DC VOLTAGE INTERNATIONAL COMPARISON

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***Abstract* – This paper presents the results of a trilateral comparison of measurements on a Zener voltage standard within the framework of EUROMET. The participants are the National Metrology Institutes of Romania (INM), Turkey (UME) and Austria (BEV) which acts as the pilot laboratory. The comparison was performed in order to link the National Institute of Metrology Bucharest (INM) to the key comparisons BIPM.EM-K11.a and BIPM.EM-K11.b[1]. The results of the measurements show good agreement between the participating laboratories for the nominal voltage of 10 V.**

Keywords: *DC voltage standard***,** *comparison, EUROMET, measurement uncertainty, degrees of equivalence.*

1. INTRODUCTION

The objective of this comparison was to link the National Institute of Metrology Bucharest (INM) to the key comparisons BIPM.EM-K11.a and BIPM.EM-K11.b[1].

The primary standard for DC voltage is formed by the Josephson Array Voltage Standard (JAVS). This type of standard is used by UME and BEV. The national standard of INM is a Zener standard, calibrated at BIPM [1] .

National Institute of Metrology Bucharest uses a standard Zener diode based electronic DC voltage standard Fluke 732 B as itinerant DC voltage standard. This itinerant standard ensures the SI traceability [2] of Romanian DC voltage standard to a primar standard, such as an instalation based on Josephson effect.

The main targets of this comparison are:

- to demonstrate equivalence of metrological practice,
- to contribute to acceptance of INM in EUROMET,
- to confirm the proposed CMC values of INM in the field of DC voltage,
- to check the correctness of the calibration results,
- to check the correct traceability of the standards.

2. PARTICIPANTS

The participating institutes are:

- Bundesamt für Eich- und Vermessungswesen -BEV- Austria
- Ulusal Metroloji Enstitüsü-UME -Turkey
- National Institute of Metrology – INM – Romania.

The comparison was organized in a loop of the participating laboratories. The circulation of the standard started in June 2005 and was finished in July 2005. Due to difficulties in organizing the time schedule it was decided that the pilot laboratory BEV was doing the measurements at the end of the loop.

The participants were asked to follow their usual measurement procedure to achieve their best measurement capabilities.

3. TRAVELLING STANDARD

The standard used was a Fluke 732 B electronic DC reference standard with s/n 8008001 provided by INM. The Fluke 732 B electronic DC reference standard, henceforth denoted by the standard, has two output voltages, nominally 1.018 V and 10 V respectively.

The main advantages of Zener diode based electronic DC voltage standard are:

- theirs lustiness,
- easy to carry and to use, being ideal devices as itinerant standards
- the dependence of the output voltage with the environmental factors is much smaller than in the Weston cells occurrence.

The time stability ensured by manufacturer for electronic DC standard Fluke 732B is given in the following table:

Output voltage	Stability (±ppm)		
	30 days	90 days	1 year
10 V	0,3	0,8	2,0
1,018 V	0,8	NA	NA

Table 1: The time stability for electronic DC standard Fluke 732B

4. MEASUREMENTS

The quantities to be measured were:

- 10 V outputs,
- resistance of the oven temperature thermistor,
- ambient temperature, humidity and pressure.

No correction for the influence of thermistor temperature, air pressure and humidity was applied. The internal thermistor resistance was measured by applying a current ≤ 10 µA. Before and after this comparison, measurements at INM were performed to check the stability of the standard. These measurements showed the expected behaviour of the standard.

The device under test was connected continuously to the AC line power except during the measurements, where at least 2 hours between disconnecting the main power and the start of the measurements elapsed. During the measurements the front panel GUARD binding post was connected to the guard of the measuring system and to the front panel CHASSIS binding post. In one point of the measuring system the guard was connected to ground.

The measurement conditions at the different laboratories are listed in the following tables.

Partici-pant	Room temperature [°C]	Thermistor resistance [kΩ]	Humidity [%]
UME	23.0 ± 1	38.73 ± 0.01	57 ± 10
INM	23.5 ± 0.4	38.65 ± 0.05	60 ± 7
BEV	23.0 ± 0.2	38.74 ± 0.04	48 ± 5

Table 2: The measurement conditions

Partici-pant	Air pressure [hPa]	Measurement method
UME	995 ± 3	comparison with JAVS voltage
INM	1007 ± 5	comparison with a calibrated Zener standard
BEV	992 ± 2	comparison with JAVS voltage

Table 3: The measurement conditions and method

5. RESULTS

Each of the laboratories gave one value for the output voltage at 10 V, the corresponding measurement uncertainty for a confidence level of 95 % and the mean measurement date, respectively.

The mathematic relation used by INM to obtain the value of the unknown voltage was:

$$V_X = V_S + \delta V_D + \delta V_{SN} + \overline{\Delta V} + \delta V_N + \delta V_{ND} + \delta V_P - \delta V_{OFF} \quad (1)$$

where:

V_S - value of the reference voltage Fluke 732 B

δV_D - change of V_S since its last calibration, due to drift

δV_{SN} - nanovoltmeter correction

$\overline{\Delta V} = V_{Xi} - V_{Si}$ - difference between the indicated values of the reference and the unknown voltages; the value $\overline{\Delta V}$ was calculated as an average of the differences of values obtained in n cycles of measurement:

$$\overline{\Delta V} = \frac{\sum_{i=1}^{n} \Delta V_i}{n} \quad (2)$$

δV_N - nanovoltmeter resolution

δV_{ND} - change of δV_{SN} since its last calibration, due to drift

δV_P - change of the indicated values due to instabilities of the nanovoltmeter

δV_{OFF} - offset correction

The uncertainty budget of each laboratory was presented in the form of a table according to chapter 4 of the EA-4/02 document 'Expression of the Uncertainty of Measurement in Calibration' [3].

Participant	U_{meas}	$u(U_{meas})$
	[V]	[µV]
UME	9.999 994 96	0.44
INM	9.999 998 30	5.04
BEV	9.999 994 82	0.70

Table 4: Measurement results and uncertainties ($k = 2$) of the participating laboratories

It is well known that the output voltage of Zener standards presents some drift effects as a function of time. The JAVS measurements at UME and BEV were used to calculate this drift by assuming a linear time dependence [4]:

$$U = a\,t + b \quad (3)$$

with t as the time and the coefficients a, b.

With this linear interpolation the reference value U_{ref} of the standard at the mean measurement date at INM

was calculated. This fictitious reference value was also used to calculate the degree of equivalence for INM.
For the uncertainty of this reference value the maximum uncertainty of the measurements from UME and BEV were taken.
The degree of equivalence DINM with the reference value was calculated by subtracting the reference value from the INM result according to:

$$D_{INM} = U_{INM} - U_{ref} \quad (4)$$

with an associated uncertainty given by:

$$u(D_{INM}) = \sqrt{u^2(U_{INM}) + u^2(U_{ref})} \quad (5)$$

No correlations between the different measurements were taken into account.
The degree of equivalence for the measurements performed at INM are stated in the table 5.

U_{nom}	[V]	10
U_{ref}	[V]	9.999 994 89
$u(U_{ref})$	[μV]	0.70
D_{INM}	[μV]	3.41
$u(D_{INM})$	[μV]	5.09

Table 5: The degree of equivalence for the measurements performed at INM

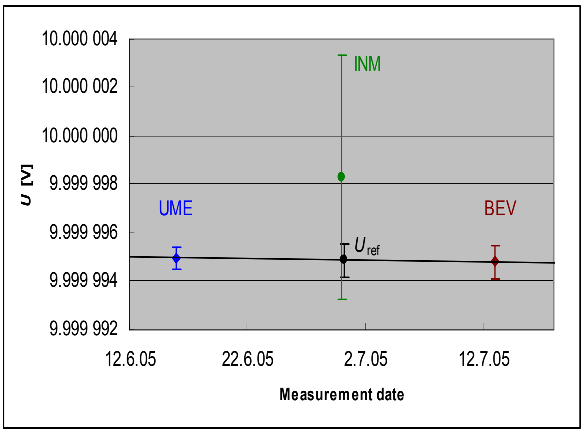

Figure 1: Measurement results and estimation of reference value for 10 V (uncertainty bars for $k = 2$)

6. EVALUATION OF DEGRREES OF EQUIVALENCE

For the INM measurement of DC voltage a link is given to the comparisons BIPM.EM-K11.b: "DC voltage: 10 V, Zener diode". BEV took part in these comparisons and therefore the BEV degrees of equivalence and the corresponding uncertainties were used for the link.
The degrees of freedom were obtained with the relationship:

$$\nu_{ef} = \frac{u_c^4(y)}{\sum \frac{u_i^4(y_i)}{\nu_i}} \quad (6)$$

In the Rapport BIPM-2001/03 (April 2001) the final results of the comparison are presented as the differences between the values assigned to a 10 V standard by each laboratory and stated together with the combined standard uncertainty u_c (for $k = 1$). According to the results stated in the "BIPM key comparison database" these differences are used as the degree of equivalence $D_{K11,BEV}$ and the expanded uncertainty:

$$U_{K11,BEV} = 2 \times u_c \text{ (for } k = 2)$$

of BEV as follows:

$$D_{K11,BEV(10\ V)} = -0.04\ \mu V$$

$$U_{K11,BEV(10\ V)} = 0.20\ \mu V$$

The same values are used in this comparison for the evaluation of degrees of equivalence linked to BIPM.EM-K11.a and BIPM.EM-K11.b comparisons for the following reasons:
As BEV used in the BIPM.EM-K11.a and BIPM.EM-K11.b comparisons and in this comparison the same Josephson system for measuring the Zener standards used as travelling standards, the same reproducibility of these measurements can be assumed.
No drift of the Josephson measurements has to be taken into account as the Josephson system is a primary standard.
Therefore the degree of equivalence $D_{K11.6,INM}$ and the expanded uncertainty $U_{K11.6,INM}$ of INM with respect to the BIPM Reference Value given in the Rapport BIPM-2001/03 can be calculated as follows:

$$D_{K11.6,INM(10\ V)} = D_{K11,BEV(10\ V)} + D_{INM(10\ V)} =$$
$$= -0.04\ \mu V + 3.41\ \mu V = 3.37\ \mu V$$

$$U_{K11.6,INM(10V)} = \sqrt{U^2_{K11,BEV(10V)} + U^2_{D,INM(10V)}} = \sqrt{(0.20\ \mu V)^2 + (5.09\ \mu V)^2} = 5.09\ \mu V$$

$$D_{K11.6,INM(1.018\ V)} = D_{K11,BEV(1.018\ V)} + D_{INM(1.018\ V)} =$$
$$= -0.01\ \mu V + 0.21\ \mu V = 0.20\ \mu V$$

7. CONCLUSIONS

Because the implementation of the quality system is a task of the modern economy, the study of the quality of the measurements is absolutely necessary. To report the result of a measurement of a physical quantity means to give a quantitative indication of the quality of this result so as the users can evaluate its credibility.
The measurements of this trilateral comparison were carried out according to the agreed time table. The results of the participants show adequate agreement within the stated uncertainties.

References

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