Comparison of the Josephson voltage standards of the Republic of Belarus and Russian Federation

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The results are presented of key comparisons of national voltage standards of the Republic of Belarus and Russian Federation using a quantum transfer standard at 10 V. The comparison results are in good agreement with the reference value of the BIPM voltage standard: the voltage difference is 0,9 nV at a combined standard uncertainty of 2,6 nV.

Introduction. The Josephson effects occur if two superconductors are weakly coupled, e.g. by separating them by an insulating layer of a few nanometers in thickness. Irradiation of this Josephson junction with microwaves (being an electromagnetic wave) creates between the superconductors discrete voltage levels depending only on the ratio of fundamental constants and the frequency of the microwaves. It is the most accurate method to generate or measure voltage and, by international agreement, is the basis for voltage standards around the World. In the BelGIM was conducted comparison of the Josephson voltage standards at 10 V of the Republic of Belarus (BelGIM) and Russian Federation (VNIIM). In the Mutual Recognition Arrangement (MRA) it is stated that the metrological equivalence of national measurement standards will be determined by a set of key comparisons chosen and organized by the Consultative Committees of the CIPM working in close cooperation with the Regional Metrology Organizations. The RMO key comparison supplementing the COOMET.EM.BIPM-K10.b comparison was carried out to link COOMET national laboratories. The purpose of this comparison is to link the voltage standard of BelGIM (Belarussian State Institute of Metrology) to that of the VNIIM (D.I. Mendeleyev Institute of Metrology) in the frame of the COOMET-RMO key comparisons and have link to BIPM voltage standard. In the KCDB, the deviation of the result obtained by BelGIM from the BIPM value will be indicated with value of the combined uncertainty obtained in measurements BelGIM – VNIIM and VNIIM – BIPM [1]. The transfer quantum standard was used for this comparison. The transfer standard was developed specialists VNIIM together with the National Metrology Institute of Germany (PTB). Earlier this transfer standard involved in comparison of the Josephson voltage standards of the VNIIM and BIPM, which took place in France [2-3]. The comparison with the application of this standard has been decided to be held in the Republic of Belarus. The choice fell on the measuring lab is not accidental. This is primarily the result of years of professional cooperation of Russian and Belarusian metrology plus modern equipment laboratory measurement of electrical quantities.

The transfer standard (TS) was transported was to BelGIM. TS has an cryoprobe with Josephson array, shielded from the Earth magnetic field. Cryoprobe design allows it to change its size, which provides compactness of the TS during transportation. The microwave generator circuit was isolated from the TS frame. Built-in filters allowed TS to operate with or without TS chassis grounding. After dipping in a Dewar with liquid helium the TS probe was kept there for at least 4 hours prior to the measurements.

The BelGIM voltage standard is based on the supraVOLTcontrol system. The system features a 3-channel Josephson Voltage Standard (JVS) with microprocessor-based control and allows calibration of voltage standards and external voltmeters. To maintain a high accuracy of the nanovoltmeter (used as a null detector), at the beginning of each working day the system option “Calibration nanovoltmeter” was used, after which the amplification factor was saved in the system’s memory [4]. For measurements by the transfer standard, the secondary standards calibration mode M1 and comparison mode M2 were used. The photo the Josephson voltage standards during comparison in BelGIM are shown in Figure 1.


Fig.1 Photo the Josephson voltage standards during comparison.

Measurements methods

The TS was measured at BelGIM using voltage standard. After the measurements the TS was transported to VNIIM, where it was measured it was measured against the VNIIM standard. For the realization of 10 V voltage both BelGIM and VNIIM standards use type SIS Josephson microcircuits. During the comparisons the measurements of voltage difference of the TS and the used standard are performed.

The measurements are carried out for two polarities and the results are averaged [5-6]. Measurement conditions including the laboratory room temperature, relative humidity and air pressure were monitored. The TS frequency was synchronized with the frequency of the compared standard.

In the M2 mode the BelGIM standard measured the voltage realized by the transfer standard as follows:

- The BelGIM standard changed the present frequency which allowed obtaining a voltage difference of 1 μV, the maximum allowed difference measured by the nanovoltmeter having been set to be 500 μV.
- The resistance of the measuring terminals of the BelGIM standard was 3 Ω, the resistance of the measuring terminals leakage was 90 GΩ.
- The resistance of the TS measuring outputs was 10 Ω, the resistance of the measuring outputs leakage is more than 100 GΩ.
- Output voltage control and monitoring of TS parameters is performed by compact bias unit based on batteries.
- The result of a single measurement includes for positive and negative Josephson voltage offsets in both systems.
- The number of single measurements was 8.
- The result that was used for the further measurement analysis was the average of the single measurements.
- The time of single measurement reading was about 10 minutes.
- Time to obtain the result from 33 reading was about 5,5 hours.

The TS voltage is measured with the VNIIM using nanovoltmeter Keithley 2182A [3]. The TS voltage is defined as a mean voltage value measured at the two polarities of the VNIIM standard output voltage. Measurements were carried out for different operation modes of the measurement circuit, including: enabling and disabling of the galvanic coupling between the TS and the reference frequency source of 10 MHz; TS microwave generator power line supply or battery supply; measurements with switched off cooling fan in the TS microwave generator.

Results

The results of measurements of the voltage difference between the BelGIM standard and the TS are shown in Figure 2. Mode M2 was used in points 1 to 32, mode M1 was used in point 33.

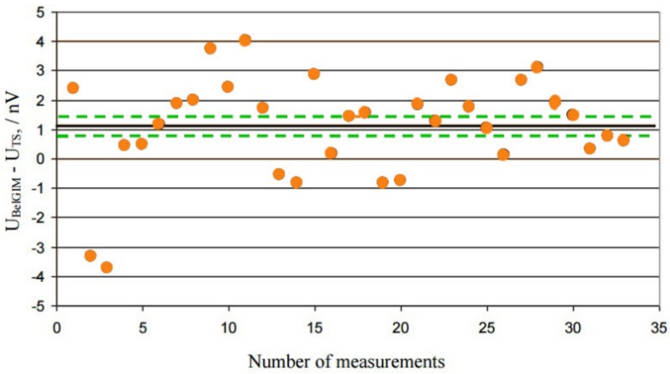

Fig.2 The results of measurements of the voltage difference between the BelGIM standard and the TS.

In this way, results of the TS and BelGIM standard comparisons:

Voltage difference is defined as

$$U_{BelGIM} - U_{TS} = \frac{1}{33}\sum_{i=1}^{33}\Delta U_i = D = 1{,}08 \text{ nV} \quad (1)$$

where D - the degree of voltage equivalence, reproduced the compared standards.

Uncertainty type A and uncertainty type B are defined as

$$u_A = \sqrt{\frac{1}{33}\sum_{i=1}^{33}\frac{(\Delta U_i - D)^2}{32}} = 0{,}3 \text{ nV} \quad (2)$$

$$u_B = \sqrt{u_{B\ BelGIM}^2 + u_{B\ TS}^2} = 1{,}3 \text{ nV} \quad (3)$$

The results of measurements of the voltage difference between the VNIIM standard and the TS are shown in Figure 3.

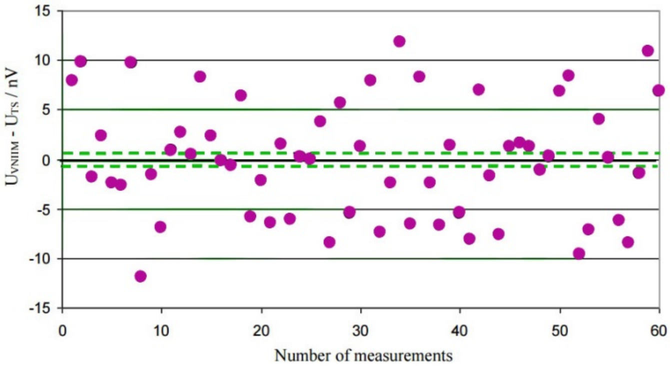

Fig.3 The results of measurements of the voltage difference between the VNIIM standard and the TS.

In this way, results of the TS and VNIIM standard comparison:

Voltage difference is defined as

$$U_{TS} - U_{VNIIM} = \frac{1}{60}\sum_{i=1}^{60}\Delta U_i = D = -0{,}1 \text{ nV} \quad (4)$$

Uncertainty type A and uncertainty type B are defined as

$$u_A = \sqrt{\frac{1}{60}\sum_{i=1}^{60}\frac{(\Delta U_i - D)^2}{59}} = 0{,}7 \text{ nV} \quad (5)$$

$$u_B = \sqrt{u_{B\ VNIIM}^2 + u_{B\ TS}^2} = 1{,}1 \text{ nV} \quad (6)$$

Degree of equivalence with respect to reference value

The reference value is the BIPM voltage standard value, which is assumed to be time-independent. The reference voltage value is disseminated from the BIPM by means of the results obtained in the comparisons of the TS and BIPM, VNIIM and BelGIM standards.

The degree of equivalence D between the BelGIM and BIPM voltage standards is calculated on the basis on the BIPM-VNIIM and VNIIM-BelGIM comparisons using the TS with the uncertainty

$$D_{BelGIM-BIPM} = D_{VNIIM-BIPM} + D_{BelGIM-TS} + D_{TS-VNIIM} \quad (7)$$
$$u^2_{c\,BelGIM-BIPM} = u^2_{c\,VNIIM-BIPM} + u^2_{c\,BelGIM-TS} + u^2_{c\,TS-VNIIM} \quad (8)$$

The results of the voltage standards comparisons are presented in Table 1.

Table 1. The results of the voltage standards comparisons

Standard compared	D, nV	Combined uncertainty, nV
VNIIM-BIPM	-0,105	2,04
BelGIM-TS	1,08	0,8*
TS-VNIIM	-0,1	1,3
BelGIM-BIPM	0,9	2,6

*The value does not consist type B uncertainty of TS as it is included in TS-VNIIM measurements

Conclusion

The degree of equivalence between BelGIM and BIPM voltage standards at a 10 V voltage was obtained at the level of 0,9 nV with the combined uncertainty of 2,6 nV.

The conducted comparisons demonstrated high metrological characteristics of the BelGIM voltage standard and its reliable operation.

The uniqueness of these comparisons was that for the first time in Belarus, direct comparisons at a voltage of 10 V with accuracy up to units of nV was carried out using the standard based on the Josephson effect. The comparisons voltage standards of previous years were carried out using transportable measures based on the basis of Zener diodes having insufficiently stable characteristics due to the noise of measures, which did not allow to obtain such precision in determining the value of the voltage.

The results of these comparisons make it possible to link units of national standards BIPM and BelGIM comparisons completed using voltage standards of the VNIIM and the BIPM.

References:

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