12th IMEKO TC4 International Symposium
Electrical Measurements and Instrumentation
September 25−27, 2002, Zagreb, Croatia

RESISTANCE MEASUREMENT CAPABILITIES OF THE PRIMARY ELECTROMAGNETIC LABORATORY

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Abstract − Ensuring a system of international traceability of its standards is the main task of Primary Electromagnetic Laboratory (PEL). PEL has established resistance traceability for the group of resistance standards in the range of 1 mΩ to 100 MΩ. 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. Another method for calibrating high-ohm resistance standards is currently being developed to extend the resistance measuring capability of PEL to the GΩ range.

Keywords: resistance measurement method, traceability, digital multimeter.

1. RESISTANCE STANDARDS

Croatian primary resistance standard group currently consists of standard resistors ranging from 1 mΩ -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 regularly calibrated in PTB and have well known time drift. The resistance standard of 1 Ω has changed less than 1,5 ppm in over 30 years (Fig. 1).

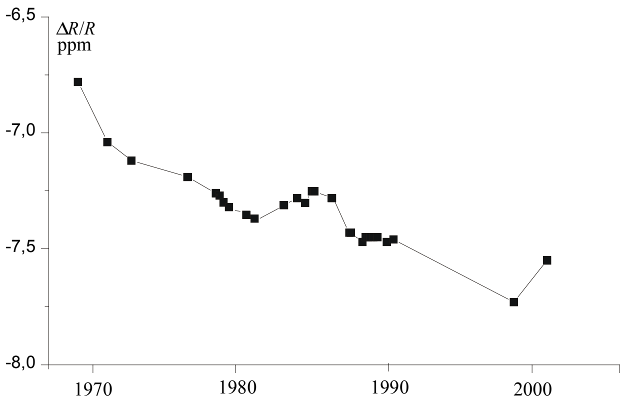

Fig. 1. 1 Ω resistance standard history.

Some of PEL standards (1mΩ to 10 kΩ - VEB type) are placed in a specially constructed oil bath in which they are held at the temperature of 23 °C. The same oil bath contains three other 1 Ω resistance standards of types Siemens&Halske, Leeds&Northrup and Guildline (Fig. 2).

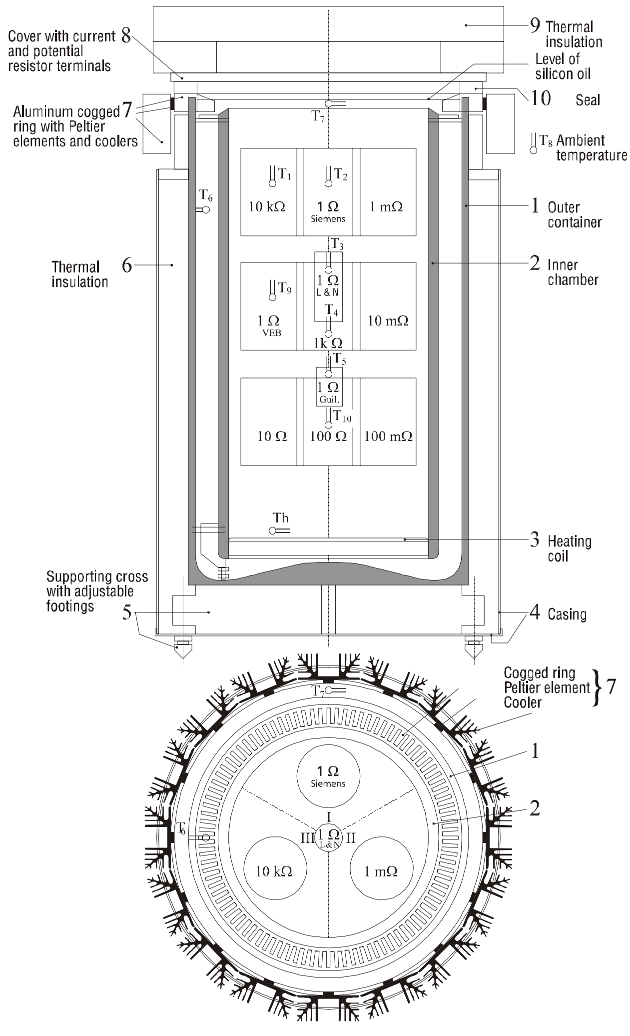

Fig. 2. Oil bath UTEO-94

The rest of standards are held at air-conditioned laboratory temperature. Those are the resistors between 10 kΩ and 100 MΩ, some taken from the group of commercially available resistors, and others from the group of our own production. The traceability of PEL resistance is shown in Fig. 3. A new oil bath UTEO-97 has been built for maintainance of two standard resistors (1 Ω and 10 kΩ) donated from PTB.

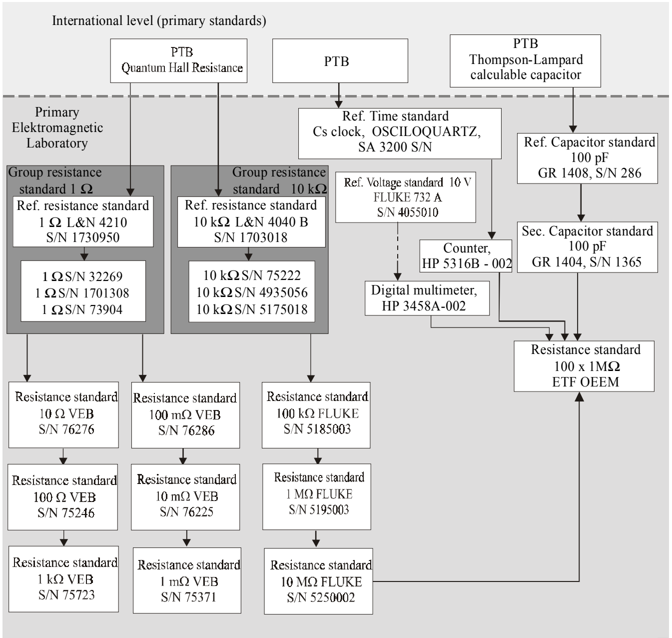

Fig. 3. Traceability of PEL resistance standards

2. RESISTANCE COMPARISON METHOD

A number of laboratories around the world are using simple DVM method for calibration of resistors. Since introduction to the market, the high-precision 8 ½ digits voltmeters have been extensively used even for the most precise measurements, formerly exclusively done by the more expensive direct current comparator bridges [1,2]. For establishing internal traceability for standard resistors ranging from 1 mΩ to 100 MΩ two methods of comparison of the nominal ratio 1:1 and 1:10 have been developed, using two digital multimeters (DVM) with 8 ½ digits, (Hewlett Packard model 3458A) [3,4,5]. As seen on Fig. 4., each DVM (designated as HP1 and HP2) is measuring voltage drop on one standard resistor.

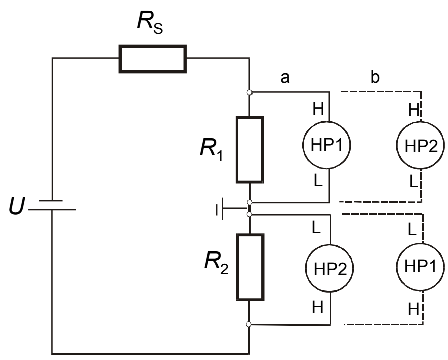

Fig. 4. Measurement method using two voltmeters, one parallel to each resistor. Each of DVMs designated as HP1 and HP2 is measuring voltage drop across one resistor. In measurement b) (dotted line) the voltmeters change positions

DVMs are connected with IEEE-488 bus to the PC computer, and then triggered simultaneously using GET (Group Execute Trigger) command from the PC to avoid errors by drifting current during measurements. The DVMs can be connected differently as seen in Fig. 5.

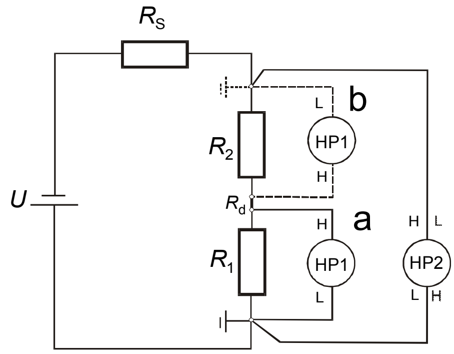

Fig. 5. Measurement method where HP1 is measuring the voltage drop across the resistor R_1 and then on R_2, while the HP2 is measuring total voltage supplied to both resistors, and changes only 'high' and 'low' position in second measurement (b), so both voltmeters always have 'low' on the same potential and always grounded. The doted lines indicate second measurement (b)

The measurements in both methods are repeated with changed polarity of the current to avoid thermoelectric and offset voltages, and also with interchanged DVM's to average the DVM readings. The method according to Fig. 4. is more convenient for measuring low-Ohm resistors because of relatively small influence of DVM's high input resistance (R_{V1} > 10 GΩ) in relation to the measured values. The method according to Fig. 5 gives better results for measuring high-ohm values because the shunting errors are practically negligible in this method. The measurement process is automated by a personal computer equipped with GPIB-488 card for operating the voltmeters, and by a specially built PC controlled apparatus for changing the polarity of the current and changing the position of voltmeters. The self-developed automated data acquisition software has been developed using the Pascal programming language. In contrast to commercially available software, it offers the necessary flexibility to operator, which includes measurement set-up, such as range, number of samples and duration of DVM integration time. It also builds the calibration database, records the enviromental conditions during measurement, performs the statistical analysis including measurement uncertainty calculation following Guide to the expression of uncertainty in measurement, predicts the values of the standards on a given day using the past calibration data, and creates print-ready calibration report with all relevant data. To establish the traceability chain, and to scale the resistors two additional methods have been developed. One is used to determine the DVM linearity errors using modified Hamon device [4], and the other to obtain the standard resistor load coefficients [7].

3. MEASUREMENT UNCERTAINTY

The measurement uncertainty is calculated for each standard separately. The uncertainty budget can be divided in two parts – the uncertainty of referent resistor which includes uncertainty of PTB calibration, its value prediction and the uncertainty of temperature and load unbalances of compared resstors, and the uncertainty of comparison and scaling with ratios of 1:10 and 10:1 which includes DVM linearity error and random errors of measurement. The measurement budget for each of PEL resistance standards is described in detail [6], producing total uncertainties given in Table 1. PEL plans to extend its resistance calibration capabilities to the range of 1 TΩ, and currently investigates method according to the Fig. 5 for that purpose.

Table 1. Uncertainty of PEL standards

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

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