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Using historical data to improve electrical resistance standards measurement uncertainty

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Abstract **– This paper presents methodologies for the evaluation of historical data of electrical resistance standards in order to improve their performance in relation to manufacturer's specification, in order to improve test uncertainty ratio and measurement uncertainty.**

I. INTRODUCTION

Calibration of electrical resistance measurement instruments, such as ohmeters, earth meters and Kelvin bridges, together with voltage and current measurement instruments, is a significant part of the workload of electrical calibration laboratories. Some of these instruments are highly accurate, as resistance measurements instruments used for accurate temperature measurements and precision digital multimeters.

For these measurement instruments, sometimes metrological performance of the standards specified by their manufacturers is overestimated when compared to the actual performance, leading to low test uncertainty ratios (TURs). In such a case, it is recommended for the calibration laboratories to evaluate alternatives for TUR improvement, such as purchasing new higher accuracy standards or evaluation of methodologies to improve the performance of their standards. Purchasing new higher accuracy standards usually envolves significative amount of financial resources, that might not be available for the calibration laboratory. A less expensive alternative is to characterize the performance of the standards, based on their historical data, using statistical and other techniques of data analysis. The behaviour over time of the values assigned to the measurement standards can follow a well-defined drift that can be modelled in order to predict the values, for a given moment, with certain uncertainty [1].

This paper presents application of methologies to improve metrological performance of electrical resistance standards. Historical calibration data of the standards are analysed and used to define new performance parameters better than manufacturer's specifications, leading to higher TUR and lower measurement uncertainties.

II. RESISTANCE STANDARDS

Electrical calibration laboratories have several options of resistance standards depending on the measurement uncertainty level. Standard resistors are often used by primary or high level calibration laboratories, while secondary or lower level calibration laboratories use precision digital multimeters. For both laboratories' types, working standards are usually decade boxes and multi-function calibrators.

In this paper, the reference standard considered is a precision digital multimeter from Fluke, model 8588A. Working standards are a multi-function calibrator (MFC) from Fluke, model 5720A and a resistance decade box, from Tettex, model 1108-B GR. Figure 1 shows the Fluke 8588A digital multimeter, Figure 2 shows the Fluke 5720A multifunction calibrator and the Tettex 1108-B GR resistance decade box and Figure 3 shows their traceability chain.

Fig. 1. Fluke 8588A DMM reference standard.

Fig. 2. Tettex 1108-B GR decade box and Fluke 5720A MFC working standards.

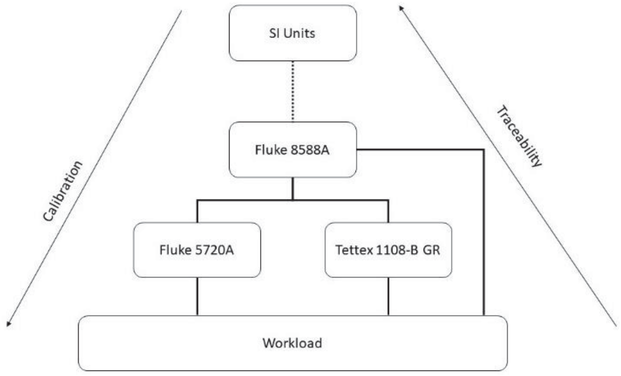

Fig. 3. Resistance standards traceability chain.

Fluke 8588A precision DMM, as a reference standard, should be calibrated at regular intervals at the National Metrology Institute (NMI) or at a 17025 standard accredited laboratory. It also can be used as working standard. This instrument is new, so there is a low quantity of avaliable historical data. According to its manufacturer, accuracy performance relative to the standards is as low as 7.5 μΩ/Ω at 100 Ω (1-year, 2σ) [2].

Fluke 5720A MFC and Tettex 1108-B GR are working standards, calibrated by the Fluke 8588A reference standard and used to calibrate the main part or the laboratory's workload. 5720A MFC has a set of discret resistors from 1 Ω, 1.9 Ω, 10 Ω to 100 MΩ. Absolute uncertainty defined by its manufacturer is 27 μΩ/Ω at 10 Ω (1-year, 2.58σ) [3]. Tettex 1108-B GR has resistors in decade values from 0.1 Ω to 100 kΩ, and 0.01 % accuracy from 1 Ω to 100 kΩ.

III. DATA ANALYSIS

The historical calibration data of an instrument can be useful when describing the normal variation of the instrument or a population of substantially identical instruments. The use of historical data is recommended when the laboratory has a considerable amount of data that allows the estimation of the standard uncertainty due to the variability of the readings, to confidently characterize the drift of instruments and standards. This use must be done with great caution, as some occurrences, such as overload, maintenance, adjustment and natural aging itself, may invalidate the use of the accumulated data. By using standards historical data, a calibration laboratory can improve performance specifications of them. Also, standards calibration intervals may be lengthened or shortened by performing a technical and statistical analysis using their calibration history, thus reducing costs with traceability maintenance in the case of calibration interval lengthening [4, 5, 6].

Data analysis techniques are applied to identify patterns, relations and trends that help interpret data and extract explicit and implicit information. [7]. One of these techniques is the regression. Regression problems occur in many metrological applications. Such problems arise when the quantity of interest cannot be measured directly, but has to be inferred from measurement data (and their uncertainties) using a mathematical model that relates the quantity of interest to the data. This is the case for estimating the drift or long-term stability of standards or measuring instruments. Nowadays, regression is also often used in supervised machine learning field [8].

Linear regression is often used for the prediction of values assigned to measurement standards whose behaviour over time is linear, and the function that predicts this behaviour is the simple model described by a straight line. One of the most common methods to estimate a straight line that best fits a set of data is the least squares method. The goal is to find the straight line $y = Ax + B$ that best fits the measurements, that is, to find the best estimates for the constants A and B based on the data [9]. Uncertainty of the data fit to the straight line can also be evaluated by the regression method.

Other simpler data analysis techniques can be used instead of regression or other sophisticated techniques for standards performance evaluation, depending on the target uncertainty or reliability, or on the amount of available historical data. One simple technique is the estimation of the standards drift by subtraction of successive calibration values.

IV. PERFORMANCE ANALYSIS

This section presents the performance analysis of the 5720A MFC and 1108-B GR decade box working standards, based on their historical calibration data. Before analysis, it was ensured that both standard were not submitted to maintenances, adjustments or other occurrences that could impair the quality of the analysis. All the calibrations used in the analysis were performed with controlled temperature of (23 ± 3) °C.

Table 1 and Figure 5 show last five calibration results of the 1108-B GR decade box, at 100 Ω (dial position 1x100 Ω), where *R* is the measured resistance, *U* is the uncertainy at 95.45% confidence and drift was calculated by subtracting the measured resistance of a calibration from the measured resistance of the previous calibration. All these calibrations were performed in the laboratory, using the standards Fluke 8588A DMM (2022), Fluke 8508A (2021 and 2019) and Agilent 3458A (2018 and 2017) precision digital multimeters. Before performing the measurements, the switches were rotated several times, in order to reduce the effect of the contact resistance. In this calibration point, accuracy defined by the manufacturer is 0.01 %. As it can be seen, the highest drift value is almost three times lower than accuracy specified by the manufacturer.

Table 1. Tettex 1108-B GR 100 Ω calibration history.

Date	R (Ω)	U (%)	Drift (%)
07-feb-22	100.000 0	0.0015	0.003 0
21-jan-21	100.003 01	0.000 93	0.003 5
02-sep-19	100.006 5	0.0013	0.000 5
10-jan-18	100.007 0	0.0029	0.002 0
06-jan-17	100.009 0	0.0029	

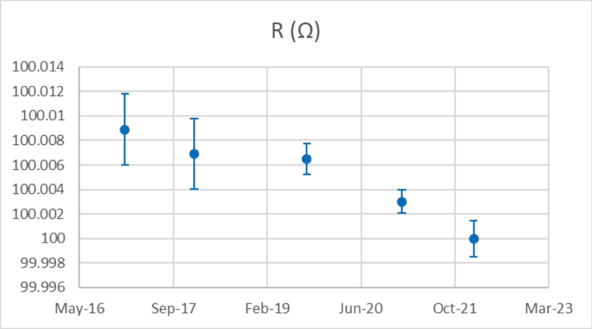

Fig. 5. Tettex 1108-B GR 100 Ω calibration history.

Applying linear regression to the calibration data of Table 1, it is possible to fit the data to the straight line shown on Figure 6. Uncertainty of the 1-year predicted resistance value is 0.0012 % (95.45%, k=2.87), about eight times lower than manufacturer's specification.

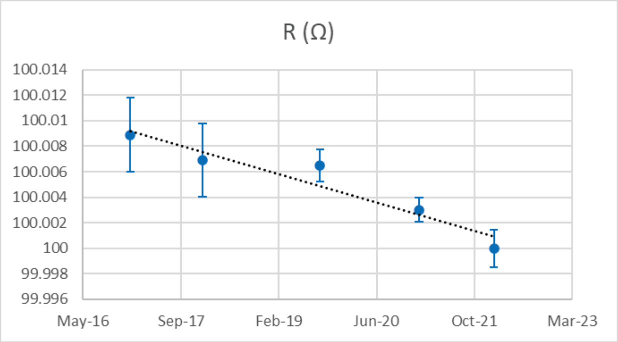

Fig. 6. Tettex 1108-B GR 100 Ω calibration history linear regression.

Table 2 and Figure 7 show last five calibration results of the 5720A MFC, at 10 Ω. All these calibrations were performed in the laboratory, using the standard Fluke 8588A DMM (2021) and Fluke 8508A DMM (the significant difference in uncertainty values in each year for this DMM is due to the fact that this standard was calibrated in different laboratories with different measurement capabilities). In this calibration point, absolute uncertainty defined by the manufacturer is 27 μΩ/Ω (1-year, 2.58σ).

Table 2. Fluke 5720A 10 Ω calibration history.

Date	R (Ω)	U (μΩ/Ω)	Drift (μΩ/Ω)
12-mar-21	10.000 50	11	6.2
06-jun-19	10.000 43	22	13
06-apr-18	10.000 57	13	14
08-jun-16	10.000 43	15	4.1
08-apr-15	10.000 47	19	

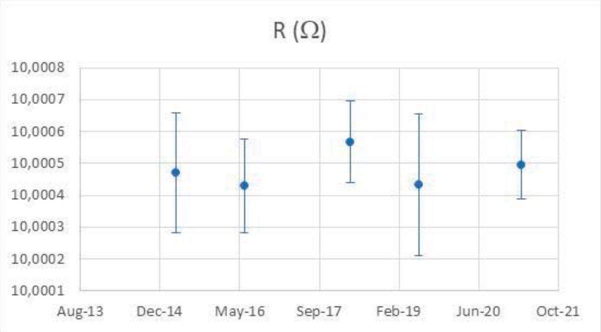

Fig. 7. Fluke 5720A 10 Ω calibration history.

Linear regression was used to fit a straight line to the calibration history data of Table 2. Estimated uncertainty of the 1-year predicted resistance value is 6.4 μΩ/Ω (95.45%, k=2.87), about three times lower than performance specified by the standard's manufacturer.

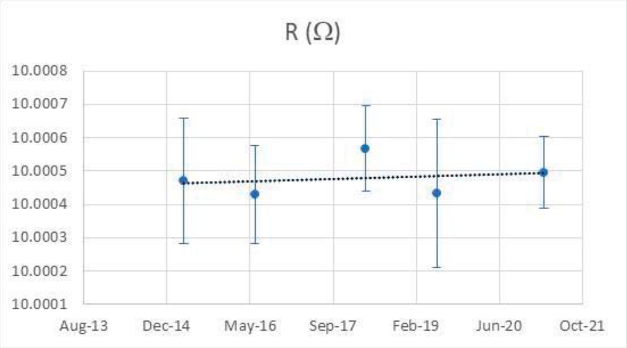

Fig. 8. Fluke 5720A 10 Ω calibration history linear regression.

V. DISCUSSION

After performing analysys of historical calibration data, electrical calibration laboratories can choose between assigning an improved accuracy specification to the characterized instruments, or lengthening their calibration interval, enabling reduction of the maintenance costs of the laboratory.

If the laboratory decides to improve standard's performance specification, first it should check if uncertainty due to it is one of the most significative of the uncertainty sources. In many electrical resistance calibrations, uncertainty due to standard's performance is the most significative. In this case, after evaluation of the combined measurement uncertainty from the standard uncertainties from all input quantities (uncertainty sources) using the rules defined by [10], laboratory can obtain lower measurement uncertainties. Care should be taken in this case, because the new uncertainty due to standard's performance will replace uncertainty due to standard's performance based on manufacturer's apecification, which usually includes, besides long-term stability or drit, other performance parameters. For example, 5720A MFC manufacturer's performance specification includes stability, but also temperature coefficient, linearity, line and load regulation.

Considering the case of the Tettex 1108-B GR decade box working standard reported on the previous section, there are three performance specifications: the first is the accuracy stated by the manufacturer (I), the second is the highest value from subtraction of successive calibration values (II), and the last is the uncertainty of the predicted value by the linear regression (III). Table 3 and Figure 8 shows a comparison of the uncertainties considering the three cases above. As it can be seen, reduction of the combined standard uncertainty can be as high as 85% in the case III. Still in the case III, there is the accuracy improvement too, as the resistance predicted value is determined.

Table 3. comparison of the uncertainties considering the three cases.

Case	I	II	III
Root of square sum of all other uncertainties except performance/drift (Ω)	7.3E-4		
Standard uncertainty due to performance/drift (Ω)	5.8E-3	2.0E-3	4.2E-4
Combined standard uncertainty (Ω)	5.8E-3	2.2E-3	8.4E-4

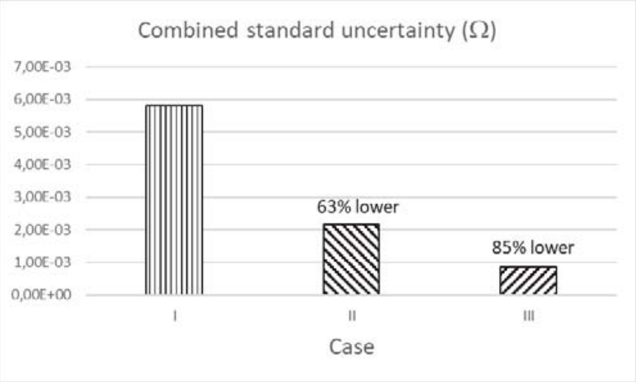

Fig. 8. Combined standard uncertainties comparison.

VI. CONCLUSION

This paper presented evaluation of electrical resistance standards historical calibration data, with the objective of improve manufacturer's performance specification and thus also improving measurement uncertainty and test uncertainty ratio (TUR) when performing accurate measuring instruments calibration. Two methodologies were presented, a simple one and a complex one, based on data analysis methods. Estimated combined standard uncertainty could be reduced at about 85%. For futher work, For future work, the application of other data analysis and prediction methods will be evaluated, such as weighted least squares.

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