Александар Радоњић
ул. Фрушкогорска 4/11
21000 Нови Сад

ИНСТИТУТ ТЕХНИЧКИХ НАУКА САНУ
Кнез Михаилова 35/IV
11000 Београд

НАУЧНОМ ВЕЋУ ИНСТИТУТА ТЕХНИЧКИХ НАУКА САНУ

Предмет: Молба за покретање поступка за избор у научно звање

Молим да Научно веће Института техничких наука САНУ, у складу са Правилником о поступку и начину вредновања и квантитативном исказивању научноистраживачких резултата истраживача (Правилник донесен на основу члана 14. став 1. тачка 8, и члана 70. став 8. и 9. Закона о научноистраживачкој делатности - "Службени гласник РС", бр. 110/05 и 50/06-исправка), покрене поступак мог избора у звање научни сарадник.

За чланове Комисије за припрему извештаја Научном већу предлажем:

1) проф. др Владимира Вујичића, редовног професора у пензији, Факултет техничких наука, Нови Сад
2) академика Зорана Ђурића, научног саветника, Институт техничких наука САНУ, Београд
3) др Драгана Ковачевића, научног саветника, Електротехнички институт "Никола Тесла", Београд
4) др Зорана Николића, научног сарадника, Институт техничких наука САНУ, Београд
5) др Миодрага Кушљевића, научног сарадника, Термоелектро Енел АД, Београд

У прилогу достављам:

1) Биографију
2) Библиографију
4) Електронске верзије радова објављених на домаћим и међународним скуповима
3) Фотокопије диплома и уверења о докторирању

С поштовањем,

Александар Радоњић

Прилог 1 - Биографија др Александра Радоњића

Др Александар Радоњић рођен је 30.09.1977. године у Зеници, Босна и Херцеговина. Основну и средњу школу завршио је у Добоју. Дипломирао је два пута на Факултету техничких наука у Новом Саду, одсек Електротехника и рачунарство, смер Енергетика, електроника и телекомуникације: први пут 2003. године на усмерењу Телекомуникације (назив дипломског рада: "Одређивање тренда сигнала применом стохастичке адиционе А/Д конверзије"), а други пут 2004. године на усмерењу Инструментација (назив дипломског рада: "Баждарење положених цилиндричних резервоара"). Докторске академске студије уписао је школске 2006/07 године на Факултету техничких наука у Новом Саду, студијски програм Енергетика, електроника, и телекомуникације. Докторску дисертацију под називом "Мерења у фреквенцијском домену у концепту паметне дистрибутивне мреже" одбранио је 21.11.2013. године.

Област истраживања: дистрибуирани мерни системи, заштитно кодовање, рачунарске комуникације.

Прилог 2 - Библиографија др Александра Радоњића

M21 (8.0) – Радови у врхунском међународном часопису

1. **Aleksandar Radonjić**, Vladimir Vujičić: "Integer Codes Correcting Burst Errors within a Byte", *IEEE Transactions on Computers*, vol. 62, pp. 411-415, Feb. 2013. (**IF 2012 = 1.379**)
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6109243

M22 (5.0) – Радови у истакнутом међународном часопису

1. **Aleksandar Radonjić**, Platon Sovilj, Vladimir Vujičić: "Stochastic Measurement of Power Grid Frequency Using a Two-Bit A/D Converter", *IEEE Transactions on Instrumentation and Measurement*, vol. 60, pp. 56-62, Jan. 2014. (**IF 2012 = 1.357**)
http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6587089

M23 (3.0) – Радови у међународном часопису

1. **Aleksandar Radonjić**, Vladimir Vujičić: "Integer SEC-DED Codes for Low Power Communications", *Information Processing Letters,* vol. 110, pp. 518-520, June 2010. (**IF 2010 = 0.612**)
http://www.sciencedirect.com/science/article/pii/S0020019010000852

M33 (1.0) – Саопштење са међународног скупа штампано у целини

1. **Aleksandar Radonjić**: "Control of Industrial Systems Based on IP Addressing", *15th International Symposium on Power Electronics*, Novi Sad, T4.2-8, pp. 1-4, Oct. 2009.
2. **Aleksandar Radonjić**, Vladimir Vujičić: "Application of a New Class of SEC-DED-BED Codes in Intelligent Instrumentation", *15th International Symposium on Power Electronics*, Novi Sad, T4.2-9, pp. 1-4, Oct. 2009.
3. **Aleksandar Radonjić**, Platon Sovilj, Vladimir Vujičić: "Measurement Uncertanity Bounds of DSM Method", *IEEE Conference on Precision Electromagnetic Measurements (CPEM) 2012,* Washington, pp. 572-573, July 2012.

M63 (0.5) – Саопштење са скупа националног значаја штампано у целини

1. **Александар Радоњић**, Бојан Вујичић, Иван Жупунски: "Еталонирање хоризонталних цилиндричних резервоара: један математички модел", *Конгрес метролога Србије,* Палић Окт. 2009.

M71 (6.0) – Одбрањена докторска дисертација

1. **Александар Радоњић**: "Мерења у фреквенцијском домену у концепту паметне дистрибутивне мреже", Факултет техничких наука у Новом Саду, 2013.

M85 (2.0) - Прототип, нова метода, софтвер, стандардизован или атестиран инструмент, нова генска проба, микроорганизми

1. **Александар Радоњић**, Владимир Вујичић: "Софтвер за симулацију кода који коригује сноп грешке у бајту", Факултет техничких наука у Новом Саду, 2011. http://deet.ftn.uns.ac.rs/index.php/publikacije/tehnicka-re%C5%A1enja-lista (решење број 1.18).

2. **Александар Радоњић**, Платон Совиљ, Драган Пејић, Небојша Пјевалица, Владимир Вујичић: "Метода мерења мрежне учестаности двобитним А/Д конвертором", Факултет техничких наука у Новом Саду, 2013. http://deet.ftn.uns.ac.rs/index.php/publikacije/tehnicka-re%C5%A1enja-lista (техничка решења која су резултат рада на пројекту MPS TR32019, решење број 1).

Прилог 3 - Електронске верзије радова објављених на домаћим и међународним скуповима

Measurement Uncertainty Bounds of DSM Method

Aleksandar Radonjic, Platon Sovilj and Vladimir Vujicic

Faculty of Technical Sciences, University of Novi Sad, Serbia
E-mail: vujicicv@uns.ac.rs

***Abstract*—Digital Stochastic Measurement (DSM) method provides Fourier coefficients by using dithered samples of the measured signal. In this paper we evaluate the uncertainty bounds of this method, and compare our results with the Cramer-Rao Lower Bound findings.**

***Index Terms*—Measurement, stochastic, noise, measurement uncertainty, Fourier coefficients.**

I. Introduction

The common way to measure analog signals is the application of sampling method: analog to digital converter (ADC) with input range ±*R*, that performs the digitalization of input signal $y_1(t)$, and digital signal processor (DSP), that used ADC output to calculate signal parameters. This simple approach has several limitations. Most significantly, modern ADCs cannot provide high sampling rate and high precision of digitization simultaneously. This issue brings following problem: is it possible to measure fast and noisy signals very accurately if useful resolution of flash ADCs is limited to n = 10 bits [3]?

Fortunately, the answer is positive if we add a uniform random noise h_1 (dither) to a signal $y_1(t)$ before its digitalization [2]. Following this idea, in [4], [5] DSM approach was suggested. DSM method compenzates flash ADC limit in terms of bit resolution by increasing either measurement time interval or sampling frequency. Originaly, this approach was intended for high precision measurements of the integral (the mean value) of a product of two signals (e.g. voltage and current [6]). Lately, [7], [8] show the vaibilty to measure harmonics: Fourier coefficients a_k and b_k of a signal

$$y_1(t) \approx \frac{a_0}{2} + \sum_{k=1}^{M} a_k \cdot \cos(k\omega t) + b_k \cdot \sin(k\omega t) \qquad (1)$$

if the input to multiplier on the second channel is replaced by digitized dithered base function from the memory (Fig.1)

$$y_2(t) = R \cdot \cos(k\omega t) + h_2, \text{ or } y_2(t) = R \cdot \sin(k\omega t) + h_2 \qquad (2)$$

Function (2) can be generated and memorized in advance. Parallel structure is formed of 2*M*+1 blocks: each having common flash ADC, memory for the dithered base function, a multiplier and an accumulator. This highely parallel approach allows us to perform harmonic analysis of a signal $y_1(t)$ very quickly, even faster than using the FFT method on the fastest DSP.

However, although DSM approach enables extremely fast calculations of Fourier coefficients, it is interesting to explore how the accuracy of the Fourier coeficients depends on flash ADC resolution. This is the motivation to evaluate the measurement uncertainty bounds of DSM method, and compare our results the Cramer-Rao Lower Bound (CRLB).

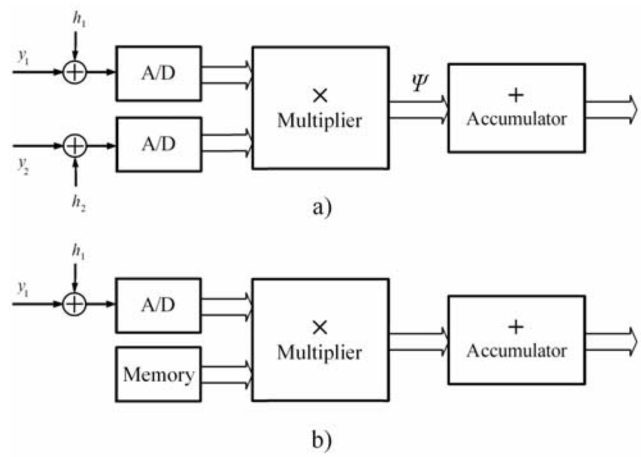

Fig. 1. Stochastic measurement instrument f: a) the mean value of a product of two physical quantities b) one Fourier coefficient.

II. Measurement Uncertainty and Fourier Coefficients

From [1] we know that CRLB (the most precise estimation of Fourier coefficients in the white Gaussian noise) is defined as

$$\mathrm{var}(\overline{a_k}) = \mathrm{var}(\overline{b_k}) = \frac{2 \cdot \sigma^2}{N} \qquad (3)$$

where σ^2 represents the noise variance, while N denotes the number of samples over a measurement interval.

In contrast to this, in [8] it was shown that the Measurement Uncertainty Upper Bound (MUUB) for the digital multiplier output Ψ (see Fig. 1) is limited by

$$u \leq \frac{Y_2 \cdot (\sigma_n + \frac{\Delta_1}{2})}{\overline{\Psi} \cdot \sqrt{N}} \qquad (4)$$

where Y_2 is the Root Mean Square (RMS) value of the dithered base function, σ_n^2 is the noise variance, Δ_1 is the quantum of ADC in channel one, while N represents the number of samples over a measurement interval.

Although the expressions for CRLB and MUUB starts from different theoretical assumptions, it is easy to see that MUUB includes more general case CRLB. These most significant cases are:

- instead of ideal ADC ($\Delta = 0$), MUUB includes the case of using real ADC (whose quantum is $\Delta \neq 0$).

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- instead of orthonormal Fourier transform, MUUB treats an arbitrary orthonormal transform (whose norm is Y_2).
- instead of white Gaussian noise, MUUB treats an arbitrary unbiased noise (whose standard deviation is σ_n).

Considering these statements, it is easy to conclude that for real ADC, orthonormal Fourier transform, and white Gaussian noise, when

$$Y_2 = \frac{R}{\sqrt{2}}; \quad \overline{\Psi} = \frac{R \cdot a_k}{2}; \quad \sigma_n = \sigma; \quad \Delta_1 = \Delta; \tag{5}$$

the inequality

$$\left|\overline{\Delta a_k}\right| = \left|\overline{\Delta b_k}\right| \le \frac{\sqrt{2} \cdot \left(\frac{\Delta}{2} + \sigma\right)}{\sqrt{N}} \tag{6}$$

defines the measurement uncertainty bounds of DSM method. These bounds, that correspond to the minimum ($\Delta = 0$) and maximum ($\Delta \neq 0$) values of (6) are shown in Fig. 2. As we can see, the lower bound, or MULB (Measurement Uncertainty Lower Bound) is equal to the $\sqrt{\mathrm{var}(\overline{a_k})}$, which confirms that (6) represents a generalization of CRLB in the case of using real ADC.

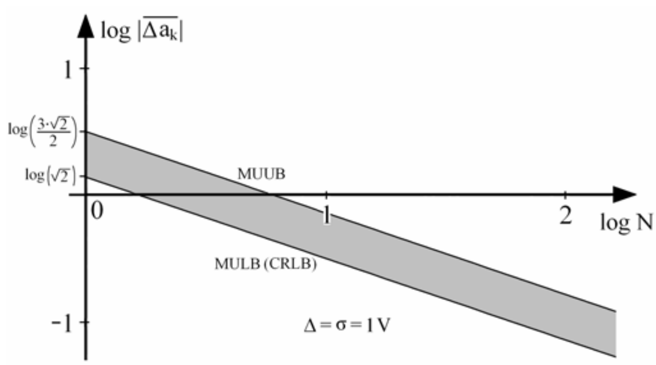

Fig. 2. The measurement uncertainty bounds of DSM method.

III. Discussion

Since (6) is not only MUUB, but CRLB as well, it can be used for optimal choice of ADC resolution. Obviously if

$$\varepsilon = \frac{\sqrt{2} \cdot \left(\frac{\Delta}{2} + \sigma\right)}{\sqrt{N}} = \frac{\sqrt{2} \cdot \left(\frac{R}{2^n - 1} + \sigma\right)}{\sqrt{N}} = const. \tag{7}$$

represents a tolerable limit of MUUB (defined in advance), then from

$$n = \left\lceil log_2\left(\frac{2 \cdot R}{\varepsilon \cdot \sqrt{2 \cdot N} - 2 \cdot \sigma} + 1\right)\right\rceil \tag{8}$$

it is possible to conclude that knowing σ opens the possibility of choosing an optimal ADC. In addition, (8) also shows that by using fast low-resolution ADCs (n low, N high) accuracy of slow high-resolution ADCs (n high, N low) is achievable. These conclusions offer many advantages compared to the classical approach, especially in terms of hardware implementation (the lower resolution implies the simpler hardware). Likewise, from (8) we see that DSM based system can achieve an excellent accuracy even when the measurement noise is significant, in contrast to classical approach (based on signal estimation).

IV. Conclusion

In this paper we evaluate the measurement uncertainty bounds of the method called "digital stochastic measurement". We have shown that these bounds represent a generalization of CRLB in the case of using real ADC. In addition, we have shown that DSM method leads to optimal use of flash ADCs, i.e. for a given flash ADC it is possible to find the limits of its performance.

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APPLICATION OF A NEW CLASS OF SEC-DED-BED CODES IN INTELLIGENT INSTRUMENTATION

Aleksandar Radonjić, Vladimir Vujičić
Faculty of Technical Sciences, Novi Sad, Serbia
sasa_radonjic@yahoo.com, vujicicv@uns.ac.rs

Abstract: *Electric power system monitoring is in most cases reduced to tracking only extremely dangerous situations, but not those that are not yet drastically developed. The possibility of detecting potentially dangerous situations and a fast notification mechanism represent one of the main challenges in terms of securing the most reliable electric power system operation. In this paper the principle of work of the communication subsystem of the integrated instrument for harmonics measurement (IMH), i.e. a device that in a very simple way detects all threatening situations in a system, is presented. Besides operating in the certain frequency domain, the advantage of the IMH instrument, compared to devices of similar purpose, lies also in a fast system of notification based on sending packets protected by a new class of SEC-DED-BED codes. Apart from a high level of data integrity, the mentioned codes offer also the possibility of adapting the IMH instrument to conditions within a communication channel. Depending on the type of medium, the packet length can vary from 128 bits in case of a high noise level, up to 524288 bits, in case of a very low noise level.*

Key Words: ***Harmonic measurement, fault recording, SEC-DED-BED codes, data transmission.***

1. INTRODUCTION

An adequate power supply represents the main condition for correct functioning of industrial, communication and transportation systems, etc. In order to regulate this field by law, the European norm BS EN 50160:2000 strictly defines the limit values for different occurrences that can affect the quality of electric energy. However, the presence of a great number of non-resistive consumers, has been always threatening the normal operation of certain parts of electric power system and in some situations, also the functioning of the system itself. To prevent this from happening, a few years ago a large number of devices have been developed, that beside detection of unusual states within the system also have fault recording function [1], [2]. The device that is commonly used in Serbia for this is osciloperturbograph. However, its basic flaw is seen in its ties to protecting relay, so that with this device several periods of network voltage, power before malfunction and failure itself can be recorded, but not the potentially dangerous situations. Considering that this fact significantly limits the quality analysis of power supply, a certain number of autonomous devices that can define classes of triggering events which are detected and recorded, has appeared on the market. One of them is the integrated instrument for harmonics measurement (IMH) [3], [4], i.e. a device which by directly measuring 50 harmonics within a period in a very simple way detects all threatening situations. In addition to working in a frequency domain, the advantage of IMH instrument, in relation to other devices of the similar purpose is also in the realisation of communication subsystem, where the measured data is protected with a very high level of integrity using the new class of SEC-DED-BED codes. Apart from that, an additional advantage of using the mentioned code lies in the possibility of adapting the IMH instrument to communication channel conditions. For example, if multi-bit errors occur, on receipt of the request for retransmission, the IMH instrument may shorten the data packet for one of the pre-defined lengths, encoding the actual size in appropriate header field.

2. BASICS OF INTEGRATED INSTRUMENT FOR HARMONICS MEASUREMENT

The IMH instrument is based on the generalized low-frequency stochastic true-RMS instrument which is presented in detail [3]. Its block schematic is presented in Fig. 1.

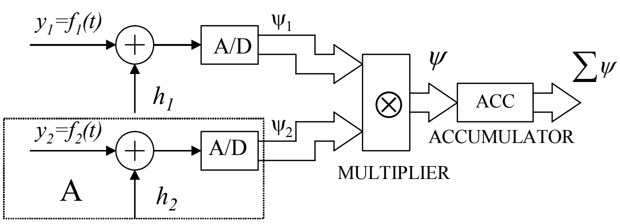

Fig. 1. *Generalized low frequency stochastic true RMS instrument*

Signals h_1 and h_2 are uniform, non – correlated dither signals, superimposed onto the input signals y_1 and y_2, respectively. This instrument obtains measurement results during $t_2 - t_1$ measurement time given by:

$$\bar{\psi} = \frac{1}{t_2 - t_1} \int_{t1}^{t2} f_1(t) f_2(t)\, dt \qquad (1)$$

while the variance of its measurement error is defined by $e = \psi - y_1 y_2$ and it is given by:

$$\sigma_{\bar{e}}^2 = \frac{\sigma_e^2}{N} \le \frac{\sigma_s^2}{N} \qquad (2)$$

where N is the number of samples in the measurement interval $t_2 - t_1$, while the stochastic variance is determined by the quantum of applied A/D converters (Δ) and the norm of the two internal signals:

$$\sigma_s^2 = \frac{\Delta^2}{4} \frac{1}{t_2 - t_1} \int_{t1}^{t2} [f_1^2(t) + f_2^2(t)]\, dt + \frac{\Delta^4}{16} \qquad (3)$$

Harmonic components can be measured if sum of the signals y_2 and h_2 in Fig.1. is replaced by memorized samples of this sum. This can be done, since signal y_2 is the base function from the orthogonal base function set, so y_2 is known in advance. If $y_2 = R \cdot \cos(i\omega t)$ then the average value in the accumulator in Fig 1. is

$$\bar{\psi} = \frac{1}{T} \int_0^T f_1(t) \cdot R \cdot \cos(i\omega t)\, dt = R \cdot \frac{a_i}{2}, (i = 0,1,2,...,n) \qquad (4)$$

In this equation R represents the signal range, i harmonic order, ω fundamental frequency, and a_i cosine component of i-th harmonic

$$a_i = \frac{2}{T} \int_0^T f_1(t) \cdot \cos(i\omega t)\, dt \qquad (5)$$

this means that (5) gives one-half of an i–th cosine coefficient of a trigonometric polynomial, multiplied by a range value. If $y_2 = R \cdot \sin(i\omega t)$ then the average value in the accumulator in Fig 1. is

$$\bar{\psi} = \frac{1}{T} \int_0^T f_1(t) \cdot R \cdot \sin(i\omega t)\, dt = R \cdot \frac{b_i}{2}, (i = 1,2,...,n) \qquad (6)$$

and b_i is sine component of i-th harmonic

$$b_i = \frac{2}{T} \int_0^T f_1(t) \cdot \sin(i\omega t)\, dt \qquad (7)$$

consequently (7) gives one-half of an i–th sine coefficient of a trigonometric polynomial, multiplied by a range value. From (5) and (7) cosine and sine component of i-th harmonic can be easily obtained, which is enough for calculating the amplitude and the phase angle of each harmonic.

However, although with the use of the IMH instrument we can measure 50 harmonics per one input and in one period, for purposes of tracking the electro-energetic system's state, amplitude and phase values of first 10-12 harmonics are enough. By comparison with standard fault recorders (FR), which take 256 values per period, this principle of work does not only lead to significant savings of memory resources, but also to a much faster mechanism of detecting system malfunctions. Namely, with standard FR it is necessary to compare values of 256 numbers in two adjacent periods, while with the IMH instrument that procedure is mostly reduced to comparing the values of 20-24 numbers.

3. IMH INSTRUMENT COMMUNICATION SUBSYSTEM AND DATA PROTECTION

For purposes of providing data integrity, within the communication subsystem of the IMH instrument, the new class of SEC-DED-BED codes is used, i.e. codes which can correct single bit errors and detect all double bit errors, i.e. error packets b bit in length. In order to explain they functionality, let us assume that data word is made by a sequence of k bytes ($k \le 2^{b-1}$), while every byte consists of b bits (Fig. 2.).

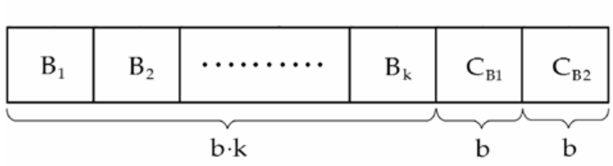

Fig. 2. *The code word structure*

In that case, the procedure of forming check-bytes C_{B1} and C_{B2} implies the use of following expressions

$$C_{B1} = B_1 \oplus B_2 \oplus B_3 \oplus ... \oplus B_k = \sum_{i=1}^{k} B_i \bmod (2) \qquad (8)$$

$$C_{B2} = [1 \cdot p_1 + ... + k \cdot p_k] \bmod (2^b) = \sum_{i=1}^{k} i \cdot p_i \bmod (2^b) \qquad (9)$$

where $\oplus$ represents XOR operation on byte B_i, while the value $p_i \in [0, 1]$ is a result of a horizontal parity check on bits b_j inside B_i, i.e.

$$p_i = \sum_{j=1}^{b} b_j \bmod (2), \quad b_j \in B_i \qquad (10)$$

On the receiving side using identical methods we calculate the values

$$\hat{C}_{B1} = \hat{B}_1 \oplus \hat{B}_2 \oplus \hat{B}_3 \oplus ... \oplus \hat{B}_k = \sum_{i=1}^{k} \hat{B}_i \bmod (2) \qquad (11)$$

$$\hat{C}_{B2} = [1 \cdot \hat{p}_1 + ... + k \cdot \hat{p}_k] \bmod (2^b) = \sum_{i=1}^{k} i \cdot \hat{p}_i \bmod (2^b) \qquad (12)$$

and based on them, syndromes S_1 and S_2 are formed

$$S_1 = \hat{C}_{B1} \oplus C_{B1} \qquad (13)$$

$$S_2 = [\hat{C}_{B2} - C_{B2}] \bmod (2^b) \qquad (14)$$

Taken into account that the error control at this code is based on modular arithmetic according to two different modulo, as a final result we get syndromes, whose values will be interpreted in two different ways - syndrome S_1 we will observe from the angle of its Hamming's weight, while the value of syndrome S_2 will always be expressed arithmetically. If we have the case where both of those values are equal to zero, decoder will conclude that the data word is correct, while in other cases it will start with single bit error correction, i.e. multi-bit error detection procedure. In the analysis that follows it will be shown which combinations of those two syndromes indicate the case of single bit errors, and which the situations where double bit error, i.e. burst errors occurs.

A. Single bit error correction

If single bit error occurs, from the form of syndrome S_1 we can easily find its bit position and from the value of S_2, the position of the byte that is affected by it can be instantly determined. Namely, if we take into account that a single bit error always produces a change in value p_i, whereby the arithmetical sum from (8) is increasing or decreasing by i ($1 \le i \le k$), from the basic theorems of modular arithmetic the position of byte affected by error is obtained directly from S_2, i.e.:

$$i = S_2, \qquad for \quad S_2 \in (0, k] \tag{15}$$

$$i = 2^b - S_2, \qquad for \quad S_2 \in [2^b - k, 2^b) \tag{16}$$

After calculating the values of the parameter i, error correcting procedure consists in the use of XOR operation on byte that is affected by error, i.e.

$$B_i = S_1 \oplus \hat{B}_i \tag{17}$$

Based on (15), (16) and (17) it can be easily concluded that the procedure of correcting single bit error does not depend on the number of bytes.

B. Double bit error detection

In case of double bit error it is sufficient to analyze two cases. First of them relates to a situation where the double error occurred on different bit positions inside one or two bytes implying a situation where $w(S_1) = 2$ and $S_2 = 0$, i.e. a situation where $w(S_1) = 2$ and $S_2 \neq 0$. In the second case, error can appear on the same bit positions at two different bytes, which means that the values of syndromes will be $w(S_1) = 0$ and $S_2 \neq 0$. This conclusion comes from the fact that for every $i_1, i_2 \in (0, k], i_1 \neq i_2$ inequation $0 < |\pm i_1 \pm i_2| < 2^b$ must be satisfied.

C. Burst error detection

Considering the method used, for detection of burst errors of b length, the value of syndrome S_1 is sufficient. This type of error will be detected in case if it affected one or two adjacent bytes, though in certain situations we can detect burst errors which affect three or more bytes. In order to achieve that, Hamming's weight of S_1 has to be between $2 \le w(S_1) \le b$, except in cases when certain forms of burst errors causes situations where $w(S_1) = 1$ and $S_2 = 0$ or $w(S_1) = 0$ and $S_2 > 0$ are possible. Burst errors would be also detected if for $k < 2^{b-1}$ we have $w(S_1) = 1$ and $k < S_2 < 2^b - k$ because in that case the syndrome S_2 would indicate a single bit error on a non-existent byte.

4. PERFORMANCE AND WORKING MODES OF IMH INSTRUMENT

In 1990 the 3 layer EPA model was adopted as the basis for telemetry data transmission in standard IEC 870. One of the early parts of it were Transmission Frame Formats, which included the specification of four frame formats that would be suitable for telecontrol applications - FT1.1, FT1.2, FT2 and FT3 frames. This led to independent development of two electric power-oriented protocols [5] – DNP, which uses FT3 frame format and IEC 60870-5-101, which uses FT1.2 frame format (Fig.3.).

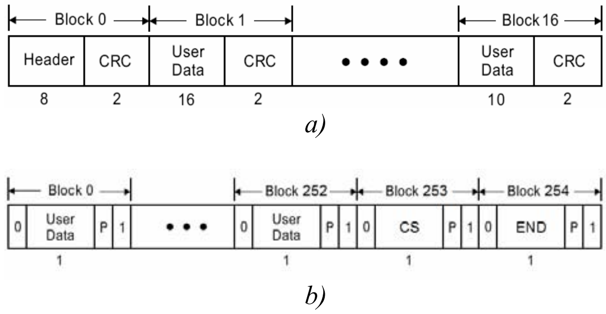

Fig. 3. *Frame formats: a) DNP b) IEC 60870-5-101*

However, considering that the IMH instrument sends data (70 KB/s) most frequently through a medium (UTP) which is characterized by a low bit error rate, their integrity check could be done on every 2048 bits and not on every block, as it is the case with those two protocols. This solution does not come only from the characteristic of the medium, but also because of the fact that the proposed SEC-DED-BED code has excellent additional error detection capabilities (Table I), reducing in that way the possibility that an error remains undetected or miscorrected. For example, if we assume that BER $\approx 10^{-5}$ and the data word length is $K = 2048$ bits, the probability that the receiver would perform an erroneous decoding is 1:630000, which is enough to consider the transfer as very reliable. An even more favorable situation is given if we want to check data integrity done on every 128 bits, where under worse conditions (BER $\approx 10^{-4}$) the probability of erroneous decoding amounts to approximately 1:2930000. However, given the fact that the proposed SEC-DED-BED code has the ability to perform single bit correction, its main advantage compared to the CRC is reflected in the significant reduction of the number of requests for retransmission of erroneous received packets. If we have in mind the conditions mentioned above, i.e. when BER $\approx 10^{-5}$ and $K = 2048$ bits, using a 16-bit CRC a request for retransmission will happen on average on each 50-th received packet, while the use of (2070, 2048) SEC-BED-ded code would lead to the same occurrence after 4870 received packets. In another case, when BER $\approx 10^{-4}$ and $K = 128$ bits, this ratio is even more advantageous in favor of the proposed code – the use of 16-bit CRC will require retransmission for every 80-th, while on the other side the use of the (144, 128) SEC-DED-BED code would reduce it to one request for every 12460-th received packet.

On the other hand, if the data transfer happens through the medium that is characterized by a very low bit error rate (optical fiber), the advantage of using the proposed code gets even greater significance. Namely, for many years intensive research are done for a code that would provide reliable transfer of large amounts of data, where the main emphasis was put on the 32-bit CRC. It is known that the 32-bit CRC has great error detection possibilities, but its final performances have never been precisely determined. In a general analysis Koopman [6] showed that the error detection capabilities of 32-bit CRC decrease with increasing number of bits, giving the example that the most famous IEEE 802.3 CRC polynomial has only double bit error detection possibility for data words longer than 91607 bits.

Unlike the CRC, in the case of proposed code, data bit length does not play such an important role, because for fixed *b*, the proposed code always has SEC-DED-BED characteristics. In practical terms, this means that for $b = 16$ it is possible to transfer up to 524288 data bits, i.e. that with two 280K bit packets all data generated by IMH instrument (70 KB/s) could be transfered.

Having in mind all those characteristics of the proposed code we can easily conclude that the IMH instrument can be extremely well adapted to conditions within communication channel, even during the data transfer (when the receiver sends the request for retransmission). Therefore, the IMH instrument can work in one of three general modes:

1) high noise level mode (10^{-3} < BER < 10^{-5}), where the packet length is 144 bits

2) low noise level mode (10^{-5} < BER < 10^{-7}), where the packet length is 2070 bits

3) very low noise level mode (10^{-7} < BER < 10^{-12}), where the packet length is 280032 bits

Table 1. shows additional error detection capabilities of the proposed code for mentioned packet lengths. From it we can easily notice that the proposed code offers much higher level of data integrity compared to [7], [8].

Table 1. *Error detection capabilities of the proposed code for typical packet lengths*

Packet length (data word + redundancy)	*b*	Triple-bit errors	Byte plus bit errors	Double byte errors
K = (128 + 16) bits	8	78.24 %	97.25 %	96.67 %
K = (2048 + 32) bits	8	88.11 %	99.98 %	99.98 %
K = (280000 + 32) bits	16	82.03 %	99.98 %	99.98 %

5. CONCLUSION

Detecting potentially dangerous situations and fast mechanism of notification represent some of the main challenges in terms of reliability of the electric power system. In this paper the communication subsystem of the integrated instrument for harmonics measurement (IMH) is presented. In contrast to devices of the similar purpose, the advantage of the IMH instrument is also seen in the use of a new class of SEC-DED-BED codes which allow efficient adaptation to the conditions within a communication channel. This is best seen in the fact that the packet length can vary from 128 up to 524288 bits, which represents a very important improvement compared to existing electric power-oriented protocols. In addition to that, the proposed code offers a high level of protection with the possibility of single bit error correction that CRC has not. This feature can reduce the number of requests for retransmission, which enables a fast information transfer from the IMH instrument to the central computer.

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CONTROL OF INDUSTRIAL SYSTEMS BASED ON IP ADDRESSING

Aleksandar Radonjić
Faculty of Technical Sciences, Novi Sad, Serbia
sasa_radonjic@yahoo.com

Abstract: *Centralized control of industrial systems represented a great problem for a long time, because the communication between industrial devices was based on outdated field-bus protocols. In the end of the 1990s, when industrial ethernet was implemented, this situation has been dramatically changed. As a result of new technologies, control of working state of the device through IP address, which is assigned to every device connected to the network, was enabled. However, considering that IP address assignment is still not standardized, this work will show possibilities of DHCP Option 82 and Auto-IP methods, i.e. methods which are mostly used in practice. While the first one of them represents a modification of classical DHCP, which is used in local area networks, the other method is based on different and much more flexible principle. Thanks to that, it accomplishes a set of advantages such as Plug & Play principle, localization of network traffic, the possibility of integration with SCADA software, etc.*

Key words: ***Industrial ethernet, IP address assignment, DHCP Option 82, Auto-IP.***

1. INTRODUCTION

Thanks to great achievements in the field of electronics and computing, at the begining of the 70s of the last century marked a certain kind of revolution in industrial system work. In addition to direct control over the production process the appearance of intelligent devices such as programmable logical controllers (PLC) has led to the generation of large quantities of information, which needed to be collected and subsequently processed by the use of communication infrastructure [1]. Up to the end of 90s, the trend of connecting industrial system's components into networks, was being based on developing different communication protocols which prevented the introduction of unique standard. On the other hand, communication over internet and ethernet networks was widely spread and standardized that indirectly initiated the introduction of these technologies into industrial systems. However, before it happened, ethernet had to undergo some major changes – stochastic approach to medium has been eliminated [2], standard IEEE 1558 [3] that allows synchronization among devices has been defined, etc . (Fig.1.).

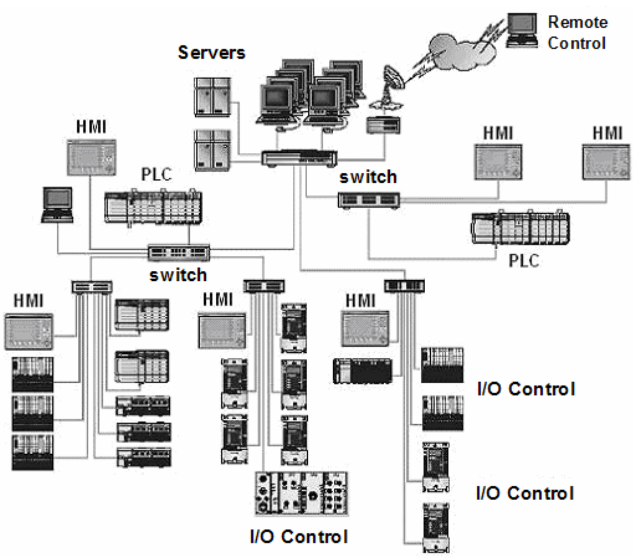

Fig. 1. *Network based on industrial ethernet*

Apart from adapting to real-time communication demands [4], [5] the introduction of ethernet into industrial systems also meant the use of great number of services based on TCP/IP protocol and among them also IP addressing. As it is known, for identification purpose, in computer networks every device (PC station, router, switch, etc.) is given an IP address, temporarily assigned from local DHCP server [6]. It is also known that this procedure always initiates the device in the moment of its connection to the network in the way that through DHCP protocol (DHCP - Dynamic Host Configuration Protocol) requesting information from local DHCP server about network configuration, including IP address. In most cases the exchange of messages between the device and DHCP server will take place without the mediator, because within every subnetwork there is almost always at least one DHCP server. However, if that is not the case, the request for IP address will be taken over by an appropriate DHCP agent (switch) that knows the exact location of DHCP server based on which the received request is being forwarded.

In contrast to this approach, which enables that with every subsequent connection to the network the same computer is assigned a new IP address, in case of industrial environment devices must be assigned a fixed IP address. This approach appeared from the need that in every moment it is possible to have a simple insight into working condition of every device, regardless of its location. Additionally, this approach enables fast search in case of certain device's failure, whereby the time necessary for system recovery is reduced to the minimum and with it also the loss of productivity.

In order to find the solution that will fulfill all of these requests, in the last couple of years several steps in that direction have been made (the use of configuration tools for local application, the use of ARP/RARP protocols, Port-specific DHCP, etc.), but none of them has been proved completely successful in terms of performances as well as profitability. Considering that segment of IP addressing still has not been officially standardized, research that would provide the most acceptable solution for this sort of problem still continues. When it comes to topical methods, in industrial systems we find the use of DHCP Option 82 and Auto-IP method.

2. DHCP OPTION 82 METHOD

In contrast to standard LAN networks, in which client computer in most cases gets to DHCP server without the use of DHCP agent, industrial systems have hierarchical organization where DHCP servers are set in for that purpose designed places. To simplify the process of getting the IP address in that kind of surrounding, DHCP Option 82 method [7], [8] is often applied in practice, whose work is based on communication between three standard components:

1) *DHCP client* (HMI, PLC, U/I device, etc.)

2) *DHCP agent with Option 82 support* (switch)

3) *DHCP server with Option 82 support*

As it can be seen, the difference between this method and standard DHCP is related to Option 82 support that has to be implemented in every DHCP agent and DHCP server. In other words, besides standard fields that are found in DHCP packet, at DHCP Option 82 method we also meet three additional fields (Circuit ID, Remote ID and GiAddr) which allow DHCP server to identify the location of DHCP agent in a unique way and the port number from which it received the request for IP address.

To clarify the working principle of this method, let us assume that in the network shown in Fig. 2. PLC_1 represents predstavlja DHCP client, and a $switch_1$ an appropriate DHCP agent. In that case, immediately after connection to the network PLC1 will initiate process of getting the IP address that involves the exchange of the following DHCP messages:

1) *DHCP_Discover* – broadcast message sent by PLC_1, which is received by every adapters on subnetwork

2) *DHCP_Discover_Option_82* – unicast message which is sent by $switch_1$ towards DHCP server

3) *DHCP_Reply_Option_82* – unicast response from DHCP server towards $switch_1$

4) *DHCP_Reply* – unicast message sent by $switch_1$ towards PLC_1

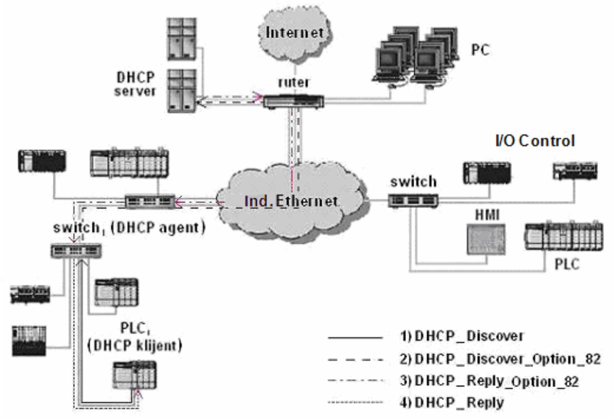

Fig. 2. *IP addressing based on DHCP Option 82 method*

When it comes to this method, it is important to emphasise that the exchange of DHCP messages is preceded by configuration of an appropriate switch as DHCP agent. It is done either remotely or automatically, in such a way that a chosen switch addresses to an adequate file server asking for information about DHCP server location as well as ports at which it will receive incoming requests.

3. AUTO-IP METHOD

While DHCP Option 82 method uses DHCP messages in process of assigning IP address, Auto-IP method is based on combined use of two application level protocols - BOOTP and SNMP protocol [6]. Considering this fact, at the beginning it can be probably thought that with the use of two protocols the situation will become more complicated compared to previous method, especially considering the number of messages that network devices exchange. However, observing from the angle of functionality, combined use of two protocols enables number of other advantages [9] which are not seen at first sight, for example:

a) BOOTP protocol, because of its earlier wide use is supported by almost every industrial device (unlike the DHCP which is supported only by the most recent ones)

b) the elimination of DHCP server enables localization of network traffic (transfer of information no longer goes “from bottom to the top“ and vice versa)

c) there is a possibility of introducing an efficient redundancy within the network using more servers with identical data bases

d) full coexistence with SCADA software with the possibility of integration within the same computer

e) the need for additional configuring of switches as it is in DHCP Option 82 method is unnecessary (all switches support SMNP protocol)

f) simplicity of implementation through "Plug & Play" principle, etc.

In order to realize all these possibilities, every network which has implemented Auto-IP method must have three characteristic components:

1) *BOOTP client* (HMI, PLC, U/I device, etc.)

2) *SNMP agent* (switch)
3) *Auto-IP server (modified BOOTP server)*

At the moment when BOOTP client is connected to the network it will a initiate process of getting the IP address which in most cases implies communication with local Auto-IP server. However, to present additional possibilities, which this method gives in Fig. 3. the redundancy implementation case is shown, which implies communication not only with local, but also with remote Auto-IP server. Therefore, if we suppose that PLC1, which contains two network cards, represents BOOTP client, the procedure of assigning IP address will imply sending the following configuration messages:

1) *BOOTP_Request* – broadcast message sent by PLC1 which through switch1 is being forwarded to Auto-IP server 1, i.e. through switch2 to Auto-IP server 2.

2) *SNMP_Query* – message which is sent by appropriate Auto-IP server to adequate switch

3) *SNMP_Response* – response of every switch individually sent to Auto-IP servers

4) *BOOTP_Response* – response of Auto-IP server which contains IP address intended for PLC_1

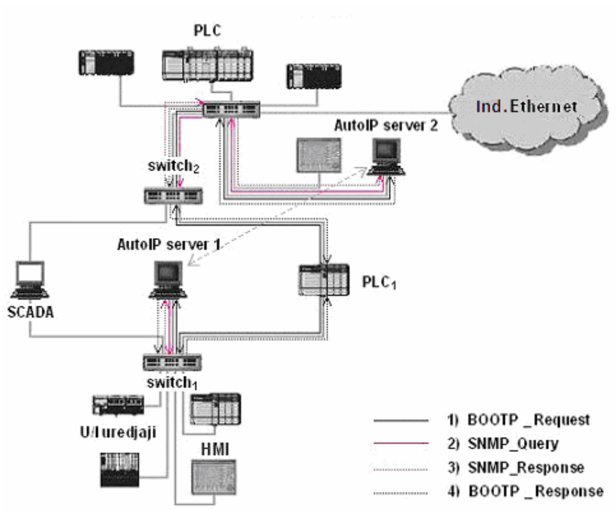

Fig. 3. *IP addressing based on Auto-IP method*

With this way of industrial device addressing i.e. use of more Auto-IP servers, besides introducing redundancy, network traffic is significantly localized. Observing from the angle of implementation, it implies configuration with one primary and one or more secondary Auto-IP servers. Apart from the difference in physical location, primary server, which is put in the central part of the network, gets also the function of refreshing data base on every secondary server (thick discontinuous line in Fig. 3). This provides the solution where every BOOTP request will reach addresses on both Auto-IP servers, but as a valid response will be accepted only the one that gets to the adapter of that particular device first.

4. COMPARISON OF DHCP 82 METHOD WITH AUTO-IP METHOD

As it was said at the beginning, DCHP Option 82 and Auto-IP represent two equal and sole topical methods today. Considering that none of them has been yet standardized, it would be interesting to compare them and see the advantages and disadvantages that the implementation of every one of them brings with it. If we consider the main principles based on which both methods are functioning and if we assume that one network based on industrial ethernet implies the configuration and adequate interventions in cases of incorrect work, their comparisons can be made on following issues:

a) Complexity of device configuration

a1) DHCP Option 82 method implies the use of modern switches and the DHCP server with Option 82 support. This implies additional configuration of switches, as well as data input into data base on the DHCP server for every device individually.

a2) Auto-IP method uses standard switches without any need for additional configuration. Still, because insufficient information which is contained within such an approach (absence of information on the port from which a BOOTP request arrived), in this case there is an exchange of additional messages.

b) Detecting of device failure

b1) DHCP Option 82 method uses a complex software for monitoring ports on switches which imply preventing the possibility to assign wrong IP addresses to devices in cases of failure or appearance of reset function.

b2) Auto-IP method utilizes standard messages on availability of certain devices (ICMP packet is sent on every 30 seconds) for malfunction detection, while in cases of reset, rebooting of operating system is followed by sending the BOOTP request with the MAC address of the corresponding device. Because of information that Auto-IP servers already contain in their data bases, every possibility that those devices get a wrong IP address is prevented.

c) The existence of redundancy

c1) The introduction of redundancy within the network that utilizes DHCP Option 82 method is hardly feasible, because for IP address distribution it is necessary to use at least one more server. Therefore, the solutions which are used at standard LAN networks are also being used here.

c2) Auto-IP method implies the possibility of introducing redundancy principle which contains primary and secondary Auto-IP servers with identical data bases.

d) Connection to hub

d1) Because of the need that every connected device is assigned with an adequate port, the use of less intelligent network devices such as hub, using the method DHCP the Option 82 is not enabled.

d2) Thanks to the use of the SNMP protocol, which is supported by every network device, the Auto-IP method implies the use of classic hubs and switches, etc.

By observing all those situations that can happen in practice, it can be easily concluded that the Auto-IP method represents a better solution in relation to at this time more represented DHCP Option 82 method.

To support that there is Table 1, and also very efficient software implementation done by Network Vision, Inc. [10].

Table 1. *DHCP Option 82 i Auto-IP method capabilities*

Perfomance and capabilities	**DHCP Option 82**	**Auto-IP**
Detection of device failure	Not easily	Yes
Support for BOOTP enabled devices	No	Yes
Redundancy support of the IP address server	Not easily	Yes
Work with all existing networking equipment	No	Yes
Requiring of configuration at each switch	Yes	No
Support for devices connected to hub	No	Yes

5. CONCLUSION

Considering the problem of IP addressing of industrial devices, it can be easily noticed that the basis of such idea lies in methods which are also used today in up to date LAN networks. This is primarily related to the use of DHCP protocol, which has with the appearance of mobile computing completely suppressed BOOTP protocol, as **its** direct predecessor. However, unlike today's computer networks, in which the assignment of IP addresses is being made by dynamical principle, i.e. on certain period of time, industrial devices have been given exclusively fixed IP addresses. Such circumstances prompted the development of the idea to reuse BOOTP protocol at IP addressing, so that contemporary networks based on industrial ethernet use DHCP Option 82 method, based on modification of standard DHCP and Auto-IP method which is further based on combined use of BOOTP and SNMP protocol.

Taking into account that these methods are different in their way of functioning, they are characterized by certain advantages and disadvantages as well: DHCP Option 82 method requires the use of modern switches that can enable the exchange of DHCP messages on relation between industrial devices, while Auto-IP method allows the use of less intelligent devices, but because of insufficient information which it provides the additional use of SNMP protocol is required. When the rest of the characteristics are added to all that was previously said, such as: the easy way of implementing, introduction of redundancy through parallel work with other types of servers, timely diagnostic of network etc. then it can be concluded that Auto-IP method is, after all, practically and at this moment economically the most acceptable solution.

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ETALONIRANJE HORIZONTALNIH CILINDRIČNIH REZERVOARA: JEDAN MATEMATIČKI MODEL

Aleksandar Radonjić, Bojan Vujičić, Ivan Župunski

Ključne reči: baždarenje, cilindrični rezervoar, matematički model, merna nesigurnost

KRATAK SADRŽAJ

U radu je prikazan jedan postupak za etaloniranje položenih cilindričnih rezervoara, zasnovan na matematičkom modelu koji nudi procenu merne nesigurnosti etaloniranja. Opisan je matematički model, prikazana simulacija rezultata kao potvrda ispravnosti modela i postupak testiran na podacima dobijenim tokom stvarnog etaloniranja rezervoara.

CALIBRATION OF HORIZONTAL CILINDRICAL TANKS: A MATHEMATICAL MODEL

Keywords: calibration, cylindrical tank, mathematical model, measurement uncertainty

ABSTRACT

A method for calibration of horizontally laid cylindrical tanks and appropriate mathematical model is presented in the paper. This method offers possibility for estimating measurement uncertainty of calibration. Simulation was used for the testing of a given mathematical model. Also, the method is tested using real calibration data.

UVOD

Evidentna je potreba da se poznaje količina (zapremina, masa) tečnosti koje se nalaze u sudovima, bez obzira da li se radi o potrebama tehnoloških procesa ili u svrhu trgovine. Merenja mogu biti zasnovana na direktnim merenjima zapremine tečnosti, ali su često pogodnije druge, indirektne metode, koje se svode na merenja mase, merenja geometrijskih veličina (parametri suda, nivo tečnosti), merenja protoka i vremena itd.

Ovaj rad se odnosi prvenstveno na merenje količine goriva u rezervoarima organizacija koje se bave prometom tečnih naftnih derivata. Od brojnih metoda kojima je moguće meriti zapreminu tečnosti u rezervoarima, u ovom radu će se imati u vidu samo metode koje imaju praktični značaj za ovu vrstu merenja. Osim samog tehničkog karaktera merenja, u našoj zemlji se ova merenja tretiraju i kao obračunska (merenja za svrhu kupovine i prodaje), pa je metrološki ova oblast merenja uređena, osim čisto tehničkom, i odgovarajućom zakonskom regulativom.

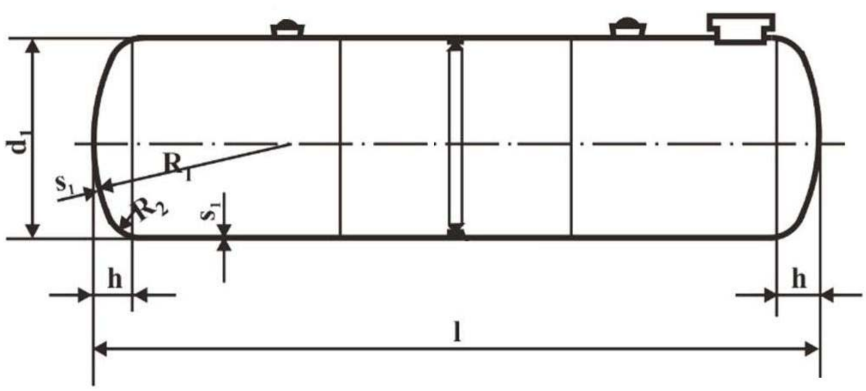
U praksi kod nas dominira metoda prema kojoj se meri nivo tečnosti u rezervoaru, a zatim se, uz upotrebu prethodno načinjenih tabela, određuje količina tečnosti. Ove tabele, za svaki rezervoar posebno, sastavljaju se prilikom periodičnog pregleda rezervoara.

Samo etaloniranje rezervoara (uspostavljanje veze između zapremine tečnosti i njenog nivoa, putem eksperimenta) može da se obavi na dva načina: *i*) *„geometrijskom metodom*“ – gde se na osnovu merenja niza geometrijskih veličina (dužina, prečnik, itd) i *apriori* poznatim oblikom rezervoara, propisanim proračunom generišu tabele zapremine. Metodu karakteriše relativna jednostavnost i upotreba etalonske opreme kao i jednostavnost samog postupka etaloniranja. Osim „geometrijske metode“, u praksi se koristi i *ii*) *„volumetrijska metoda“* – u rezervoar se ulivaju porcije tečnosti čije su zapremine određene etalonskim instrumentima i nakon svake porcije se mere i ukupnoj zapremini dodeljuju odgovarajući nivoi. Načelno govoreći, za etaloniranje ovom metodom nije potrebna prethodna informacija o obliku rezervoara.

U ovom radu razvijen je jedan matematički model rezervoara čiji oblik je definisan prema dokumentu JUS (SRPS) M.Z3.010 i analizirane su mogućnosti etaloniranja rezervoara takvog oblika, uključujući i mogućnost ocene merne nesigurnosti rezultata etaloniranja. Postupak je primenljiv i na drugačije sudove ako je definisan njihov oblik.

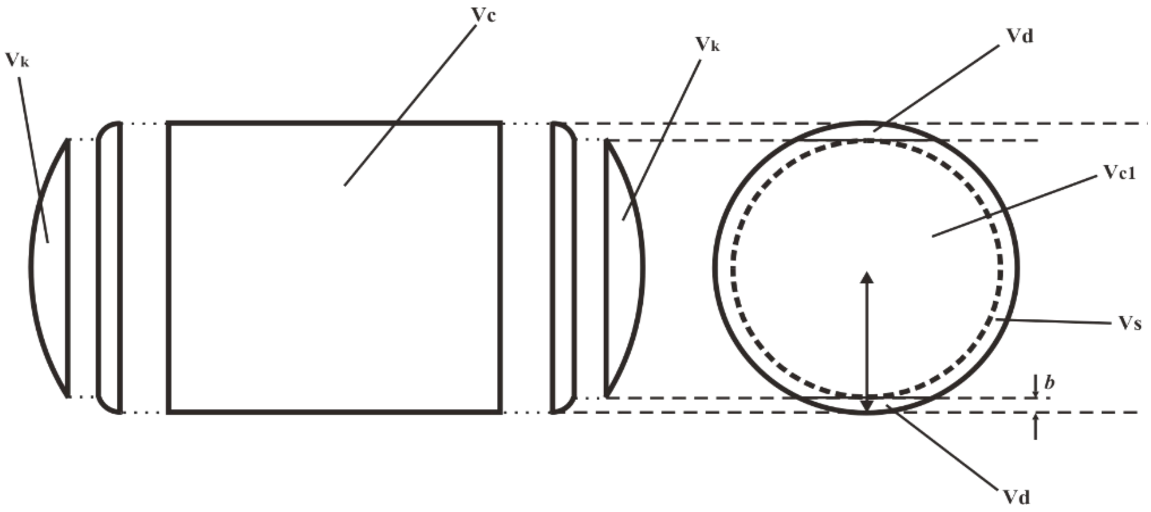
MATEMATIČKI MODEL REZERVOARA

Model rezervoara u ovom radu predstavlja zapreminu tečnosti ulivene u rezervoar kao funkciju nivoa tečnosti, uz podatke o dužini i prečniku rezervoara kao parametrima. Analiziran je slučaj kada je rezervoar u horizontalnom položaju. Standardom JUS (SRPS) M.Z3.010 u potpunosti je opisan oblik rezervoara i on je predstavljen na slici 1.



Slika 1. Cilindrični rezervoar prema standardu JUS (SRPS) M.Z3.010

Mogu se uočiti pet segmenata rezervoara, i oni su prikazani na slici 2.



Slika 2. Cilindrični rezervoar, razložen na segmente

U *x*-*y*-*z* kordinatnom sistemu, zapremine tečnosti u pojedinim segmentima, kao funkcije nivoa *t* tečnosti u rezervoaru, date su izrazima:

$$V_c(t) = \int_{-R}^{t} dz \int_{0}^{L} dy \int_{0}^{\sqrt{R^2-z^2}} 2dx \quad ; \quad -R \le t \le R \tag{1}$$

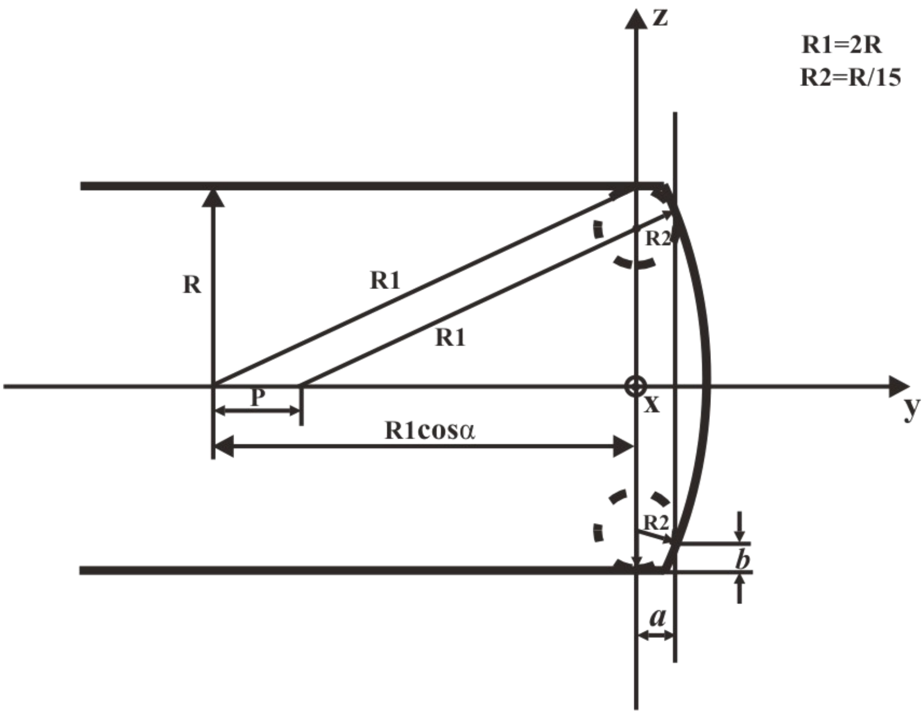
$$V_d(t) = \int_{-R}^{t} dz \int_{0}^{\sqrt{R_2^2-\left[z+\left(R-R_2\right)\right]^2}} dy \int_{0}^{\sqrt{\left[\sqrt{R_2^2-y^2}+\left(R-R_2\right)\right]^2-z^2}} 2dx \quad ; \quad t \le -R+b \tag{2}$$

$$V_s(t) = \int_{-R+b}^{t} dz \int_{0}^{a} dy \int_{0}^{\sqrt{\left[\sqrt{R_2^2-y^2}+\left(R-R_2\right)\right]^2-z^2}} 2dx \; - \int_{-R+b}^{t} dz \int_{0}^{a} dy \int_{0}^{\sqrt{(R-b)^2-z^2}} 2dx \quad ; \quad -R+b \le t \le R-b \tag{3}$$

$$V_{c1}(t) = \int_{-R+b}^{t} dz \int_{0}^{a} dy \int_{0}^{\sqrt{(R-b)^2-z^2}} 2dx \quad ; \quad -R+b \le t \le R-b \tag{4}$$

$$V_k(t) = \int_{-R+b}^{t} dz \int_{a}^{\sqrt{R_1^2-z^2}-\left(R_1\cos\alpha-p\right)} dy \int_{0}^{\sqrt{R_1^2-\left[y+\left(R_1\cos\alpha-p\right)\right]^2-z^2}} 2dx \quad ; \quad -R+b \le t \le R-b \tag{5}$$

Veličine *a*, *b* i *p* su određene iz uslova koji slede iz standarda, a prikazani su na slici 3.



Slika 3. Odnosi medju parametrima rezervoara, određenih standardom JUS (SRPS) M.Z3.010

Vrednosti veličina a i p dobijaju rešavanjem sistema jednačina,

$$\begin{gathered}\sqrt{R_2^2-a^2}+\left(R-R_2\right)=\sqrt{R_1^2-\left[a+\left(R_1\cos\alpha-p\right)\right]^2}\\ \frac{a}{\sqrt{R_2^2-a^2}}=\frac{a+\left(R_1\cos\alpha-p\right)}{\sqrt{R_1^2-\left[a+\left(R_1\cos\alpha-p\right)\right]^2}}\end{gathered} \tag{6}$$

dok se vrednost veličine b dobija iz uslova

$$b=R+\left[-\sqrt{R_2^2-a^2}-\left(R-R_2\right)\right] \tag{7}$$

Na osnovu izloženog, jasno se vidi da je zapremina tečnosti visine t funkcija poluprečnika R i dužine L rezervoara.
Ako se dozvoli da veličine R i L malo variraju oko svojih nominalnih vrednosti, zapremina tečnosti u rezervoaru će da se promeni za iznos $\Delta V(t)$.

$$\Delta V(t)=V(t)-V_0(t)=\frac{\partial V(t)}{\partial R}\Delta R+\frac{\partial V(t)}{\partial L}\Delta L \tag{8}$$

Neka se stvarna vrednost zapremine $V(t)$ za neki nivo t odredi volumetrijskim postupkom ($V(t)$ i t određuju se etalonskom opremom). Veličina $V_0(t)$ i parcijalni izvodi u jednačini (8) dobijaju se iz poznatog matematičkog modela. Tada dve nepoznate, ΔR i ΔL mogu da se odrede iz dva merenja zapremine $V(t)$ i njima odgovarajućih nivoa t.

$$\left(\frac{\partial V(t)}{\partial R}\right)_1 \Delta R + \left(\frac{\partial V(t)}{\partial L}\right)_1 \Delta L = \left(\Delta V(t)\right)_1$$
$$\left(\frac{\partial V(t)}{\partial R}\right)_2 \Delta R + \left(\frac{\partial V(t)}{\partial L}\right)_2 \Delta L = \left(\Delta V(t)\right)_2 \tag{9}$$

Iza ovog razmatranja stoji sledeći koncept: *Razlika zapremine V(t) određene etalonom i izračunate $V_0(t)$ iz modela, za neku vrednost t, nastaje zbog toga što se „prave“ vrednosti R i L razlikuju od njihovih nominalnih vrednosti R_0 i L_0.* Izračunavanje ΔR i ΔL će dati mogućnost da se vrednosti R i L koriguju i time uskladе sa rezultatom etaloniranja. Pokazuje se, ustvari, da je putem određivanja nekih ekvivalentnih, fiktivnih vrednosti za R i L moguće korigovati rezultate merenja zbog ukupnog delovanja niza uticajnih veličina koje bi inače bili veoma teško pojedinačno tretirani.

MERNA NESIGURNOST POSTUPKA ETALONIRANJA

Neka se suksesivo ulivaju u rezervoar porcije tečnosti V_i i neka se mere njima odgovarajuće vrednosti nivoa t_i. Nakon k dosipanja, ukupna zapremina ulivene tečnosti je V_k:

$$V_k = \sum_{i=1}^{k} V_i \tag{10}$$

Ocena merne nesigurnosti veličine V_k može se izvesti na različite načine, u zavisnosti od informacija kojima se raspolaže. Na primer, imajuću u vidu sertifikat etalonskog protokomera i korišćenog hronometra, lako je odrediti merne nesigurnosti ulivenih porcija V_i. Isto tako, znajući klase tačnosti protokomera i hronometra (određene su propisima), mogu se odrediti odgovarajuće nesigurnosti merenja (tip B) na osnovu podataka o sigurnim granicama greške merenja. Za ovaj drugi slučaj, merna nesigurnost u_{vk} ukupne zapremine tečnosti nakon k ulivanja je:

$$u_{vk} = \frac{G_e}{\sqrt{3}} \sqrt{\sum_{i=1}^{k} V_i^2} \tag{11}$$

gde veličina G_e predstavlja sigurne granice greške etalonskog protokomera (uz zanemarivanje nesigurnosti merenja vremena).

Dalje, nivo tečnosti u rezervoarima se meri pomoću etalonskog merila sa granicama greške merenja G_t. Tada (uz uobičajene pretpostavke o raspodeli grešaka merenja) nesigurnost u_t merenja nivoa tečnosti t iznosi $G_t / \sqrt{3}$. Nesigurnost $u_{\Delta v}$ veličine $\Delta V(t)$, date izrazom (8), iznosi:

$$u_{\Delta v} = \sqrt{u_v^2 + u_{v0}^2} = \sqrt{u_v^2 + \left(\frac{\partial V_0}{\partial t} u_t\right)^2} \tag{12}$$

Rešavajući sistem jednačina (9), dobija se:

$$\begin{bmatrix} \Delta R \\ \Delta L \end{bmatrix} = \begin{bmatrix} \left(\frac{\partial V}{\partial R}\right)_1 & \left(\frac{\partial V}{\partial L}\right)_1 \\ \left(\frac{\partial V}{\partial R}\right)_2 & \left(\frac{\partial V}{\partial L}\right)_2 \end{bmatrix}^{-1} \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \end{bmatrix} \tag{13}$$

pa se mogu oceniti i merne nesigurnosti korekcija ΔR i ΔL:

$$u_{\Delta R} = \sqrt{a^2 u_{\Delta V1}^2 + b^2 u_{\Delta V2}^2}$$
$$u_{\Delta L} = \sqrt{c^2 u_{\Delta V1}^2 + d^2 u_{\Delta V2}^2} \tag{14}$$

Teorijski gledano, dovoljno je rezervoar baždariti u dve tačke, kako bi se dobile korekcije ΔR i ΔL. Medjutim, ukoliko se baždarenje izvrši u većem broju tačaka, trebalo bi očekivati smanjivanje merne nesigurnosti. Ako bi se rezervoar etalonirao u n tačaka, dobilo bi se $m = n\cdot(n-1)/2$ parova (u prvoj aproksimaciji, međusobno nezavisnih) jednačina, iz kojih se dobija isto toliko parova korekcija ΔR i ΔL. Tada bi bilo opravdano da se za konačne vrednosti korekcija uzmu njihove srednje vrednosti. Time bi se donekle umanjilo dezinformaciono dejstvo slučajnih grešaka merenja, a i nekih sistematskih grešaka koje je teško definisati i manifestuju se kao slučajne, i stekla bi se osnova za ocenu nesigurnosti merenja tipa A.

Imajući u vidu da se odgovarajuće pojedinačne nesigurnosti određivanja vrednosti ΔR_i i ΔL_i mogu međusobno znatno razlikovati, opravdano je, umesto »obične« srednje vrednosti, uzimati takozvanu ponderisanu srednju vrednost. Ponderi $p_{\Delta L,i}$ i $p_{\Delta R,i}$ se određuju na uobičajen način: kao recipročne vrednosti kvadrata mernih nesigurnosti pojedinačnih ΔR_i i ΔL_i. Dakle,

$$\overline{\Delta R} = \sum_{i=1}^{m} p_{\Delta R,i} \Delta R_i = \sum_{i=1}^{m} \frac{\frac{1}{u_{\Delta R,i}^2}}{\sum_{i=1}^{m} \frac{1}{u_{\Delta R,i}^2}} \Delta R_i$$
$$\overline{\Delta L} = \sum_{i=1}^{m} p_{\Delta L,i} \Delta L_i = \sum_{i=1}^{m} \frac{\frac{1}{u_{\Delta L,i}^2}}{\sum_{i=1}^{m} \frac{1}{u_{\Delta L,i}^2}} \Delta L_i \tag{15}$$

dok su odgovarajuće merne nesigurnosti date izrazom:

$$u_{\overline{\Delta R}} = \sqrt{\sum_{i=1}^{m} \left[\frac{\frac{1}{u_{\Delta R,i}^2}}{\sum_{i=1}^{m} \frac{1}{u_{\Delta R,i}^2}} u_{\Delta R,i} \right]^2}$$
$$u_{\overline{\Delta L}} = \sqrt{\sum_{i=1}^{m} \left[\frac{\frac{1}{u_{\Delta L,i}^2}}{\sum_{i=1}^{m} \frac{1}{u_{\Delta L,i}^2}} u_{\Delta L,i} \right]^2} \tag{16}$$

EKSPERIMENTALNI REZULTATI

Sprovedeni su brojni eksperimenti nad simuliranim i realnim podacima dobijenim tokom pregleda rezervoara, i za potrebe ilustracije opisanog postupka biće prikazana dva primera.

Primer 1.

Neka je rezervoar koji treba etalonirati definisan standardom JUS (SRPS) M.Z3.010 i neka su njegove nominalne vrednosti $L_0 = 10{,}8$ m i $R_0 = 1{,}25$ m. Neka su, dalje, za granice grešaka pri merenju parcijalnih zapremina etalonskim protokomerom uzete granice grešaka etalon posude (kojom je protokomer etaloniran), i koje neka iznose 0,02 %, dok greške očitavanja nivoa tečnosti u rezervoaru ne prelaze 0,5 mm.

Simuliraju se rezultati etaloniranja, koji odgovaraju takođe idealnom rezervoaru, ali koji ima dužinu i poluprečnik veće za 10 mm od nominalnih vrednosti L_0 i R_0.

U kojoj meri će predloženi postupak da »otkrije« prave dimenzije rezervoara a time i da uspostavi ispravnu vezu između nivoa i zapremine tečnosti u rezervoaru? Uz koje merne nesigurnosti?

Rezultati dobijeni simulacijom prikazani su u Tabeli 1. Vrednosti t su proizvoljno izabrane ekvidistantne tačke po visini rezervoara. Koristeći se nazivnim vrednostima za poluprečnik rezervoara R_0 i njegovu dužinu L_0, i u skladu sa matematičkim modelom, dobijaju se odgovarajuće zapremine tečnosti V_0. Veličina V predstavlja simulirane rezultate etaloniranja. Veličina Vk predstavlja korigovanu zapreminu, koja se dobija tako što se poluprečnik R_0 i dužina L_0 rezervoara koriguju za opisanim postupkom nađene vrednosti ΔR i ΔL, pa se iz matematičkog modela izračuna nova vrednost zapremine za zadat nivo t.

Iz rezultata etaloniranja u pet tačaka konstituišu se $m = 5 \cdot (5-1)/2 = 10$ međusobno nezavisnih sistema linearnih jednačina sa dve nepoznate, ΔR i ΔL. Njihovim rešavanjem dobija se po m vrednosti za korekcije ΔR i ΔL, čijim se usrednjavanjem dobijaju konačne vrednosti korekcija, $\overline{\Delta R}$ i $\overline{\Delta L}$. Njima su pridružene odgovarajuće merne nesigurnosti $u_{\overline{\Delta R}}$ i $u_{\overline{\Delta L}}$, čije vrednosti iznose:

$$\overline{\Delta R} = 9{,}91 \text{ mm} \; ; \; u_{\overline{\Delta R}} = 0{,}42 \text{ mm} \quad ; \quad \overline{\Delta L} = 10{,}5 \text{ mm} \; ; \; u_{\overline{\Delta L}} = 4{,}3 \text{ mm}$$

Veličina Vk-V predstavlja grešku etaloniranja koja je ostala nakon obrade dobijenih rezultata, a u mernu nesigurnost etaloniranja pod datim uslovima.

Tabela 1. Rezultati etaloniranja, dobijeni simulacijom

t mm	V_0 L	V L	V-V_0 L	Vk L	Vk-V L	u L
250	2613,5	2627,4	13,9	2627,4	0,02	4,6
750	12862,8	12938,8	77,1	12939,8	0,01	9,2
1250	25701,8	25881,3	179,5	25881,1	- 0,24	14,6
1750	38540,8	38869,8	329,0	38868,9	- 0,93	21,3
2250	48790,0	49353,1	563,0	49350,5	- 2,53	30,1

Primer 2.

Opisani postupak sproveden je i nad podacima (dobijenim ljubaznošću Kontrole mera i dragocenih metala Novi Sad) sa stvarno izvršenog periodičnog pregleda rezervoara, a rezultati su dati u tabeli 2. Sada veličine t i V prikazuju realne podatke dobijene etalonskim instrumentima tokom etaloniranja. Veličina V_0 je ponovo ona izračunata *apriori*, na osnovu nominalnih vrednosti dužine i prečnika rezervoara. Opis ostalih veličina u tabeli 2. odgovara onima iz tabele 1. Etaloniranje je obavljeno u 20 tačaka; znači, veličina m sada ima vrednost $20 \cdot (20-1)/2 = 190$. Rezultat korekcija, sa pridruženim nesigurnostima je:

$$\overline{\Delta R} = 14{,}7 \text{ mm} \; ; \; u_{\overline{\Delta R}} = 0{,}1 \text{ mm} \quad ; \quad \overline{\Delta L} = -613 \text{ mm} \; ; \; u_{\overline{\Delta L}} = 1{,}1 \text{ mm}$$

Analizirajući dobijene vrednosti veličine Vk-V treba uočiti izrazito izraženu sistematsku komponentu greške Vk koja se manifestuje negativnim predznakom do približno trećine rezervoara, koji prelazi u pozitivni za ostatak do punog rezervoara. Dodatna ispitivanja ukazuju na činjenicu da se ovde sada radi o rezervoaru koji nije postavljen sasvim horizontalno, pa nisu ispunjeni svi uslovi iz početnih predpostavki. Uprkos tome, primetne su znatno manje greške kod korigovanih rezultata, u odnosu na nekorigovane.

Šta se, ustvari, radi ovim postupkom? Korekcija poluprečnika i dužine rezervoara nije sama sebi cilj i ne mora da predstavlja njihove realne vrednosti. Ona predstavlja samo pomoćno sredstvo za optimiziranje (minimizovanje) greške etaloniranja Vk-V. *Postupak na svojevrstan način uzima u obzir i usrednjava zajedničko parazitno delovanje uticajnih veličina, bez potrebe da se svaka od njih pojedinačno kvantifikuje*.

Tabela 2. Rezultati etaloniranja, dobijeni na osnovu stvarnih rezultata merenja

t mm	V_0 L	V L	V-V_0 L	Vk L	Vk-V L	u L
65	351,6	99,9	-251,7	332,3	-232,4	2,4
139	1093,7	619,3	-474,4	1034,2	-415,0	3,4
177	1566,8	1088,6	-478,2	1481,9	-393,3	3,8
252	2644,5	2137,0	-507,5	2501,9	-364,9	4,5
342	4145,9	3609,8	-536,1	3923,9	-314,1	5,2
431	5813,3	5247,3	-566,0	5503,9	-256,6	5,7
541	8079,2	7463,9	-615,3	7652,5	-188,6	6,3
663	10806,7	10159,7	-647,0	10240,8	-81,1	6,8
803	14152,7	13454,5	-698,2	13418,8	35,7	7,3
976	18515,9	17748,0	-767,9	17567,5	180,5	7,7
1162	23375,7	22500,8	-874,9	22194,8	306,0	8,1
1346	28238,9	27190,9	-1048,0	26833,1	357,8	8,3
1537	33222,1	31981,0	-1241,1	31591,1	384,9	8,5
1714	37667,4	36274,0	-1393,4	35857,2	416,8	8,5
1860	41126,0	39628,4	-1497,6	39184,4	444,0	8,5
1978	43920,3	42323,9	-1596,4	41885,0	438,9	8,5
2102	46227,5	44520,2	-1707,3	44128,9	391,3	8,4
2204	48050,6	46217,1	-1833,6	45918,5	298,6	8,4
2300	49525,3	47614,7	-1910,6	47388,5	226,2	8,5
2392	50652,7	48613,3	-2039,4	48548,9	64,4	8,6

ZAKLJUČAK

Opisan postupak prestavlja jednu vrstu sinteze dve metode etaloniranja rezervoara: geometrijske i volumetrijske. Volumetrijskom metodom se uspostavljaju parovi vrednosti (nivoa i zapremina) dobijeni etalonskim instrumentima koji dalje služe da se izvrši svojevrsna identifikacija parametara i da se matematički model snabde optimalnim podacima. Dodatne analize ukazuju na to da se zadovoljavajući rezultati dobijaju i sa znatno manje tačaka baždarenja nego što je to propisano. Kao sporedni rezultat, dobija se merna nesigurnost svakog rezultata etaloniranja. Raspolažući podešenim modelom, nije više neophodno da se koriste tabele zapremina – zapremina tečnosti u rezervoaru se dobija direktnim računom (što, na primer, isključuje grešku interpolacije rezultata). Dalji razvoj opisanog postupka može biti usavršen uvođenjem još jedne karakteristike objekta etaloniranja – njegovim nagibom – a da se ne odstupi od osnovnog koncepta: *doći do pouzdanog matematičkog modela rezervoara koji se etalonira i koristiti model i za praktična merenja i izračunavanja.*

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[8] *Međunarodni rečnik osnovnih i opštih termina u metrologiji*, Savezni zavod za mere i dragocene metale, Beograd 1996.

[9] *JUS (SRPS) M.Z3.010*, Službeni list SFRJ br. 9/80.

Прилог 4 - Фотокопије диплома и уверења о докторирању

РЕПУБЛИКА СРБИЈА

УНИВЕРЗИТЕТ У НОВОМ САДУ
ФАКУЛТЕТ ТЕХНИЧКИХ НАУКА, НОВИ САД

Оснивач високошколске установе НАРОДНА СКУПШТИНА НАРОДНЕ РЕПУБЛИКЕ СРБИЈЕ је издала ФАКУЛТЕТУ ТЕХНИЧКИХ НАУКА, НОВИ САД дозволу за рад ИВ бр. 238 од 18. маја 1960. године.

ДИПЛОМА

Александар Миленко Радоњић

Рођен 30.09.1977. год. у месту Зеница, општина Зеница, Босна и Херцеговина, завршио је студије у трајању од пет година на Факултету техничких наука, на одсеку: Електротехника и рачунарство - Електроника и телекомуникације - Телекомуникације, са просечном оценом 8,06 (осам и 06/100) у току студија одбраном дипломског рада 18.03.2003. године и стекао звање Дипломирани инжењер електротехнике и рачунарства.

На основу члана 127. Закона о високом образовању ("Сл. гласник" Р.С. бр. 76/2005.), дана 29.12.2006. године извршено је усклађивање стеченог назива са интегрисаним основним академским и дипломским академским - мастер студијама на студијском програму: Енергетика, електроника и телекомуникације - Комуникационе технологије и обрада сигнала са постигнутим укупним бројем ЕСПБ бодова 300 (триста) и на основу тога му се издаје ова диплома о стеченом високом образовању и академском називу

ДИПЛОМИРАНИ ИНЖЕЊЕР
ЕЛЕКТРОТЕХНИКЕ И РАЧУНАРСТВА - MASTER

из области ЕЛЕКТРОТЕХНИЧКОГ И РАЧУНАРСКОГ ИНЖЕЊЕРСТВА

Број: 012-МЕ-109/Е, 01.03.2008. године
у Новом Саду

Број из евиденције о издатим
дипломама и додацима диплома
82-2006/07, 01.03.2008. год.

(М.П.)

ДЕКАН
проф. др Илија Ћосић

РЕКТОР
проф. др Радмила Маринковић - Недучин

СРБИЈА И ЦРНА ГОРА
РЕПУБЛИКА СРБИЈА

ФАКУЛТЕТ ТЕХНИЧКИХ НАУКА НОВИ САД
УНИВЕРЗИТЕТ У НОВОМ САДУ

ДИПЛОМА

О СТЕЧЕНОМ ВИСОКОМ ОБРАЗОВАЊУ

РАДОЊИЋ Миленко АЛЕКСАНДАР

Рођен 30. 09. 1977. у месту Зеница, општина Зеница, Босна и Херцеговина, уписан школске 2001/2002. године, а дана 28. 12. 2004. године завршио је студије на Факултету техничких наука, из области електротехнике и рачунарства, одсек: електротехника и рачунарство, смер: електроника и телекомуникације, усмерење: инструментације са општим успехом 8,21 (осам и 21/100) у току студија и оценом 10 (десет) на дипломском испиту.

Просечна оцена са дипломским радом је 8,26.

На основу тога издаје му се ова диплома о стеченом високом образовању и стручном називу

ДИПЛОМИРАНИ ИНЖЕЊЕР ЕЛЕКТРОТЕХНИКЕ И РАЧУНАРСТВА

Редни број из евиденције о издатим дипломама 012-3148/Е

У Новом Саду, 27. 01. 2005.

(М.П.)

ДЕКАН
проф. др Илија Ћосић

РЕКТОР
проф. др Радмила Маринковић - Недучин

УНИВЕРЗИТЕТ У НОВОМ САДУ
ФАКУЛТЕТ ТЕХНИЧКИХ НАУКА

Трг Доситеја Обрадовића 6, 21000 Нови Сад, Република Србија
Деканат: 021 6350-413; 021 450-810; Централа: 021 485 2000
Рачуноводство: 021 458-220; Студентска служба: 021 6350-763
Телефакс: 021 458-133; e-mail: ftndean@uns.ac.rs

Број уверења: ФТН-012-01036
Број досијеа: ДР 29/2006
Нови Сад, 21.11.2013.

На основу члана 161. Закона о општем управном поступку („Сл. лист СРЈ“ бр. 33/97, и 31/2001) и („Сл. гласник РС“ бр. 30/2010), у складу са чланом 99. Закона о високом образовању („Сл. гласник РС“ бр. 76/05, 100/07 аутентично тумачење 97/08 и 44/2010) и члана 145. Статута Факултета техничких наука, издаје се:

У В Е Р Е Њ Е

О СТЕЧЕНОМ ВИСОКОМ ОБРАЗОВАЊУ НА ДОКТОРСКИМ АКАДЕМСКИМ СТУДИЈАМА

РАДОЊИЋ (МИЛЕНКО) АЛЕКСАНДАР

Рођен 30.09.1977. године у месту Зеница, Босна и Херцеговина, уписан школске 2006/2007 године, а дана 21.11.2013. завршио је докторске академске студије трећег степена, из области: Електротехничко и рачунарско инжењерство, студијски програм: Енергетика, електроника и телекомуникације.

Кандидат је завршио студије у трајању од три године са постигнутих 180 (сто осамдесет) ЕСПБ и са просечном оценом 9,71 (девет и 71/100).

На основу тога издаје му се ово уверење о стеченом високом образовању и научном називу ДОКТОР НАУКА - ЕЛЕКТРОТЕХНИКА И РАЧУНАРСТВО.

Уверење се издаје на лични захтев и може се употребити до издавања дипломе под бројем 012-ДС-8/Е1.

Декан

Проф. др Раде Дорословачки