

## Microcontroller converter of corrosion rate with current output

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Received September 27, 2007, Revised February 19, 2008

The converter discussed in this report is a part of the task of introducing automatic corrosion rate control in steam boilers, which could facilitate inhibitor dosing optimization for boiler water. The polarization resistance technique is used for corrosion rate determination. Microcontroller arrangement allows introduction of automatic correction of solution resistance effect. A simplified block-diagram is discussed. Experimental results obtained by corrosion probe simulation in the Randle model are presented.

**Key words:** corrosion monitoring, linear polarization resistance, conductivity.

### INTRODUCTION

Corrosion is one of the major causes for problems in steam boiler operation. For ship boilers particularly, corrosion effects include reduction of the equipment lifecycle, need of emergency repairs, increased fuel consumption, and downtime-associated losses.

In order to limit acidic and caustic corrosion, a specific pH of boiler water must be maintained. Measures against oxygen corrosion include deaeration or heating of incoming water up to 90°C and adding of an inhibitor. Currently, there is no constant monitoring of corrosion rate in steam boilers. Introduction of such monitoring may improve the operational conditions and facilitate optimal inhibitor dosing. A yet limited number of companies now offer corrosion monitoring equipment at high price. Development of relatively cheap corrosion rate converters with current output and parameters suited to specific applications would lead to their wider use in automation systems.

The review [1] on corrosion monitoring techniques in industrial waters shows that electrochemical techniques are appropriate from application point of view – the polarization resistance technique based on Stern-Geary equation [1]:

$$i_{corr} = \frac{1}{R_p} \cdot \frac{b_a b_c}{2,303(b_a + b_c)} \quad (1)$$

where  $i_{corr}$  – corrosion current density (mA/cm<sup>2</sup>),  $b_a$  – anodic Tafel slope (mV),  $b_c$  – cathodic Tafel slope (mV), and  $R_p$  – polarization resistance (ohm·cm<sup>2</sup>). The relationship between corrosion current density

and corrosion rate, in mm per year, is expressed by Faraday law [1]:

$$mm/year = 3,15 \cdot 10^5 \frac{M}{n \cdot F \cdot d} \cdot i_{corr} = 1,37 \cdot 10^5 \frac{M}{n \cdot F \cdot d} \cdot \frac{B}{R_p} \quad (2)$$

where M – molecular weight of metal (g/mole), n – number of electrons involved in the corrosion reaction (mole), F – Faraday's constant, d – density of metal (g/sm<sup>3</sup>), and  $B = (b_a b_c)/(b_a + b_c)$  mV. After substitution of specific values of constants for iron, the result is [1]:

$$mm/year = \frac{3,03 \cdot 10^2}{R_p} \quad (3)$$

For industrial applications, an electrochemical probe is commonly used with two equal electrodes fed with square pulses [2, 3]. The equivalent circuit of such probe is shown in Fig. 1.

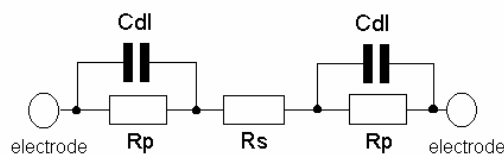


Fig. 1. Equivalent circuit:  $R_p$  – polarization resistance,  $R_s$  – solution resistance of electrolyte between electrodes,  $C_{dl}$  – double layer capacitance of liquid/metal interface.

When a small potential is applied to the electrodes (10–20 mV), after the capacitors  $C_{dl}$  become charged, the current through the probe will depend on the applied voltage and the sum of resistances  $2R_p + R_s$ . The effect of solution resistance in high conductivity conditions may be ignored; for low conductivity, however, it must be taken into consideration. In Ref. [3] the use of three-electrode probe in low conductivity conditions is recom-

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mended, but this makes the device more complex and expensive. In Ref. [4] measurement of  $R_s$  is suggested by conductometric method and correction of the result for  $R_p$  thereafter. The use of micro-controller and a contact measurement technique for the specific electrical conductivity [5] allows automatic correction of the result depending on solution resistance. Where required, an output conductivity block may be included, the signal whereof is used for management of boiler “blow down” operation.

PRINCIPLE OF OPERATION

The converter discussed herein uses a two-electrode corrosion probe with two equal electrodes powered with rectangular voltage. The simplified block-diagram is shown in Fig. 2. It includes square-pulse generator G controlled by the micro-controller  $\mu C$ , the output of which is connected to the buffer input A1. The electrochemical probe is placed between the buffer output A1 and the current-voltage converter input A2; the latter’s output being connected to one of the micro-controller’s ADC module inputs. PWM module output, through the low pass filter F, is connected to the voltage-current converter input  $U/I$ . Its output is the converter output.

The principle of operation is illustrated with the time-impulse diagram on Fig. 3. The generator G produces bipolar square pulses of amplitude 15 mV and duration  $\tau = 4R_p C_{dl}$  [4], with substantial pause in-between  $-V_1$  on Fig. 3a. Through the buffer amplifier A1, the pulses are applied to the probe electrodes. The potential at the current-voltage converter output A2 ( $V_2$  on Fig. 3b) is proportional to the current between the electrodes.

Two measurements are taken – in the beginning ( $t_1$ ) and at the end ( $t_2$ ) of the positive pulse, which is described by the equations:

$$V_{2(t_1)} = \frac{V_1 \cdot R}{R_s} \quad \text{and} \quad V_{2(t_2)} = \frac{V_1 \cdot R}{(2R_p + R_s)} \quad (4)$$

Hence:

$$R_p = \frac{V_1 \cdot R}{2} \cdot \frac{V_{2(t_1)} - V_{2(t_2)}}{V_{2(t_1)} \cdot V_{2(t_2)}} \quad (5)$$

After substitution in Eqn. (3) the resulting corrosion rate is:

$$\frac{\Delta x}{\Delta t} = \frac{2 \cdot 303}{V_1 \cdot R} \cdot \frac{V_{2(t_1)} \cdot V_{2(t_2)}}{V_{2(t_1)} - V_{2(t_2)}} \quad (6)$$

This value is used for control of the PWM 1 microcontroller module. The value measured in the moment  $t_1$  is proportional to solution conductivity

and is used to control PWM 2. Thus, a second current output is included providing information about the specific electric conductivity of boiler water.

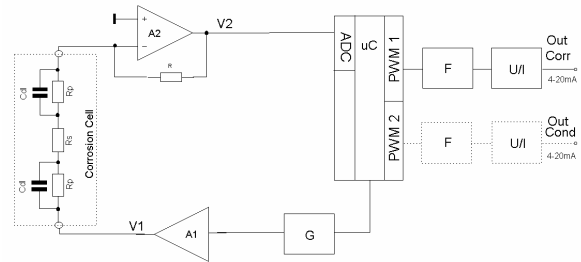


Fig. 2. Block-diagram.

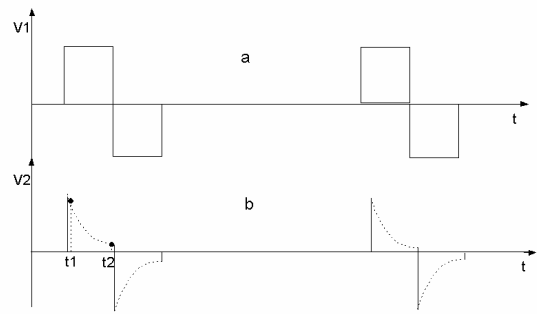


Fig. 3. Time-pulse diagram.

EXPERIMENTAL RESULTS

Converter operability was subjected to laboratory tests, where the electrochemical probe was simulated using Randle model with the following parameters:  $R_s = 100 \Omega, 150 \Omega$ ;  $C_{dl} = 11 \mu F$ ;  $R_p = 181-2424 \Omega$ . The results are shown in Table 1. Converter settings were done at solution resistance of  $150 \Omega$ . It can be seen that in this case, the maximum error of the output current is 1.25%, and when solution resistance is changed by 50%, such change being possible during boiler operation, the error does not exceed 2.5%.

CONCLUSION

The converter under review represents a step towards solving the task of the development of relatively inexpensive devices for use in steam boiler operation monitoring systems. Experimental results show that, notwithstanding the simple arrangement solution, good metrological parameters may be achieved as well as module application for automation purposes at substantially lower cost as compared to similar devices. The opportunity to obtain information also about specific electric conductivity of boiler water allows application of the converter for control of boiler “blow down”, the latter representing substantial practical benefit.

**Table 1.** Experimental results.

R <sub>s</sub> = 150 Ω										
R <sub>p</sub> , Ω	181	205	235	282	346	449	638	1101	1738	2424
I <sub>T</sub> , mA	20	18	16	14	12	10	8	6	5	4.5
I <sub>експ</sub> , mA	19.8	18	16.2	14.1	12.2	10.2	8.1	6	5	4.45
ΔI, mA	-0.2	0	0.2	0.1	0.2	0.2	0.1	0	0	0.05
δ, %	-1.25	0	1.25	0.625	1.25	1.25	0.625	0	0	0.3
R <sub>s</sub> = 100 Ω										
I, mA	20.3	18.4	16.4	14.3	12.3	10.3	8.15	6.05	5.0	4.45
Δ, mA	0.3	0.4	0.4	0.3	0.3	0.3	0.18	0.05	0	0.05
δ, %	1.9	2.5	2.5	1.9	1.9	1.9	1.2	0.3	0	0.3

#### REFERENCES

1. T. Y. Chen, R. H. Banks, J. Brecheers, S. N. Nicolich, D. M. Cicero, Corrosion Monitoring Techniques for Industrial Cooling Water and Process Systems, Ondeo Nalco Company, International Water Conference, 2002.
2. www.rohrbackcosasco.com/corrater.aspx?cid=psg
3. [http://www.cp.umist.ac.uk/CPC/L\\_Notes](http://www.cp.umist.ac.uk/CPC/L_Notes).
4. R. Raicheff, M. Aroyo, V. Ketrov, *Werkstoff. Korros.*, **31**, 923 (1980).
5. P. P. Shipkov, Y. S. Yanev, I. L. Ivanov, BG Patent 46425 (1993).

### МИКРОКОНТРОЛЕРЕН ПРЕОБРАЗОВАТЕЛ НА НИВО НА КОРОЗИЯ С ТОКОВ ИЗХОД

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Постъпила на 27 септември 2007 г., Преработена на 19 февруари 2008 г.

(Резюме)

Разглежданият в доклада преобразовател е част от задачата за въвеждане на автоматичен контрол на нивото на корозия в парни котли, което би помогнало за оптимизиране на дозирането на добавения към котелната вода инхибитор. Използван е методът на поляризационното съпротивление за определяне на нивото на корозия.. Микроконтролерната реализация позволява въвеждане на автоматична корекция на влиянието на съпротивлението на разтвора. Разгледана е опростена блокова схема. Действието е пояснено с време-импулсана диаграма. Показани са експериментални резултати, получени чрез симулиране на корозионната клетка с модел на Randle.