# MEASUREMENTS FOR DC CHARACTERIZATION OF LOW RESISTANCE STANDARDS IN BIM

*R. E. Hadzhistoykova, T. S. Konstantinova*

*Abstract:* This paper describes a measurement system for DC Characterization of Low Resistance Standards (below 0,1 Ω) in BIM-NCM in wide current level (from 1 A to 100 A). DC characterization includes direct resistance measurements, temperature coefficient measurements and current level dependence measurement (power coefficient) with uncertainties at ppm level.

*Key-Words:* low resistance standards, power coefficient, temperature coefficient.

## 1. Introduction

For the resistance standards (shunts), which are demand for using in larges current range it is necessary to know their current level dependence and power coefficient of resistance (PCR).

The resistance of all resistors varies with temperature. This variation is characterized by temperature coefficient of resistance (TCR). Its influence is more significant especially by air cooled resistance standards. TCR is used for making of corrections and/or for uncertainty calculation.

In BIM-NCM there is DC resistance measurement system in wide resistance range (from 0,0001 Ω up to 100 TΩ) in high accuracy, but mainly for calibration of the resistance standards at one current level. Some of standard resistors are calibrated at wider band current level.

Based on this system and the knowledge of method, described in [1], in NCM was build set-up for TCR and PCR measurement of low resistance standards, applied for the old designed foil shunts and Fluke A40A.

## 2. Measurement Set-up

The measurement set-up is based on measurement of ratio of output voltages of the tested and the reference standard by dual channel multimeter. Thus, the resistance of tested standard is calculated by:

$$R_X = \frac{U_X}{U_S} \cdot R_S \tag{1}$$

In BIM-NCM the following equipment is available: Multimeter 1281 Wavetek for voltage measurements, which have math function for immediately calculation of the ratio, transconductance amplifiers C&H 8100 and Wavetek 4600 for DC current source, which are driven by high accuracy voltage source Wavetek 4808, stable thermostatic oil bath (Guildline 9730 CR), temperature-stabilized air bath (MI 9300) and set of working resistance standards.

There are used two working resistance standards 0,0001 Ω and 0,001 Ω, which cover the current range from 1 A to 100 A.

### 2.1. Set of resistance standards

The reference resistance standards are oil filed and are placed in the oil bath with uncertainty contribution during the measurements 0,004 °C.

Verification of working standards is made by comparison to the reference standard resistors 1 Ω (P321) by using a direct current comparator bridge MI 6010C. Traceability is provided by calibrations of 1 Ω standard resistors at BIPM and subsequent step-down using the DCC Bridge. Thus some of the working standard could be calibrated in current level hundred times bigger than reference standard resistor. They have long history in time, so for the calculation of the reference value $R_s$, correction from the regression is used. For the measurements the working standards are so selected that their measurement currents cover the maximum currents of the shunts.

*Table 1 Parameters of working standards*

| Nominal value | Current range | Type | Producer |
|---|---|---|---|
| 0,0001 Ω | 30 A – 100 A | H&B | Hardman and Brown |
| 0,001 Ω | 1 A -30 A | Metra | Metra |

Dependence of the working resistance standards on current level was taken from their calibration certificate, shown on Fig 1 and Fig. 2.

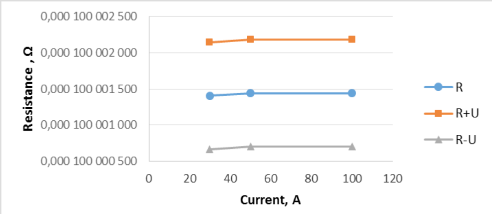


*Fig. 1 H&B resistance standard level dependence*

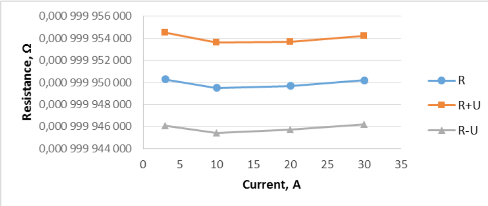


*Fig. 2 Metra resistance standard*

## 2.2. Level dependence (power coefficient) measurement

The new set-up was applied for measurements of all NCM high AC-DC current shunts: BEV manganin foil shunts – old design V16/40A/8 and V16/80A/8, Fluke A40A - 20 A and 10 A.

The working standards were placed at room temperature or in the oil bath. All shunts, especially 40A and 80 A were warmed up more than two hours.

The shunts are air cooled, thus stability of ambient temperature in laboratory was important. We achieved stability less than ± 1°C during the measurements. The uncertainty contribution due to temperature stability was taken into account, 0,35 °C.

The level dependence of foil shunts is shown on Fig. 3 to Fig. 4.

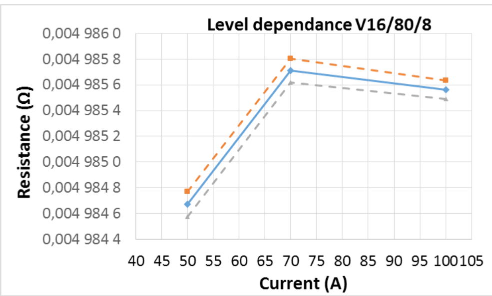


*Fig. 3 Level dependence of 0,005 Ω/ 80 A BEV shunt*

The typical level dependence of current shunts Fuke A40A is shown on Fig. 5.

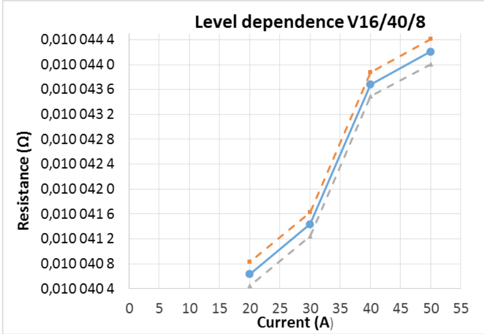


*Fig. 4 Level dependence of 0,01 Ω/ 40 A BEV shunt*

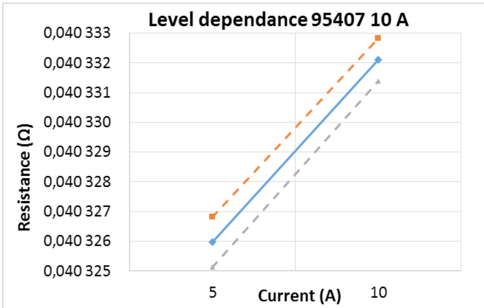


*Fig. 5 Level dependence of 10 A Fluke A40A shunt*

The shape of the characteristic can be monotonous (nearly linear half of the nominal current) and/or near of the apex as shown on Fig 3.

The power coefficient PCR is calculate according [1] as:

$$PC_R = \frac{\Delta R}{\Delta P} \quad , \qquad (2)$$

where $\Delta R$ is change of the resistance in power interval $\Delta P$.

The power coefficient of measured shunts is calculated in different current ranges 75 % - 125 % and 50 % - 100 % of nominal current. Foil shunts have PCR less than ± 32 ppm/W and Fluke shunts less than 69 ppm/W.

If resistance standard is used in wide current range whole level dependence should be verified.

## 2.3 Temperature dependence (temperature coefficient) measurements

NCM shunts were tested on ambient temperature dependence. These measurements were carried out at 1/10 and 1/2 of nominal current to reduce the warming of shunt due to passing current. In addition measurements at nominal current are done.

The shunts are warmed up at lower current. The temperature range was from 18 °C to 30 °C.

The working standards were placed in the oil bath. The tested BEV foil shunts were placed in the laboratory with uncertainty contribution due to temperature 0,08 °C. The Fluke A40A shunts - in the temperature-stabilized air bath (MI 9300) with uncertainty contribution 0,012 °C. DC current sources were transconductance amplifiers C&H 8100 and Wavetek 4600.

Dependence R(T) of BEV 0,01 Ω and 0,005 Ω are presented on Fig. 6 and 7 .is relative error; X is true value; Xm is average measured value.

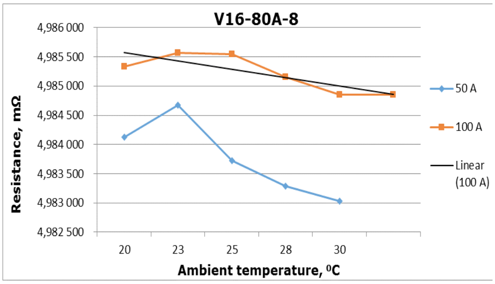


*Fig. 6 R(T) characteristic of 0,005 Ω BEV shunt*

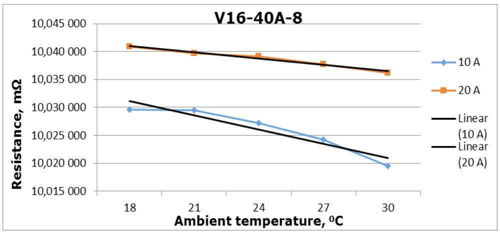


*Fig. 7 R(T) characteristic of 0,010 Ω BEV shunt*

Typical R(T) characteristic of Fluke A40A shunts are presented on Fig. 8.

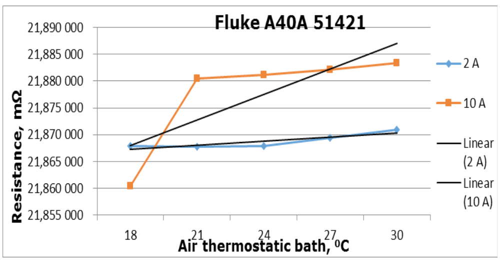


*Fig. 8 R(T) characteristic of Fluke A40A/ 20A*

The temperature coefficient TRC is calculated in accordance with [1]:

$$TC_R = \frac{\Delta R}{\Delta T}, \quad (3)$$

where $\Delta R$ is change of resistance in temperature interval $\Delta T$.

Measured foil shunts have TRC in the range from -13 ppm/°C to - 44 ppm/°C. For current less than 1/2 of nominal current TRC is -110 ppm/°C, which means that shunt should not be used by such current.

Fluke A40A shunts TRC are in the range from 7 ppm/°C to 67 ppm/°C (1/10 of nominal current) and from 21 ppm/°C to 105 ppm/°C (1/2 of nominal current or nominal current).

## 3. Uncertainty calculation

The mathematical model for calculation of DC resistance of the tested shunts is as follows:

$$R = \left[R_s + \delta R_{dr} + R_s.\alpha.\left(\bar{t} - t_{cal} + \delta t\right)\right] r_c.\bar{r}. - \delta R_t \quad (4)$$

where

$R_s$ – resistance value of the working standard;

$\bar{r}$ – estimation of ratio of output voltages;

$\delta R_{dr}$ – estimation of the working standard drift since last calibration;

$\bar{t}$ - estimation of temperature in the oil bath or room temperature;

$t_{cal}$ – calibration temperature of the working standard;

α - temperature coefficient of the working standard

$\delta t$ - correction due to the thermometer measurements ,

$\delta R_t$ – correction of the changes of shunt resistance with temperature;

$r_c$ – correction factor of DMM Wavetek 1281 specifications.

Combined uncertainty is calculated as:

$$u^2(R) = c^2(R_s)\cdot u^2(R_s) + c^2(R_{dr})\cdot u^2(R_{dr}) +$$
$$c^2(\propto)\cdot u^2(\propto) + c^2(\bar{t})\cdot u^2(\bar{t}) + c^2(\delta t)\cdot u^2(\delta t) +$$
$$c^2(\bar{r})\cdot u^2(\bar{r}) + c^2(r_c)\cdot u^2(r_c) + c^2(\delta R_t)\cdot u^2(\delta R_t)\ , (5)$$

where sensitivity coefficients are:

$c(R_s) = r_c.\bar{r}.[1+\alpha(\bar{t} - t_{cal} + \delta t)];$

$c(\delta R_{dr}) = r_c.\bar{r};$

$c(\bar{t}) = c(\delta t) = R_s.\ \alpha.\ r_c.\ \bar{r};$

$c(r_c) = [R_s + \delta R_{dr} + R_s.\alpha.(\bar{t} - t_{cal} + \delta t)].\ \bar{r};$

$c(\bar{r}) = [R_s + \delta R_{dr} + \delta R_v + R_s.\alpha.(\bar{t} - t_{cal} + \delta t)].r_c;$

$$c(\delta Rt) = -1. \qquad (6)$$

Expanded uncertainties for $k$=2, for air cooled shunts, contribution to TRC are shown in Table 2.

*Table 2.*

| Shunt type | Nominal value, Ω | Current, A | Expanded uncertainty, ppm |
|---|---|---|---|
| V16/80A/8 | 0,005 | 50 | 13 |
| | | 100 | 12 |
| V16/40A/8 | 0,01 | 10 | 30 |
| | | 20 | 18 |
| 51421 | 0,022 | 2 | 10 |
| | | 10 | 10 |
| 95407 | 0,040 | 1 | 23 |
| | | 10 | 6 |
| 315001 | 0,021 | 2 | 11 |
| | | 10 | 13 |
| 3255000 | 0,041 | 1 | 20 |
| | | 10 | 6 |
| 9060004 | 0,047 | 1 | 23 |
| | | 10 | 12 |

The analysis of realized measurements shown that most significant influences (except working resistance standard calibration and drift) are temperature influence and standard deviation of measured voltage ratio.

Combined uncertainty of temperature coefficient measurements is calculated from (3) as:

$$u^2(TC_R) = c^2(\Delta R)\cdot u^2(\Delta R) + c^2(\Delta T)\cdot u^2(\Delta T)\ , \qquad (7)$$

where contribution of $\Delta R$ is calculated as

$$u^2(\Delta R) = u^2(R_1) + u^2(R_2)\ , \qquad (8)$$

where $u(R_1)$ and $u(R_2)$ are uncertainties of shunt resistance calculated from (5),

Contribution of $\Delta T$ is equal to

$$u^2(\Delta T) = u^2(T_1) + u^2(T_2)\ , \qquad (9)$$

where $u(T_1)$ and $u(T_2)$ are calculated from calibration certificate the used thermometer and/or thermometer specification type Pt100.

Sensitivity coefficients of (7) equate:

$$c(\Delta R) = \frac{1}{\Delta T}\ ,\ c(\Delta T) = -\frac{\Delta R}{\Delta T^2}\ , \qquad (10)$$

Expanded uncertainty for $k$=2 of measured shunts TCR were less than 12 ppm.

Combined uncertainty of power coefficient measurements is calculated from (2) as:

$$u^2(PC_R) = c^2(\Delta R)\cdot u^2(\Delta R) + c^2(\Delta P)\cdot u^2(\Delta P)\ , \qquad (11)$$

where sensitivity coefficients equate:

$$c(\Delta R) = \frac{1}{\Delta P}\ ,\ c(\Delta T) = -\frac{\Delta R}{\Delta P^2} \qquad (12)$$

Contribution of $\Delta R$ is calculated as shown in (8).

Taking into account that $P = R\cdot I^2$, the contribution of $\Delta P$ ii calculated as follows:

$$u^2(\Delta P) = c^2(R_1)u^2(R_1) + c^2(I_1)u^2(I_1)$$

$$+c^2(R_2)u^2(R_2) + c^2(I_2)u^2(I_2)\ , \qquad (13)$$

where sensitivity coefficients equate:

$$c(R_i) = I_i^{\ 2}\ ,\ c(I_1) = 2\cdot I_i\cdot R_i\ , \qquad (14)$$

Contribution of $R_i$ is calculated from (5) and Contribution of $I_i$ is calculated from specification of C&H8100 and calibration certificate of Wavetek 4600.

*Table 3. Expanded uncertainty for air cooled shunts, contribution to PCR*

| Shunt type | Nominal value, Ω | Current, A | Expanded uncertainty, ppm (k=2) |
|---|---|---|---|
| V16/80A/8 | 0,005 | 50 | 19 |
| | | 70 | 18 |
| | | 100 | 14 |
| V16/40A/8 | 0,010 | 20 | 13 |
| | | 30 | 19 |
| | | 40 | 14 |
| | | 50 | 12 |
| 51421 | 0,022 | 10 | 9 |
| | | 20 | 5 |
| 3150001 | 0,021 | 10 | 29 |
| | | 20 | 10 |
| 95407 | 0,040 | 5 | 20 |
| | | 10 | 17 |
| 3255000 | 0,041 | 5 | 10 |
| | | 10 | 8 |
| 9060004 | 0,047 | 5 | 14 |
| | | 10 | 8 |

Expanded uncertainties ($k$=2) of measured shunts PCR is less than 9 ppm.

## 4. Conclusions

The new measurement system for DC resistance calibration in wide current range, TCR and PCR calibration was described as it is tested in BIM-NCM. Thus the method, described in [1] was verified.

First measurement results of NCM current shunts were shown. Typical level dependence and temperature dependence of measured shunts were discussed.

## 5. References

[1] **V. N. Zachvalova, L.Indra, M.Sira,** "Measurements for DC Characterization of Low Resistance Standards ", *NCSL Int. Conf. Proc. 2009,* San Antonio, USA, July 26-30, 2009.

## 6. Acknowledgement

Authors special thank Mrs. V. Zachovalova and the team of experts developed the method as part of EURAMET join research project on "Power and Energy".

BIM-NCM tested and verified the method for DC characterization of shunts in terms of EMPIR project 15RPT04 TracePQM "Traceability routes for electrical power quality measurement".

This project has received funding from EMPIR program co-financed by Participating States and from European Union's Horizon 2020 research and innovation program. This paper reflects only the author's view and EURAMET is not responsible for any use that may be made of the information it contains.

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