvanizing of the S specimens.

Specimens were bound in the specimen assemblies (Figure 5.) which were after that united in the specimen

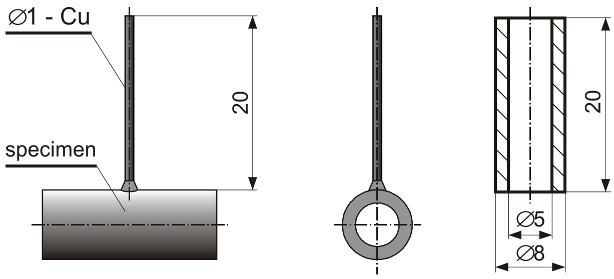

Figure 4. **Specimen**
Slika 4. **Uzorak**

assembly series (Figure 6.). The pilot plant includes 7 specimen assembly series (with $7 \times 5 \times 9 = 315$ specimens altogether) and each series was exposed to the warm potable water of different temperature (Figure 3.).

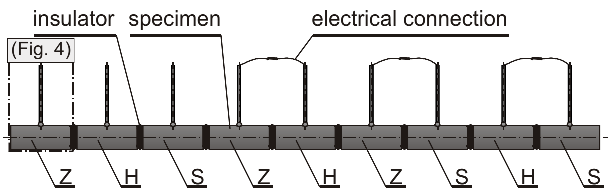

Figure 5. **Specimen assembly**
Slika 5. **Sklop uzorak**

The suitable mechanical connectors [3] enable fast taking of any specimen assembly apart and its exchange with previously prepared new one. After a 30 day exposure for each specimen were determined: average corrosion and

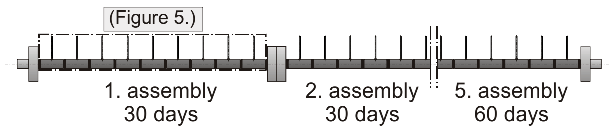

Figure 6. **Specimen assembly series**
Slika 6. **Niz sklopova uzoraka**

scale formation velocities - gravimetric method, as well as local corrosion velocities - geometric method. The experiment was finished after 60 days.

ELECTROCHEMICAL MEASUREMENTS

Specimens' exposure to the warm potable water was accompanied by the simple electrochemical measurements (Figure 7.):

1. potential of the specimen i versus j SCE, $E_{i\,(j)}$ / mV,
2. potential of the specimen a versus specimen b, E_{a-b} /mV,
3. potential of the short circuited specimens a and b versus specimen c, $E_{(a/b)-c}$ / mV,
4. current between short circuited specimens a i b, $I_{a/b}$ /μA,
5. potential of the previous short circuited specimen a (with b) versus specimen c, 10 s after the interruption of the short circuit, $E_{(a/b)-c,10}$ / mV [3].

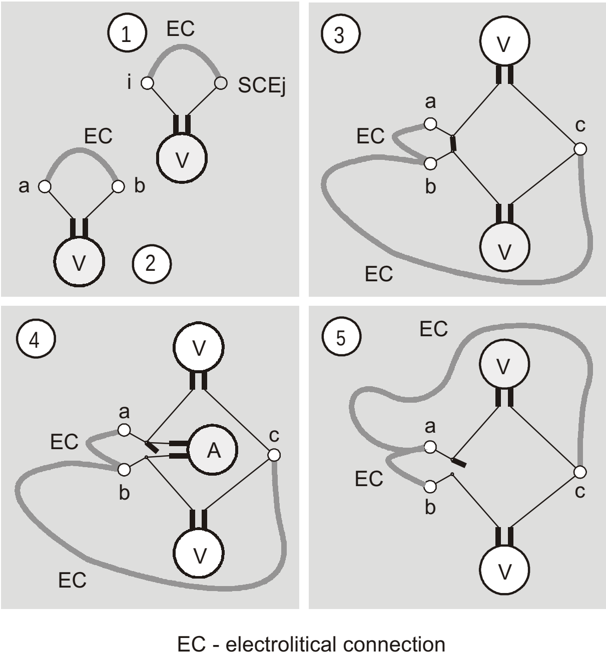

Figure 7. **Electrochemical measurements**
Slika 7. **Elektrokemijska mjerenja**

Electrochemical measurements without AMD were performed by using the mechanical switches system (Figure 8., MSS). Electrode potentials and currents were measured by the voltmeters V1, V2 (with inner resistance 10 MΩ) and ammeter A (with inner resistance 1 kΩ). After

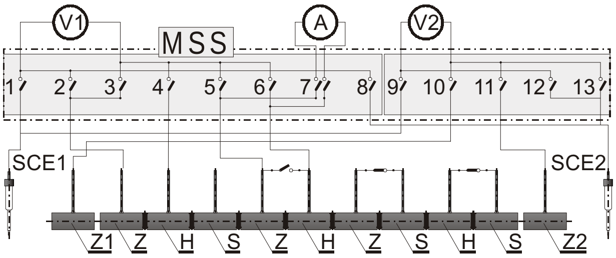

Figure 8. **Mechanical switches system**
Slika 8. **Sustav mehaničkih sklopki**

all measurements on the first specimen assembly had been finished, the instruments were bound via MSS with the second one and such procedure was being repeated until measurements on all specimen assemblies were finished.

Measuring procedure with MSS was tiring and susceptible to errors appearance. For each measuring quantity it is necessary to: a) plug in appropriate switches for readout, b) readout the values, c) write results in the table and d) switch off the plugged switches. On each specimen assembly 21 readout were performed, on each specimen assembly series 21 × 5 = 105 readouts and so on all specimen assembly series 105 × 7 = 735 readouts altogether.

Table 1. presents an example of the readouts for five specimen assemblies (Figure 6., 1. - 5.) of the forth series (Figure 3., 4.).

Table 1. **Electrochemical quantity values readouts, t = 60 °C, = 55 h, [E] = mV, [I] = A**
Tablica 1. **Očitavanja vrijednosti elektrokemijskih veličina, t = 60 °C, = 55 h, [E] = mV, [I] = A**

4. series	$E_{Z(1)}$	E_{H-Z}	$E_{(Z/H)-Z}$	$I_{Z/H}$	$E_{Z/(H)-Z,10}$	$E_{(Z/)H-Z,10}$	$E_{Z(2)}$
1. assembly	-679	94	30	33	-11	298	-500
2. assembly	-829	216	193	27	137	407	-587
3. assembly	-879	270	198	29	181	392	-644
4. assembly	-999	106	111	33	89	297	-648
5. assembly	-1099	231	145	25	107	370	-708

It is easy to observe the inconsistencies in Table 1.:
- significant systematic changes of the $E_{Z(1)}$ and $E_{Z(2)}$ values with specimen positions in the specimen assembly series,
- significant random errors.

It was impossible to analyze the observed inconsistencies on pilot plant without undesirable disturbance of the exposure conditions. After theoretical and additional experimental analysis the results accuracy was significantly increased by the suitable: a) readouts sequence change, b) recalculation of the readouts and c) statistical treatment of the recalculated readouts. The examples of the final results are shown in Figures 9. and 10. [3].

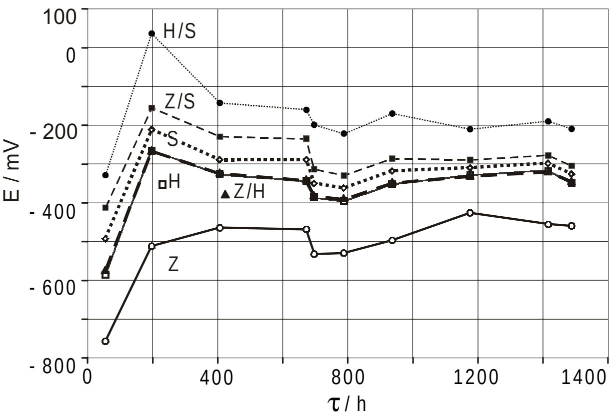

Figure 9. **Electrode potentials exchange, t = 60 °C**
Slika 9. **Promjene elektrodnih potencijala, t = 60 °C**

It can be concluded (Figure 9., 10.) that the corrosion at 60 °C does not stabilize until 400 h of the specimens exposure expires.

ELECTROCHEMICAL MEASUREMENTS WITH CAMS

In the case of electrochemical measurements with CAMS (Figure 11.) the same measurements as in the case

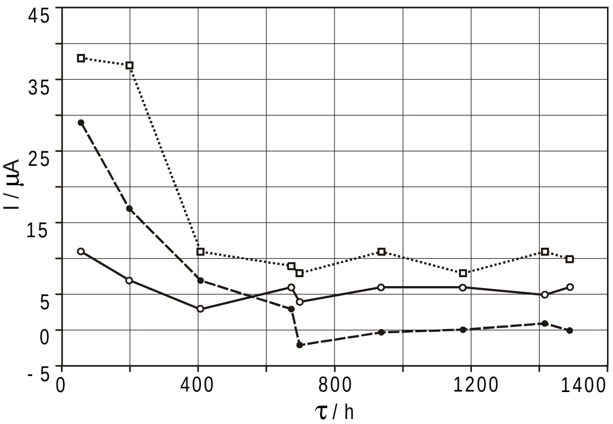

Figure 10. **Electric currents exchange, t = 60 °C**
Slika 10. **Promjene električnih struja, t = 60 °C**

without CAMS will be performed, as well as electrode potentials and currents monitoring after set up and interruption of the specimen short circuits.

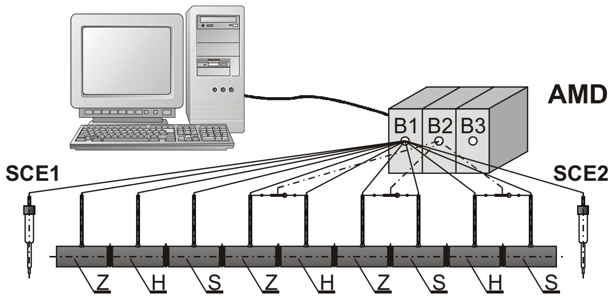

Figure 11. **Electrochemical measurements with CAMS**
Slika 11. **Elektrokemijska mjerenja s CAMS-om**

Optimal structure of the designed AMD (Figure 11.) includes:

a) measuring and controlling block B1 (Figure 12.) for electrochemical measurements,

b) controlling block B2 for on-off switching of the of the electrical connection of the specimens,

c) measuring block B3 for the temperature measurements.

Electrochemical measurements on the specimen assembly series occupy 58 connectors of the B1 - 55 for specimens connection (Figure 12.: 5 × switches 1 - 11) so as 3 for two SCE connection (1a, 2a, 3a). Measuring circles switch on-off under computer control.

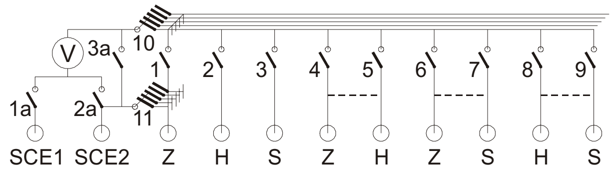

Figure 12. **Block B1 of the AMD**
Slika 12. **Blok B1 AMD-a**

The entirely suitable AMD can not be found on the market. The minimum of the hardware and software modification is needed if a suitable data acquisition system has been purchased. Prices of such system however exceed limiting costs. For example, 41000 $ is the price of the 128 channel data acquisition system "Cerebus" made by Bionic, and 16600 € is the price of the "64-Channel Rack Mount Industrial Temperature Logging System" made by National Instruments [6]. The adopted device is more expensive because only specialized electrical engineers are allowed to make appropriate modifications of the hardware.

Optimal solution of the CAMS (Figure 13.) was adopted after detailed techno-economical analysis, taking into considerations also the recommendations from practice [7]. Keeping in mind actual and planed researches, it has been decided to separate the AD converter from the CAMS (in spite of problems with the noise by analog signals transmission). CAMS will be connected accordingly with computer via RS232 port of the AD converter for the measuring signals transfer, as well as via next two RS232 ports of the computer for controlling signals transfer.

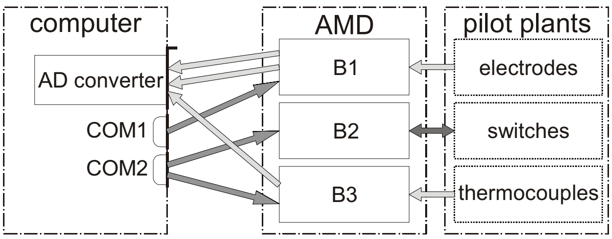

Figure 13. **Adopted solution of the CAMS**
Slika 13. **Usvojeno rješenje CAMS-a**

The approximate estimate of the material costs (excluding computer) are 1200 €. The most expensive components are:

- 350 € - PCI-5501MF Data Acquisition board, 16 channel multiplexed 12 Bit analog to digital converter [8],
- 90 € + 2×80 € = 250 € - Relays-Interface [9],
- 100 € - ES52-Flash, developing system with 89S8252 microcontroller, 8K Flash-ROM [9].

CONCLUSION

During investigations of the hot-dip galvanized steel pipes corrosion in warm potable waters, electrochemical measurements were carried out with serious problems on the pilot plant.

The problems will be eliminated by using the developing computer aided monitoring system (CAMS) which include computer with AD converter and suitable automatic measuring device (AMD).

The developing AMD consists of three blocks: B1 - with switches and resistors (potentials and currents measurement), B2 - with relays (electrical connection between specimens on/off control) and B3 - with switches and low voltage amplifier (temperatures measurement). Blocks are connected to the computer via RS232 ports. Approximate material costs (excluding computer) of the developing CAMS are 1200 €.

The developed AMD will be used also for experimental research on hard layers corrosion and work-pieces temperature field dynamics (welding, heat treatment).

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