DC resistance comparison between a current comparator bridge and the quantum Hall system at Inmetro

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Abstract: This paper presents a comparison results between the Quantum Hall System (QHS) under development at the Quantum Electrical Metrology Laboratory (Lameq) and the current comparator calibration system, traceable to the Bureau International des Poids et Mesures (BIPM), at the Electrical Standardization Metrology Laboratory (Lampe), both part of the Electrical Metrology Division, at Inmetro. Comparisons were performed with 1 Ω, 10 Ω, 100 Ω, 1 kΩ and 10 kΩ resistors. The results obtained over two years of work are presented here, showing that the comparison contributed to improve the calibration systems of both Lampe and Lameq.

Keywords: metrology, standard resistor, intercomparison, calibration, traceability.

1. INTRODUCTION

Recently Lampe acquired a new Current Comparator Bridge (CCB) [1] allowing an improvement of the calibration procedure and reduction of the uncertainties for dc resistors calibration.

The measurement of Lampe standard dc resistors in the range of 1 Ω to 10 kΩ are performed through a CCB. At this resistance range, the new CCB allows measurements at any ratios between 1:10 and 10:1. The traceability at this resistance range is performed by two 1 Ω (TH1 and TH2) and one 10 kΩ (R1) reference standard resistors which are periodically calibrated by BIPM.

The measurement in two ratios, 10:1 and 1:10, (i.e., direct and reverse measurements) reduces the CCB measurement errors, when the arithmetic mean of the two results are applied. The uncertainties specified by the CCB manufacturer for the range from 1 Ω to 10 kΩ is 0.04×10^{-6}, and for the ratio 10 kΩ : 10 kΩ is 0.1×10^{-6}.

At Lameq QHS, the measurements are performed through a Cryogenic Current Comparator (CCC). Two 100 Ω resistors are calibrated directly with the quantum Hall device. Then 1 Ω, 10 Ω, 100 Ω, 1 kΩ and 10 kΩ resistors are calibrated from these 100 Ω resistors.

After the validation of CCB at Lampe, in 2014, it was possible to perform several calibrations, which allowed reviewing the uncertainty budgets and the history of the standards resistors [2]. Thus, it was possible to increase the reliability of the measurements and reduce the calibration uncertainty budget. With the reduced uncertainty we were able to perform reliable comparisons between the results of Lampe and Lameq, allowing an improvement in the calibration system of both laboratories.

2. METHODOLOGY

Initially the calibration history of the standard resistors at BIPM was re-evaluated. These calibrations results were then applied to analyze the standards behavior tendencies, thus, determining their temporal stability and estimated corrected values. This correction is made on a monthly basis through a table of values (TabVal), both for the reference standard resistors calibrated at BIPM, and for the working standards calibrated at Lampe [3].

The application of low values of power on resistors during a calibration reduces possible errors due to the Joule effect and, consequently, the propagation errors in the range from 1 Ω to 10 kΩ. So it is possible to obtain the value of 1 Ω resistor from the 10 kΩ resistor with a smaller uncertainty than that of the manufacturer specification.

The QHS can perform measurements, using power from 0.1 mW to 1 mW. Although there are differences between the currents applied on the resistors on CCB and QHS, the Joule effect does not cause significant change in the result of this comparison, due to the small power values selected for both systems.

3. RESULTS

The following results are divided into nominal values of 1 Ω, 10 Ω, 100 Ω, 1 kΩ and 10 kΩ. During the comparisons, different resistance standards were measured, during a short time interval, for each nominal value. The comparisons between Lampe calibration systems and QHS have been started in 2013, even before validation of new CCB.

To simplify the analysis, the results of these measurements were normalized by the results obtained with the QHS, and the relative difference graphically represented by the equation (1).

$$\Delta(CCB - QHS) = \frac{\text{CCB value} - \text{QHS value}}{\text{QHS value}} \quad (1)$$

The QHS is the reference of this study, and its uncertainty is less than 0.10 μΩ/Ω. Thus, to simplify the graphic presentation, the only uncertainty represented graphically is Lampe proposed (reduced) CMC uncertainty for each range.

This paper shows how the review of the calculations and procedures, the acquisition of a new CCB, and the comparisons with the QHS led to the reduction of the difference $\Delta(CCB - QHS)$ between the two systems.

3.1. Resistance Standards of 1 Ω and 10 Ω

The graph in figure 1 shows the comparison between the results obtained with the CCB system and QHS for the nominal resistance values of 1 Ω and 10 Ω.

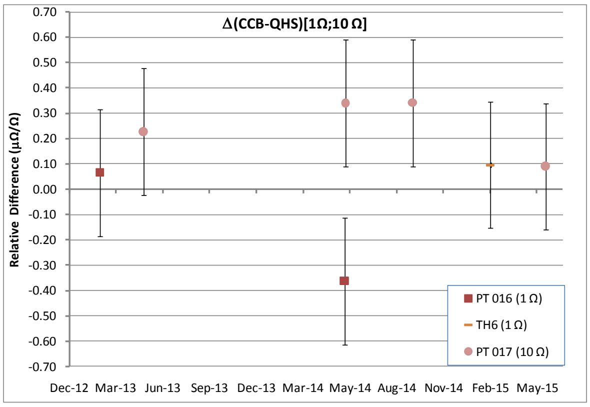

Figure 1. Comparison with nominal values of 1 Ω and 10 Ω.

The unsatisfactory results found between 2013 and the first half of 2014 led Lameq to make some improvements in initial settings procedures of CCC, during resistor calibration, in this measurement range. After these modifications, the new results obtained between the second half of 2014 and early 2015, with $\Delta(CCB - QHS) < 0.2\,\mu\Omega/\Omega$, led Lampe to propose a reduction of the CMC uncertainty budget, at this range, from 0.65 μΩ/Ω to 0.25 μΩ/Ω.

3.2. Resistance Standards of 100 Ω

This is one of the most important comparisons because the standard resistors are directly compared with the quantum Hall device during the measurements in Lameq. These results are shown in figure 2.

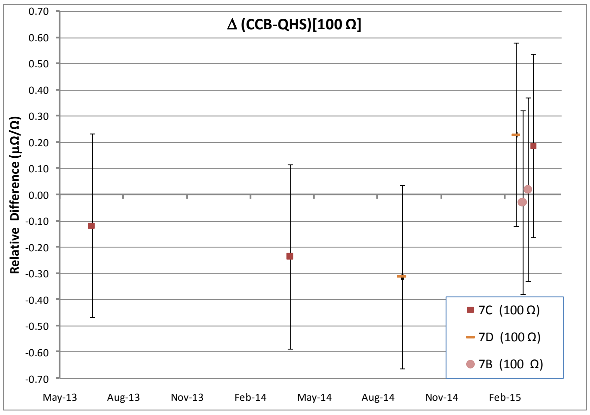

Figure 2. Comparison with nominal values of 100 Ω.

In this range, some adjustments made in Lampe calibration procedure led to a significant reduction of $\Delta(CCB - QHS)$, especially if we consider 2015 measurements. In view of these results, Lampe proposed a reduction of the CMC uncertainty budget, at this range, from 0.61 µΩ/Ω to 0.35 µΩ/Ω.

3.3. Resistance Standards of 1 kΩ and 10 kΩ

In this range Lampe CCB operates with its lowest uncertainty. The working standard resistors of 1 kΩ and 10 kΩ can be measured directly by comparison with the standard resistor R1 (10 kΩ) which presents better stability and lower temperature dependence.

Before the acquisition of the new CCB, it was only possible to calibrate 1 kΩ or 10 kΩ resistors from a 100 Ω standard resistor, with significantly higher uncertainty. Figure 3 shows the measurement results obtained before (2013) and after (2014-15) the implementation of the new CCB and the review of Lampe calibration procedures.

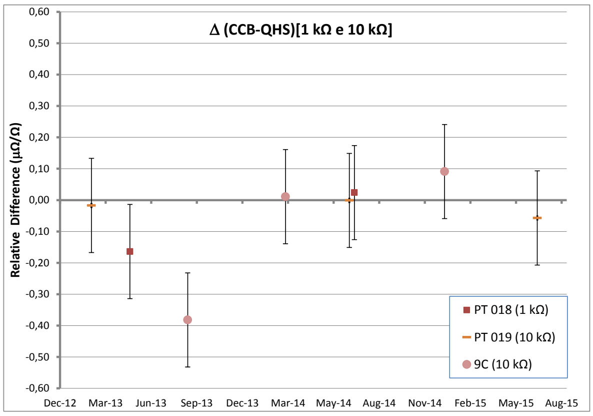

Figure 3. Comparison with nominal values of 1 kΩ and 10 kΩ.

The results obtained after 2014 present $\Delta(CCB - QHS) \leq 0.1\ \mu\Omega/\Omega$, thus leading Lampe to propose a reduction of the CMC uncertainty budget, at the 1 kΩ range, from 0.60 µΩ/Ω to 0.15 µΩ/Ω; and at the 10 kΩ range, from 1.0 µΩ/Ω to 0.15 µΩ/Ω.

3.5. Summary of the results found

Table 1 shows the relative difference $\Delta(CCB - QHS)$ and the Normalized Error Ratio (NER) of the last comparison (2014-15) between QHS and CCB, for each standard resistor. The NER is calculated according to equation (2). For values of $NER < 1$, we can consider the comparison results are coherent with the estimated uncertainty budget.

$$NER = \frac{|\text{CCB value} - \text{QHS value}|}{\sqrt{U_{CCB}^2 + U_{QHS}^2}} \quad (2)$$

Where:

U_{CCB} = Expanded absolute uncertainty of Lampe;
U_{QHS} = Expanded absolute uncertainty of Lameq.

At table 1, it is possible to observe that the values of $\Delta(CCB - QHS)$ are in between 0.02 µΩ/Ω (range of 1 kΩ) and 0.23 µΩ/Ω (range of 100 Ω), all values much below the proposed CMC uncertainty for the respective range.

Table 1. Summary of the results found.

Nominal Value	Standard	Month/Year	$\Delta(CCB - QHS)$ (μΩ/Ω)	NER
1 Ω	**TH6**	**feb/2015**	**0,096**	**0,38**
10 Ω	**PT 017**	**jun/2015**	**0,090**	**0,35**
100 Ω	**7C**	**feb/2015**	**0,187**	**0,53**
	7D	**feb/2015**	**0,229**	**0,65**
	7B	**apr/2015**	**0,020**	**0,06**
1 kΩ	**PT 018**	**jun/2014**	**0,024**	**0,15**
10 kΩ	**PT 019**	**jul/2015**	**-0,057**	**0,36**
	9C	**jan/2015**	**0,091**	**0,56**

The reliability of the comparison results is also confirmed by the NER value, between 0.06 and 0.65, i.e., smaller than 1 for all ranges.

4. CONCLUSION

The comparisons made between Lampe and Lameq contributed to improve calibration procedures for both laboratories, allowing not only to reduce uncertainties as well as to increase the reliability of the measurement results.

In the next few months, after a programmed bilateral comparison with BIPM, Lameq QHS should be internationally recognized as a primary electrical resistance laboratory. From this moment on, it will not be necessary to send Lampe reference standard resistors to be calibrated at the BIPM. Therefore Lampe standards will not be subject to drifts due to transportation, and it will be possible to perform dc resistance calibrations with even smaller uncertainties at Inmetro.

5. REFERENCES

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