Managing Calibration Confidence in Calibration Process

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Abstract – **Voltage calibrators as test standards have their own probability distribution producing uncertainty in the determination of an in-tolerance or out-of-tolerance condition. In the accredited metrology laboratory of the Faculty of Electronic Engineering in Niš, two calibrators FLUKE 5100B and METRAtop 53 are compared. In calibration process guardbanding strategy is proposed to equalizing the cost of faulty test decision between above two calibrators. Performed results of evaluation and comparison their uncertainties are presented in this paper.**

Keywords – **Voltage and current calibrator, Test uncertainty ratio, Confidence limits.**

I. Introduction

Accurate measurements are essential in test and measurement systems. However, if the measurement hardware is not calibrated, then there can be no certainty in the acquired measurements results.

With the increased acceptance of ISO standards [1,2], many users now find necessity to prove the accuracy of implemented measurements. They must produce some sort of traceable verification of their instruments in order to prove measuring correctness and specifications. In calibration process of particular concern is adequacy of standards which are used to calibrate units under test (UUT). Measurement uncertainty of used calibration standard is directly contributed the quality of calibration process. Accredited metrology laboratory must provide that uncertainty of measurement standards not exceed acceptable tolerance (manufacturer's specification).

The calibration support of the most accurate measuring instruments has always been a complex task. As technical advances make it easier for manufacturers to offer products with high-performance, the metrologist must find practical ways to calibrate measuring instruments that often need higher capabilities of the available standards.

High reliable calibration required that standards are at least ten times better than the instruments being compared to them, that is, a test uncertainty ratio (TUR) would be equal 10:1 [3]. Increased performance in the instrument being calibrated has resulted in a reduction of acceptable TURs to 4:1.

In this paper guardbanding strategy in calibration process is proposed to equalizing the cost of faulty test decision between two calibrators FLUKE 5100B and METRAtop 53. Evaluation of uncertainties is done using ”Guide for Evaluating and Expressing the Uncertainty of NIST Measurement Results” [5]. New confidence limits are proposed to assure that calibration confidence is maintained.

II. Evaluation of Uncertainty

All measurements are estimates of the true value of the measured parameter and are subject to errors, described as uncertainty. The uncertainty of measurement is evaluated according to either a Type A or a Type B method of evaluation [5,6]. The evaluation of standard uncertainty Type A is the method of evaluating the uncertainty by the statistical analysis of a series of measurements. In this case the standard uncertainty is the experimental standard deviation of the mean that follows from an averaging procedure or an appropriate regression analysis. The evaluation of standard uncertainty Type B is the method of evaluating the uncertainty by means other than the statistical analysis of a series of observations. In this case the evaluation of the standard uncertainty is based on technical documentation provided by manufacturers.

Technical specifications of used calibrators [7,8] for dc voltage range 2 mV, 200 mV, 2 V and 20 V are presented in Table 1.

Table 1.

Ranges	Fluke 5100B	Metratop 53
20mV	0.005%·U+5,2µV	0.02%·U+50µV
200mV	0.005%·U+7µV	0.02%·U+50µV
2V	0.005%·U+25µV	0.02%·U+500µV
20V	0.005%·U+205µV	0.02%·U+5mV

Values in columns 2 and 3 of Table 1 represent specification limits, where value U is set referent dc voltage on calibrator output. The worst case is value for the highest voltage value in each range, and that is shown in Table 2.

Table 2.

Ranges	Fluke 5100B	Metratop 53	TUR
20mV	6,2µV	54µV	8,7
200mV	17µV	90µV	5,3
2V	125µV	900µV	7,2
20V	1,205mV	9mV	7,5

Type A method evaluation is done using HP3290A voltmeter. Measured difference between set output dc voltage values of two calibrators for ranges 2 mV, 200 mV, 2 V, 20 V are shown in Figs. 1 to 4.

For four ranges, max value, mean value of difference and standard deviation of mean value are shown in Table 3.

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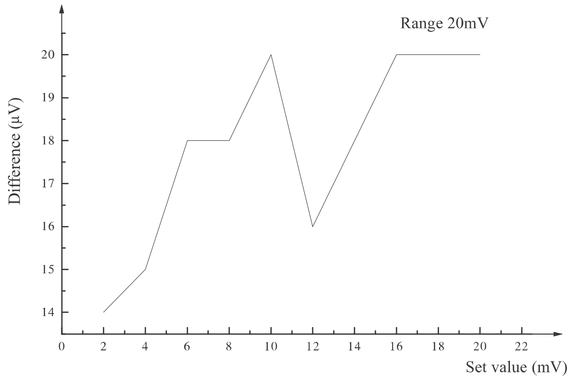

Fig. 1. Difference between set values of two calibrators

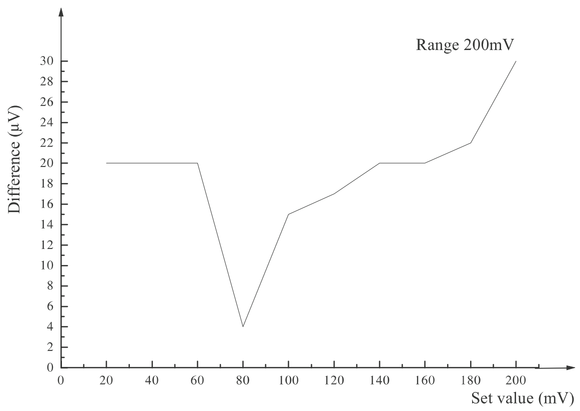

Fig. 2. Difference between set values of two calibrators

Test uncertainty ratios between two calibrators are calculated based on values in Table 2 and Table 3. Proposed method is based on correction of test uncertainty ratios provided by technical documentation of manufacturer, Table 2. Correction is done using relation between maximum value of difference, Table 3, and difference of uncertainties from Table 2. New test uncertainty ratios are shown in Table 4. For example, for calculating test uncertainty ratio on range 20 mV is shown in Eq. (1)

$$\mathrm{TUR} = (8.7 \times 20\mu\mathrm{V})/(54\mu\mathrm{V} - 6.2\mu\mathrm{V}) = 3.6 \qquad (1)$$

Table 3.

Ranges	Max value	Mean value	Standard deviation of mean value
20mV	20μV	18μV	2μV
200mV	30μV	19μV	6μV
2V	350μV	175μV	77μV
20V	1400μV	865μV	330μV

Table 4.

Ranges	Test uncertainty ratio (TUR)
20mV	3,6
200mV	2,2
2V	3,2
20V	1,3

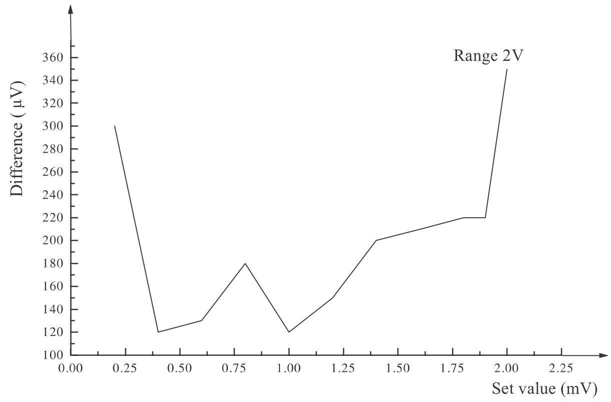

Fig. 3. Difference between set values of two calibrators

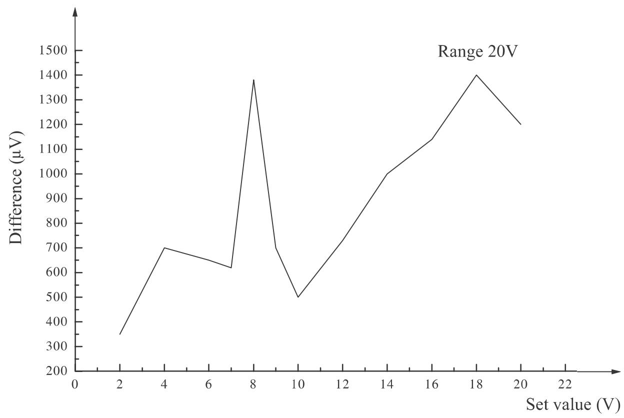

Fig. 4. Difference between set values of two calibrators

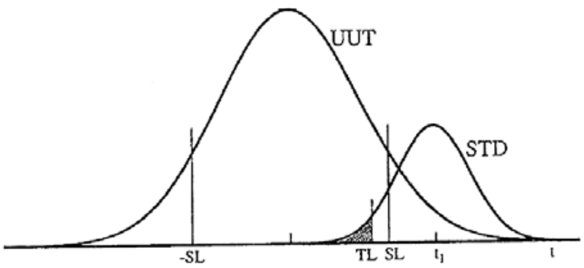

Fig. 5. Out-of tolerance unit reported as confirming

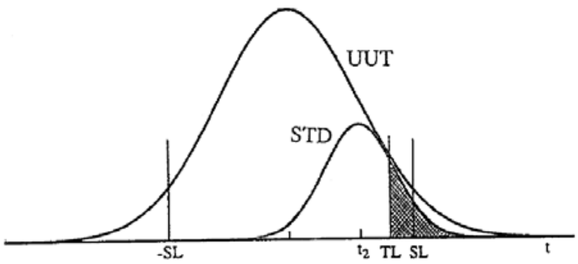

Fig. 6. In-tolerance unit reported non-confirming

III. Guardbanding Method for Estimating New Test Limits

Guardbanding is a statistical method for setting in-tolerance and out-of-tolerance limits so that calibration is done with

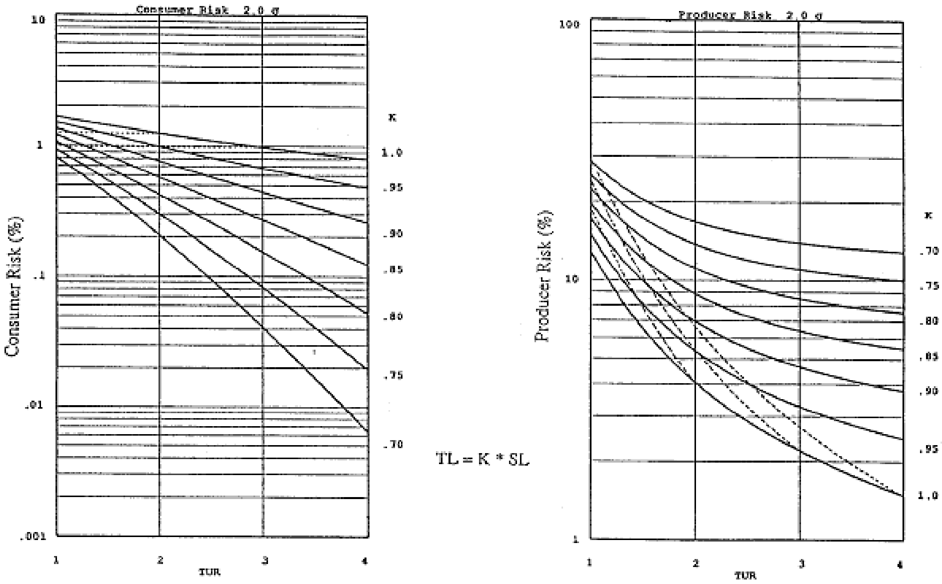

Fig. 7. Risks for different guardband limits and for $\pm 2\sigma$ (P=95%)

adequate confidence when test uncertainty ratios are small. New in-tolerance limits are calculated by comparing the uncertainty of the calibration standard with the specifications of the UUT. Consumer risk (CR) represents out-of tolerance unit reported as confirming. Producer risk (PR) represents in-tolerance unit reported non-confirming.

Though the probability of making faulty test decisions (consumer risk) increases with decreasing TURs, the test limits can be placed to set the desired level of consumer risk or producer risk. For example, it is possible, with a 2:1 TUR, to keep the same risk of accepting defective units as a 4:1 TUR by setting the test limits TL=K×SL, K<1, inside the specification limits SL. By factor K the specification limit is reduced to obtain the new test limit.

ISO Guide 25, drafts 5 and 6, released as ISO/IEC 17025 [2] is not explicit about confidence interval. Most of the literature, laboratory and industry practices, assumes $\pm 2\sigma$ confidence interval. New test limits are set to give a 95% probability of being within the UUTs specification limits.

Fig. 5 shows the effects of having a TL inside the SL for symmetrical limits, where are:

UUT: The distribution of possible values for the unit under test.

STD: The distribution of possible values for the Standard.

t: local variable for the UUT distribution.

t_1: a possible value of the UUT.

The shaded area to the left of t_1 in Fig. 5 illustrates the probability that a unit outside the SL will be accepted with new test limits. Out of tolerance probability is calculated by the double integral of Eq. (2). Test limit is obtained by reducing specification limits by factor K.

$$CR = \frac{1}{\pi} \int_{SL}^{\infty} \int_{-TUR\cdot(t+TL)}^{-TUR\cdot(t-TL)} \exp\left[-\frac{(s^2+t^2)}{2}\right] \mathrm{d}s\mathrm{d}t \qquad (2)$$

Shaded area shows the reduced probability of false accepts since units measuring inside the SL but greater than the TL will be rejected.

Similarly, the in tolerance with guardband is shown in Fig. 6.

$$PR = \frac{1}{\pi} \int_{-SL}^{SL} \int_{TUR\cdot(TL-t)}^{\infty} \exp\left[-\frac{(s^2+t^2)}{2}\right] \mathrm{d}s\mathrm{d}t \qquad (3)$$

ISO Guide 25 Draft 5 proposal is to use TL=SL when the TURs are sufficiently high, 10:1 TURs are recommended. 4:1 TURs might be tolerated.

For setting new test limits ISO Guide 25 Draft 5 proposal is to use Eq. (4).

$$TL = K \times SL = \left(1 - \frac{1}{TUR}\right) \times SL \qquad (4)$$

In Fig. 7 Consumer and producer risk for different guardband limits and for $\pm 2\sigma$ (P=95%) is presented.

In order to maintain calibration confidence for both calibrators, new test limits are calculated. Calculation of new test limits for FLUKE 5100 B is done using guardbanding method based on Eq. (4) and TURs in Table 4.

New test limits are shown in Table 5.

Table 5.

Ranges	Old Test Limits	New Test Limits
20mV	6,2μV	4,5μV
200mV	17μV	10μV
2V	125μV	86μV
20V	1,205mV	300μV

IV. Conclusion

Guardbanding is a method for setting in-tolerance and out-of-tolerance limits so that calibration is done with adequate confidence when test uncertainty ratios are small.

In this paper, guardbanding strategy in calibration process is proposed to equalizing the cost of faulty test decision between two calibrators. New confidence limits are proposed for equalizing the cost of faulty test decisions between the two calibrators and to assure that calibration confidence is maintained.

With proposed guardbanding method calibrator with lower test uncertainty ratio can be successfully used in the calibration process. This is particularly significant for portable calibrator Metratop 53, which is used for calibration outside laboratory.

References

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