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MEASUREMENT UNCERTAINTY ANALYSIS OF CROATIAN RESISTANCE STANDARDS

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Abstract: The primary electromagnetic laboratory in Croatia maintains resistance standards from 1 mΩ to 100 MΩ. The three of these standards (1 Ω, 10 kΩ and 10 MΩ) are calibrated each two years at PTB, Germany. The traceability of other resistance standards is accomplished by two standard resistance comparison methods using digital voltmeters. This paper gives the measurement uncertainty analysis of the Croatian resistance standards.

Keywords: measurement uncertainty, traceability, resistance standards

1. CROATIAN RESISTANCE STANDARDS

One of the main tasks of Primary Electromagnetic Laboratory (PEL) in Croatia is to ensure a system of international traceability for its standards [1]. The preferred way of resistance standard calibration at PEL is self-developed method using two digital voltmeters, which are measuring voltage drops on serially connected standard resistors. The method is also used for calibration purposes of all types of resistors, decades, shunts and resistance measuring devices.

Croatian primary resistance standard group currently consists of standard resistors ranging from 1 mΩ to 100 MΩ. PEL has also acquired two additional resistors: 1 Ω Thomas type and 10 kΩ type L&N donated from Physikalisch-Technische Bundesanstalt (PTB). These two resistors are calibrated every two years at PTB and have well known time drift. The resistance standard of 1 Ω has changed less than 1,5 μΩ/Ω in over 30 years (Fig. 1.). The goal for PEL is to lengthen the calibration intervals and thus lower the calibration cost, by establishing the history for its standards over several years in order to predict the behaviour of standards (drift) between calibrations at PTB. Also, as only three of the standards are calibrated at PTB, an internal traceability system must be provided for other standards. Also an additional experimental group of high-ohm standards of 10 GΩ and 1 TΩ has been designed for the purpose of developing high-ohm comparison method.

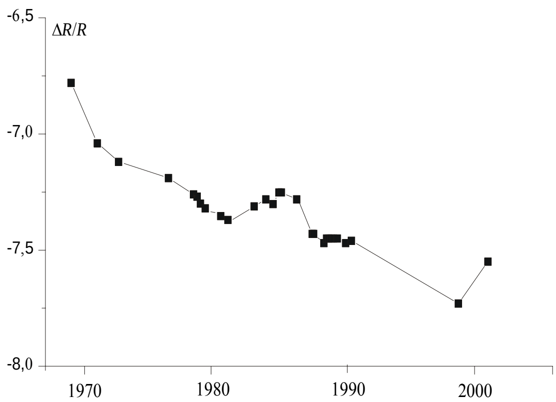

Fig. 1. 1 Ω resistance standard history.

Most of PEL standards (1mΩ to 10 kΩ, and three other 1 Ω resistance standards) are placed in a specially constructed oil bath in which they are held at the temperature of 23±0,02 °C. A new oil bath with similar characteristics has been built for maintainance of two reference standard resistors (1 Ω and 10 kΩ) donated from PTB. The rest of standards between 10 kΩ and 100 MΩ are held at air-conditioned laboratory temperature of 23±0,5 °C. The standards of 10 kΩ, 100 kΩ, 1 MΩ and 10 MΩ are Fluke 742A type, while 100 MΩ resistor is Hamon type resistor designed and made at PEL. It is made of 100 metal-film resistors, which can be connected paralelly to produce 10 kΩ.

1.1. Standard Resistance Comparison method used at PEL

For establishing internal traceability for standard resistors ranging from 1 mΩ to 100 MΩ two methods of comparison with the nominal ratio of 1:1 and 1:10 have been developed at PEL, using two digital voltmeters (DVM) with 8 ½ digits, (Hewlett Packard model 3458A). The resistors are scaled down from 1 Ω to 1 mΩ, and from 1 Ω to 10 kΩ. The resistors up to 100 MΩ are scaled from 10 kΩ [1]. Comparison method in high-ohm measurement field is also based on standard resistor comparison method using two precise digital voltmeters with 8 ½ digits [5].

2. MEASUREMENT UNCERTAINTY

The measurement uncertainty is calculated for each standard resistor separately following Guide to the expression of uncertainty in measurements [2]. The uncertainty budget can be divided in two parts:

1. The uncertainty of standard and unknown resistor which includes:

a) *Uncertainty of calibrated value of standard resistor* – this uncertainty is lowest for the 1 Ω and 10 kΩ standard resistors, as they are calibrated at PTB (PTB calibration uncertainty of 1 Ω standard is lower than 0,01 μΩ/Ω).
b) *Drift of standard resistor* – this uncertainty depends on annual drift of standard resistors, and historical data available for each resistor (Fig. 1. exhibit the 30 years historical data of 1 Ω standard resistor donated from PTB). This uncertainty is included only after some time has passed since the last calibration of resistor, usually two months, but also depends on historical data and resistor quality. The oldest standard resistor in the group is 1 Ω Siemens type standard produced in 1924, unfortunately, it has a large annual drift, and poor historical data.
c) *Residual temperature effects on resistance of standard and unknown resistors* – all the standards have temperature coefficients well known. The temperature is logged during measurement and all the standard resistor calibration values are recalculated to 23 °C. This uncertainty is only due to temperature measurement uncertainty.
d) *residual power (load) effects on resistance of standard and unknown resistors* – as each standard is calibrated at different currents, the standards have different power dissipation, but always less than 100 mW. The resistors are recalculated taking into account load effects, so that each calibrated standard resistor value has the same dissipation [3]. Only the measurement uncertainty of power load coefficient calculation is included in the final measurement uncertainty calculation.

2. The uncertainty of comparison and scaling with ratios of 1:10 and 10:1, which includes:

a) *DVM linearity errors* – DVM linearity error is determined using modified Hamon divider. It is measured only for 1:10 ratio measurement, because for 1:1 ratio measurements, all DVM errors are cancelled out [4]. Only the uncertainty of DVM linearity error determination is included in the final measurement uncertainty calculation.
b) *Random errors of measurement* – The random errors are around 0,01 μΩ/Ω for the voltage ranges of 1V and 10V, and for all resistance standards from 100 mΩ to 100 kΩ. The voltmeters used for the measurements are Hewlett Packard 3458A.

2.1. Ring comparison

Here, a part of our calibration chain will be presented, namely 1 Ω and 10 MΩ standard resistor ring comparison. The standards are compared in succession, and to complete the ring comparison, the last resistor is again compared to the first resistor to check for possible errors as shown in Table 1. Then a comparison ratio correction can be calculated. The results are given in μΩ/Ω of the nominal ratios, where:

$$v = -(r_{12}+r_{23}+r_{34}+r_{41})/4 \qquad (1)$$

is correction of the ratios. The applied voltage was 100 mV.

Table 1. Ring comparison of 1 Ω standard resistors

Date	r_{12}	r_{23}	r_{34}	r_{41}	v/μΩ/Ω
04.97	-94,322	28,486	95,934	-30,101	0,0007
11.97	-95,709	28,531	102,12	-34,973	0,0065
04.98	-95,213	28,246	98,033	-31,153	0,0217
12.98	-96,748	28,284	105,67	-37,201	-0,0021
11.99	-97,786	28,183	109,67	-40,052	-0,0042
02.00	-97,059	27,952	105,75	-36,615	-0,0067

Uncertainty of the new method for comparing high ohm resistors due to errors of its voltage measuring devices has been also performed by ring comparison of several high-stable resistances of the same value. For that purpose three well-balanced Tetrinox 1 MΩ resistors have been chosen and placed in sealed air-thermostat with temperature deviation less then 50 mK. Procedure is again based on consecutive 1:1 comparison of two resistances in sequence and stops with comparison of the last resistance with the first one. The greatest part of device systematic errors is nullified, and only uncompensated errors will cause relative error of the ratios above. The ring comparison error v is calculated by multiplication of the terms from, since this time the comparison results are given in absolute values. All ratio measurements are performed in the same conditions. If the relative ratio errors are of systematic type, they will not much differ one from another and will cause good repeatability of v. However, if repeatability of ring comparison error is not a case, limits of error for 1:1 comparison is expressed by means of standard deviation of v from a number of performed ring comparisons. The results of five 1 MΩ ring comparisons are shown in Table 2.

Table 2. Results of ring comparison of three 1 MΩ resistors for the purpose of method uncertainty estimation.

N	r_{12}	r_{23}	r_{31}	v / μΩ/Ω
1.	1,0000003	0,9999976	1,0000022	0,1
2.	1,0000003	0,9999981	1,0000017	0,1
3.	1,0000004	0,9999978	1,0000020	0,2

4.	1,0000004	0,9999978	1,0000021	0,3
5.	1,0000003	0,9999976	1,0000020	–0,1

From results given in Table 2. the mean value of *v* = 0,12 μΩ/Ω and related standard deviation of 0,15 μΩ/Ω is calculated. Conclusion is that uncertainty of 1:1 comparison method owing to voltage measurement is less then 0,5 μΩ/Ω and can be practically neglected when resistances of GΩ and greater are compared.

2.2. Total uncertainty calculated for each standard resistor

The measurement uncertainty budget for each of PEL resistance standards producing total uncertainties is given in Table 3. As the best standard of PEL is 1 Ω standard, the lowest uncertainty is achieved for standards from 100 mΩ up to 1 kΩ. PEL plans to extend its resistance calibration capabilities to the range of 1 TΩ and to improve the existing methods.

Table 3. Measurement uncertainty of PEL standards

Resistance standard	Uncertainty (k=2)
1 mΩ	10,22 μΩ/Ω
10 mΩ	2,10 μΩ/Ω
100 mΩ	0,59 μΩ/Ω
1 Ω	0,55 μΩ/Ω
10 Ω	0,65 μΩ/Ω
100 Ω	0,63 μΩ/Ω
1 kΩ	0,67 μΩ/Ω
10 kΩ	2,20 μΩ/Ω
100 kΩ	2,20 μΩ/Ω
1 MΩ	2,21 μΩ/Ω
10 MΩ	2,25 μΩ/Ω
100 MΩ	10,26 μΩ/Ω

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