THE UNCERTAINTY EVALUATION OF AUTOMATIC DIRECT CURRENT COMPARATOR BRIDGE

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Abstract

A practical procedure for ratio measurement uncertainty estimation of auto DCC Bridge is described. By comparison with CCC, the result is confirmed.

Introduction

Automatic bridge based on direct current comparator (DCC) were available since more than ten years ago, they have become popular at all level laboratories both in DC resistor and thermometry fields. A commercial DCC bridge MI6010B is also used at NIM for direct standard resistor measurement. According to the specifications [1], the ratio accuracy reaches 0.1 parts in 10^{-6}, and the linearity of full scale is 0.01 parts in 10^{-6}. It becomes a very arduous works for a general user to verify its conformance. Here offer an in-house calibration procedure realized at NIM to evaluate the accuracy of auto DCC Bridge.

Effective quantities and its estimation

From the principle of DCC, a resistive ratio measurement combines two balance equations, ampere-turn balance and voltage balance. Therefore, any unbalance ampere-turn or voltage signals will contribute errors to a ratio measurement if these signals are not detected and compensated. The accuracy of a ratio measurement by DCC Bridge is mostly limited by three quantities, as unbalance voltage measurement with noise, unbalance ampere-turn with noise, and itself non-linearity.

Although any measurement result shows a combined uncertainty from the above quantities, each contributes different levels in different resistance. In the case of lower resistance, the voltage measurement error dominates for larger current brings larger ampere-turn, and that the ampere-turn error becomes great under high resistance for large voltage. These with discrete characteristics can be expressed by the standard deviation (STD) of a specific measurement. The non-linearity behaves as a stable deviation from the nominal value in regard to a given ratio; it can be achieved by exchanging Rx and Rs under ratio 1 to 1, or by comparison with a known ratio under ratio 10 to 1.

1. Unbalanced voltage measurement error.

0.1 Ω to 0.1 Ω and 1 Ω to 1 Ω are compared with the secondary winding 1024 to the primary winding 1024 at MI6010. Considering the ampere-turn is larger enough, the STD mainly comes from the unbalanced voltage measurement. As Table I shows the voltage error is less than 0.3 nV.

Table I. the Determination of Voltage Error of MI6010B at Low Resistance under Different Current.

Res. (Ω)	STD, k=2 ($\times10^{-6}$)	Current (mA)	Voltage (V)	AT	V-Error (nV)
1	0.0039	50	0.05	51.2	0.19
	0.0019	100	0.1	102.4	0.19
0.1	0.0204	150	0.015	153.6	0.31
	0.0617	50	0.005	51.2	0.31
	0.2954	10	0.001	10.24	0.30

Table II. the Determination of Ampere-Turn Error of MI6010B at High Resistance under Different Current.

Res. (Ω)	STD,k=2 ($\times10^{-6}$)	Current (mA)	Voltage (V)	AT	AT-Error (nAT)
1 k	0.023	1	1	1.024	23
	0.008	3	3	3.072	25
10 k	0.026	1	10	1.024	26
	0.088	0.3	3	0.307	27
	0.154	0.1	1	0.102	16

2. Unbalance ampere-turn error with noise

1 kΩ to 1k Ω and 10 kΩ to 10 kΩ are compared with the secondary winding 1024 to the primary winding 1024 at MI6010. Considering the voltage is larger enough, the STD mainly comes from the unbalanced ampere-turn and noise. As Table II shows the ampere-turn error is less than 25 nAT.

3. Non-linearity error.

Exchanging Rx and Rs determine the non-linearity error at ratio 1 to 1 in deferent resistance. As Table III shows the non-linearity ranging from 0.02 to 0.05 parts in 10^{-6}, except at 10 kΩ, which may be infected by deficient insulation between two windings.

Table III. The Non-linearity Determination of MI6010B at Ratio 1 to 1 under Different Resistance.

Res. (Ω)	Relative Dev. ($\times10^{-6}$) Rx/Rs	Rs/Rx	Ratio Error ($\times10^{-6}$)	Curr. (mA)	STD ($\times10^{-6}$)
0.1	-21.362	21.30	-0.031	150	0.018
	-21.448	21.27	-0.089	50	0.076
1	-20.507	20.411	-0.048	100	0.0021
	-20.630	20.546	-0.042	50	0.0045
10	19.239	-19.307	-0.034	30	0.0029
	19.076	-19.185	-0.054	10	0.0031
100	-6.088	6.055	-0.017	10	0.0033
	-6.082	6.040	-0.021	3	0.0073
1 k	16.795	-16.875	-0.040	3	0.009
	16.778	-16.850	-0.036	1	0.022
10 k	-8.509	8.755	0.123	1	0.023
	-8.732	8.505	-0.113	0.3	0.076

The non-linearity of ratio 10 to 1 of MI6010B is compared with Hamon resistors(H71804 and H7401, s or p behind them means Serial or Parallel) as Table IV.

Table IV. Comparison of MI6010B with Hamon resistor $\times 10^{-6}$

Ratio	Rx/Rs	Ratio	100:1	Diff.
10:1	sn 66248-10Ω/sn 121-1Ω	25.602		
10:1	H71804s-100Ω/ sn 66248-10 Ω	-17.654	7.948	
1:1	H71804p-1Ω/sn 121-1Ω	7.829		-0.119
10:1	sn 001822-1kΩ/ H71804s-100Ω	15.598		
10:1	H7401s-10kΩ/ sn 001822-1kΩ	-42.044	-26.446	
1:1	H7401p-100Ω / H71804s-100Ω	-26.330		0.116

Comparison with CCC

To check the linearity and accuracy of MI6010B at the ratio 10 to 1, it is compared with Cryogenic Current Comparator (CCC) by respectively taking measurement on Tegam SR104 10 kΩ to Tegam SR102 100 Ω, and Tegam SR102 100 Ω to NML 1Ω standard resistors. As Table V shows, the ratio 100 to 1 is got by twice 10 to 1 measurements, and the difference of MI6010B to CCC at ratio 10 to 1 is calculated from that of the ratio 100 to 1 divided by $\sqrt{2}$.

Table V. The Comparison between MI6010B and CCC.

Device	100 Ω: 10 Ω	10 Ω:1 Ω	100:1
MI6010B	10.00009694	9.99992889	100.0002583
CCC			100.0002556
Diff. At 100:1 ($\times 10^{-6}$)			+0.027
Diff. At 10:1 ($\times 10^{-6}$)			+0.019

Device	10 kΩ: 1 kΩ	1 kΩ:100 Ω	100:1
MI6010B	9.999967222	10.00003455	100.0000177
CCC			100.0000221
Diff. At 100:1 ($\times 10^{-6}$)			-0.044
Diff. At 10:1 ($\times 10^{-6}$)			-0.031

Uncertainty Estimation

As mentioned above, the accuracy of DCC Bridge mainly depends on three quantities, as voltage, ampere-turn and non-linearity. Although increasing current may decrease the voltage and ampere-turn error, it would bring more dissipation on the under test resistors. Table VI shows ratio uncertainty estimations in case of 2.5mW dissipation at each resistance.

According to the above measurement, the non-linearity of the bridge expresses a stable error (fixed and far less than STD) at the specified resistance, as Table 3 shows, therefore some of them can be corrected. In substitution case, the effect of non-linearity may be reduced within 10 to 20 parts in 10^9.

Table VI. Uncertainty Estimations under Ratio 1 to 1 $\times 10^{-9}$

Res.(Ω)	0.1	1	10	100	1 k	10 k
Current (mA)	150	50	15	5	1.5	0.5
Voltage error	20	6	2	0.6	0.2	0.06
Ampere-turn error	0.2	0.5	1.6	5	16	50
Non-linearity	50	50	50	50	50	50
Standard uncert. of Type A	20	5	5	5	20	50
Combined standard uncertainty	57	51	50	51	56	87

Conclusions

A practice uncertainty estimation of MI6010B is carried out at NIM according the above procedure. In fact, ampere-turn error, non-linearity and uncertainty of type A could be improved at ratio 10 to 1 for 1 kΩ and 10 kΩ under-test resistance situation because the winding turns reach 10240.

By the way, above data is only got from the measurement of the MI6010B at NIM.

Reference

[1] MI, “Technical Manual of Automatic DC Resistance Bridge Model 6010.” 6010B.TM Rev.13, 1999.1