MEASUREMENT SYSTEM FOR HIGH CURRENT SHUNTS DC CHARACTERIZATION AT CMI

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Abstract

This paper describes a measurement system for DC characterization (direct resistance, temperature coefficient measurements and power coefficient measurements) of low resistance standards (below 0.1 Ω) in wide current level (from 5 A up to 100 A) with uncertainties at ppm level.

Measurement set up

Method: **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: $R_X = \frac{U_X}{U_E} \cdot R_E$.

Equipment:
DMM FLUKE 8508A, transconductance amplifier C&H 8100.

Set of working standards

Verification: by comparison with primary resistance standards calibrated in QHS laboratory
Parameters: oil filled and placed in the oil bath (with uncertainty contribution two hundredths of degrees of Celsius)

Nominal value	Current level	Type	Producer
0.02 Ω	5A - 20A	1682	Tinsley
0.01 Ω	10A - 20A	RN I	Metra
0.001 Ω	30A - 100A	RN I	Metra

Power and temperature coefficient measurement

The power coefficient is easily to calculate as: .
PCR measured and calculated **in current range of 50% - 100% of nominal current**
The temperature coefficient is easily to calculate as: .
TCR measured **in temperature range from 18 °C up to 30 °C** **at 1/10 of nominal current**

Equipment for TCR measurement:

air thermostatic box (temp. contribution 0.15°C, humidity 50 %)

standards:
0.02 Ω; 0.1 Ω (Tinsley oil filled); PT100

Uncertainties calculations

DCR:
Combined uncertainty:
$$u^2(\delta R_X) = c_R^2 u^2(\delta R) + c_E^2 u^2(\delta R_E) + c_{r_C}^2 u^2(\delta r_C) + c_{Edrift}^2 u^2(\delta R_{Edrift}) + c_{Etemp}^2 u^2(\delta R_{Etemp}) + c_{Xtemp}^2 u^2(\delta R_{Xtemp}) ,$$
where
δ_{rC} is influence of non complete elimination of thermoelectric voltages and multimeter stability,
$\delta_{REdrift}$ is influence of resistance value change since last calibration,
δ_{REtemp} and δ_{RXtemp} is contribution of temperature,
c_R, c_E, c_{Rc}, c_{Edrift}, c_{Etemp}, c_{Xtemp} are coefficients of sensitivity.

TCR:
Combined uncertainty:
$$u^2(\delta TC_R) = c_{\Delta R}^2 u^2(\delta \Delta R) + c_{\Delta T}^2 u^2(\delta \Delta T)$$
with $c_{\Delta R} = TC_R / \Delta R$, $c_{\Delta T} = TC_R / \Delta T$,

$u^2(\delta\Delta T) = u^2(\delta T_2) + u^2(\delta T_1)$, $u^2(\delta\Delta R) = u^2(\delta R_1) + u^2(\delta R_2)$.

PCR:
Combined uncertainty:
$$u^2(\delta PC_R) = c_{\Delta R}^2 u^2(\delta \Delta R) + c_{\Delta T}^2 u^2(\delta \Delta W)$$
with $c_{\Delta R} = PC_R / \Delta R$, $c_{\Delta P} = PC_R / \Delta P$,

$u^2(\delta\Delta R) = u^2(\delta R_1) + u^2(\delta R_2)$, $u^2(\delta\Delta P) = u^2(\delta P_1) + u^2(\delta P_2)$,

$u^2(\delta P_i) = c^2_{Ri}\, u^2(\delta\Delta R_i) + c^2_{Ii}\, u^2(\delta\Delta I_i)$ with $c_{Ri} = (P_i/R_i)$, $c_{Ii} = (P_i/I_i)$.

Table 1. Typical uncertainties budget for working standard 0.001 Ω at 50 A

Quantity	Estimate of quantity		Standard uncertainty		Coefficient of sensitivity	Uncertainty contribution	
R_E	0.000 100 008 6	Ω	0.000 000 000 6	Ω	10.0	0.006 0	μΩ
R_{Edrift}	0.000 000 000	Ω	0.000 000 000	Ω	1.0	0.000 0	μΩ
R_{Etemp}	0.000 000 000	Ω	0.000 000 000 01	Ω	1.0	0.000 0	μΩ
R_{Xtemp}	0.000 000 000	Ω	0.000 000 001	Ω	1.0	0.000 8	μΩ
r_c	1.000 000 000		0.000 006 250		0.001 Ω	0.006 3	μΩ
R	10.001 333 785		0.000 003 568		0.000 1 Ω	0.000 4	μΩ
$\boldsymbol{R_X}$	**0.001 000 219 2**	Ω				**0,008 7**	μΩ
					for k = 2	**0,017 4**	μΩ

Table 2. Typical expanded uncertainties for air cooled shunts in lab (±1 °C) and example of typical uncertainty budget for 0.005 Ω shunt at 100 A

Nominal value	Current	Expanded uncertainty (k = 2)
0.1 Ω	5 A	6.3 ppm
	10 A	6.3 ppm
0.01 Ω	10 A	10.8 ppm
	20 A	10 ppm
	40 A	19.8 ppm
0.005 Ω	40 A	21.9 ppm
	70 A	15.4 ppm
	100 A	15.3 ppm

Quantity	Estimate of quantity		Standard uncertainty		Coefficient of sensitivity	Uncertainty contribution	
R_E	0.001 000 224	Ω	0.000 000 005	Ω	5.08	0.025	μΩ
R_{Edrift}	0.000000000	Ω	0.000 000 000	Ω	1.0	0.000	μΩ
R_{Etemp}	0.000000000	Ω	0.000 000 000	Ω	1.0	0.000	μΩ
R_{Xtemp}	0.000000000	Ω	0.000 000 029	Ω	1.0	0.029	μΩ
r_c	1.000000000		0.000 001 091		0.005 Ω	0.005	μΩ
R	5.080671880		0.000 001 740		0.001 Ω	0.002	μΩ
$\boldsymbol{R_X}$	**0.005 081 811**	Ω				**0.039**	μΩ
					for k = 2	**0.078**	μΩ

Table 3. Typical expanded uncertainties for air cooled shunts in thermostatic box (±0.15 °C) and example of typical uncertainty budget for 0.005 Ω shunt at 10 A and 30 °C

Nominal value	Current	Expanded uncertainty (k = 2)
0.1 Ω	1 A	2 ppm
0.01 Ω	5 A	8.4 ppm
	10 A	8.0 ppm
0.008 5 Ω	10 A	8.9 ppm
0.005 Ω	10 A	10.4 ppm

Quantity	Estimate of quantity		Standard uncertainty		Coefficient of sensitivity	Uncertainty contribution	
R_E	0.020 000 577	Ω	0.000 000 041	Ω	0.254	0.018	μΩ
R_{Edrift}	0.000 000 000	Ω	0.000 000 000	Ω	1.0	0.000	μΩ
R_{Etemp}	0.000 000 000	Ω	0.000 000 007	Ω	1.0	0.007	μΩ
R_{Xtemp}	0.000 000 000	Ω	0.000 000 017	Ω	1.0	0.017	μΩ
r_c	1.000 000 000		0.000 000 873		0.005 Ω	0.004	μΩ
R	0.254 087 795		0.000 000 057		0.02 Ω	0.001	μΩ
$\boldsymbol{R_X}$	**0.005 081 903**	Ω				**0.0263**	μΩ
					for k = 2	**0.053**	μΩ

Typical values of TCR and PCR

TCR: 18°C – 30°C
Foil shunts: -2.8 +0.2 +8 ppm, unc. < 2.1ppm
Shunts with parallel rez.: +1.2 +1.7 ppm, unc. < 1.7 ppm
PCR: 50% - 100% of nominal current
Foil shunts: < ± 4 ppm, unc. < 3.1ppm
Shunts with parallel rez.: < ±1.5 ppm, unc. < 1.5 ppm

Conclusions

Most significant influences for DCR (except of working standard calibration): temperature influence on air cooled shunts and/or standard deviation of measured voltages ratio.
Future work focus on trying to reduce the uncertainties - especially the contribution of measured ratio (standard deviation).

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