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Interlaboratory Comparison of Thermal AC Voltage Standards

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The article presents results of comparison of the thermal converter of nominal input voltages equal to 10 V from the set of Polish National AC voltage standards, maintained at the Central Office of Measures in Warsaw, with the primary AC voltage 5 V standard, developed and maintained at the AC-DC Transfer Laboratory of the Department of Measurement Science, Electronics and Control at the Faculty of Electrical Engineering of the Silesian University of Technology in Gliwice.

Keywords: Standards of electrical quantities, AC voltage standards, AC-DC transfer, Interlaboratory comparisons, Thermal voltage converters

1. INTRODUCTION

Interlaboratory comparisons play a very important role in metrology. For example, they allow verification of measurement uncertainty and validation of measurement methods.

In this paper, results of a comparison of the AC voltage standard of nominal input voltage U_N = 10 V maintained at the Central Office of Measures (GUM) in Warsaw with the calculable AC voltage standard of nominal input voltage U_N = 5 V maintained at the Department of Measurement Science, Electronics and Control (in Polish: Katedra Metrologii, Elektroniki i Automatyki, KMEiA) at the Silesian University of Technology (SUT) were presented. The results of a similar calibration performed at 2 V level in 2018 were presented in [1].

In the future, it could possibly eliminate the need for periodical calibrations of Polish national AC voltage standards which are actually performed outside Poland.

The description of standards maintained by participants of the comparison is presented in the next paragraphs: AC voltage standards maintained at GUM and AC voltage standards maintained at SUT.

2. AC VOLTAGE STANDARDS MAINTAINED AT GUM

The AC voltage standard maintained at GUM is a set of Thermal Voltage Converters (TVCs) Model 11 produced by Holt. This set allows to perform AC–DC transfer for input voltage in range from 0.5 V to 1000 V. The standard consists of a set of TVCs equipped with Single Junction Thermal Voltage Converters (SJTCs) of different input current and a set of range resistors, which extends the nominal input voltage of the SJTCs (Fig.1.). To extend the input voltage an appropriate SJTC is connected in series with the proper range resistor. All TVCs and range resistors from this set have "hermaphroditic" GR-874 input connectors. This type of connector is not commonly used nowadays in precision AC voltage metrology, due to a difficulty in defining a reference plane of these connectors.

Fig.1. A set of AC Voltage Standards (Holt model 11) maintained by GUM with the SJTC on the top. Range resistors are inserted into box slots.

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The Holt Model 11 is not a calculable standard and has to be periodically calibrated against the more accurate AC voltage standard. Such a calibration can be performed by one of the National Metrology Institutes (NMIs) having high Calibration and Measurements Capability (CMC) in AC voltage measurements. The last calibration of the GUM's Holt Models 11 with $U_N = 2$ V and $U_N = 10$ V was made by Physikalisch - Technische Bundesanstalt (PTB), Braunschweig (Germany) in 2016. Due to a relatively high cost of such a calibration, it is usually made with long intervals (e.g., every four years).

3. AC VOLTAGE STANDARDS MAINTAINED AT SUT

The Laboratory of AC–DC Standards at the Silesian University of Technology uses a set of Planar Multijunction Thermal Voltage Converters (PMJTCs) manufactured by the Leibniz Institut für Photonische Technologien (IPHT) in Jena (Germany) in cooperation with PTB as working standards. These types of TVCs have a higher sensitivity than the SJTC and are less prone to damage [5]. Most of the PMJTCs are used together with custom-made range resistors mounted in coaxial enclosures. The nominal input voltage range of this set spans from 0.2 V to 1000 V. All SUT TVCs use N-type input connectors.

Fig.2. Two primary calculable AC Voltage Standards developed at SUT.

The set of PMJTCs in the 0.2 – 1000 V input voltage range is calibrated using the step-up and step-down method [6]. Only a few standards of input voltages between 1.5 V and 10 V are calibrated using calculable reference thermal AC voltage standards of nominal input voltage $U_N = 3$ V and $U_N = 5$ V (Fig.2.). Both standards were designed and built at SUT [3]. Each calculable standard consists of a selected SJTC of heater resistance $R_H = 90$ Ω and a range resistor, which increases the nominal input voltage of the standard. The range resistor is made from a very thin resistive wire featuring very low temperature coefficient of resistance. According to the manufacturer, the absolute value of this coefficient is below 50 μΩ/K.

The AC–DC transfer differences of these standards were calculated using a complex mathematical model in frequency range from 10 kHz to 1 MHz [3] and later extended to 30 MHz [8]. Correctness of the AC-DC transfer difference calculation was verified by comparing the measured difference of AC–DC transfer differences of the two calculable standards with the difference obtained from their mathematical models [3], [8], comparison with commercially calibrated traveling standard and interlaboratory comparison with national AC voltage standards of Denmark, Italy, and Sweden [4], [9].

A different approach to estimate the AC–DC transfer difference of the SUT reference AC voltage standards was used at lower frequencies (below 50 Hz). The AC–DC transfer difference of these TVCs in frequency range from 10 Hz to approximately 40 Hz was measured using the reduced power method [5]. A frequency-independent component of the AC–DC transfer difference was measured using the Fast-Reversed Direct Current (FRDC) method [11], [7], using the FRDC source developed and constructed at SUT [10]. The frequency-independent component is caused by thermoelectric effects in heater and it determines the value of AC–DC transfer difference in frequency in range from approximately 100 Hz to 10 kHz.

4. COMPARISON OF AC STANDARDS BETWEEN GUM AND SUT

The comparison between the AC Standards belonging to GUM and SUT was conducted at the Laboratory of AC–DC Standards at KMEiA. The Holt Model 11 TVC of nominal input voltage $U_N = 10$ V belonging to GUM was compared with SUT's reference AC Voltage Standard of nominal input voltage $U_N = 5$ V. The measurement was conducted for selected frequencies in frequency range from 10 Hz to 1 MHz using SUT's automated comparator of AC–DC standards [12]. The comparator was designed and established at SUT. Its resolution of the measurement of difference of AC–DC transfer differences reaches the value 100 nV/V for precision and stable TVCs. The comparator consists of two very stable AC and DC voltage sources (Fluke 5700A and Fluke 5440B, respectively), remotely controlled AC–DC switch and two Keithley 2182A nanovoltmeters. All measuring instruments are controlled by a PC using an optically isolated GPIB interface [2]. The coefficient of variation of Fluke 5700A output voltage during a 1 hour test was measured to be below 2 μV/V [13].

An additional TVC with nominal input voltage $U_N = 7$ V was used in the comparison. This TVC was built specially for the purpose of the comparison. It consists of SJTC connected in series with a range surface-mount resistor (MELF). This TVC was used to create a closed loop of measurements and verify consistency of measurements. A scheme of the performed comparisons is presented in Fig.3. All TVCs belonging to SUT are marked in Fig.3. and Fig.5. with abbreviation "VS". Another additional TVC (marked VS 50 V in Fig.3.) using PMJTC with a range resistor of nominal input voltage $U_N = 50$ V was used during the comparison to measure AC–DC transfer difference of Holt 11 standard at very low frequencies (below 40 Hz).

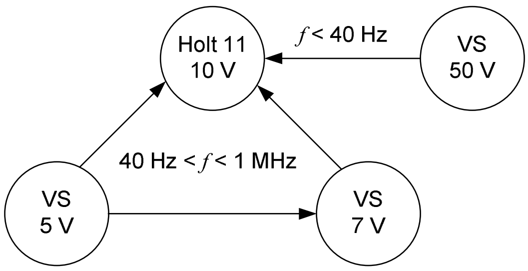

Fig.3. Scheme of the performed comparisons.

Because the Holt Model 11 standard is equipped with the GR-874 type connector, a special tee was built at SUT to connect this TVC to SUT standards and measurement system. This tee has two N type connectors and one GR-874. The construction of the tee is presented in Fig.4.

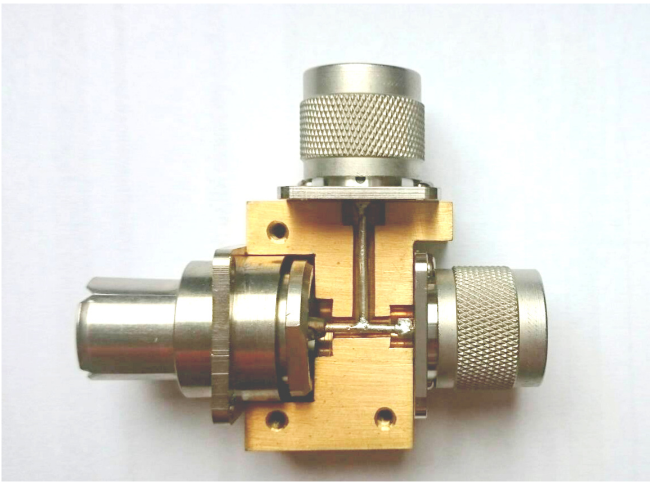

Fig.4. A tee designed and built at SUT. It allows to connect a TVC with GR – 874 input connector to SUT measurement.

The geometry of the tee was optimized to reduce its influence on measured value of AC–DC transfer difference. The length of arms of this tee is similar to the length of arms of commercially available N and GR-874 tees. Moreover, the diameter of the internal wire and diameter of the air insulation channel of the tee was designed to maintain the wave impedance of the tee at approximately 50 Ω wave impedance, i.e. the same as the wave impedance of connectors and cables.

5. Consistency of measurements

The scheme of comparison presented in Fig.3. allows to detect a systematic error during the comparison. The difference of the AC–DC transfer differences between two TVCs can be calculated as a result of the direct comparison or using the result of two other measurements shown in Fig.3. A systematic error in the measuring system will cause an inconsistency between values obtained from these two methods. An example consistency check performed at frequency 1 MHz is presented in Fig.5. The detected inconsistency is 0.3 μV/V and it is lower than the estimated standard uncertainty of the measurement, i.e. 1.3 μV/V.

The inconsistency of measurement results performed at most frequencies was lower than the standard uncertainty of measurement. Only at 1 kHz the inconsistency of measurement (0.9 μV/V) was higher than the standard uncertainty of measurement (0.6 μV/V). However, the consistency result 0.9 μV/V is within the uncertainty range determined by the standard uncertainty of the AC–DC transfer difference of the GUM standard (1 μV/V) and the SUT reference standard (0.4 μV/V) [4].

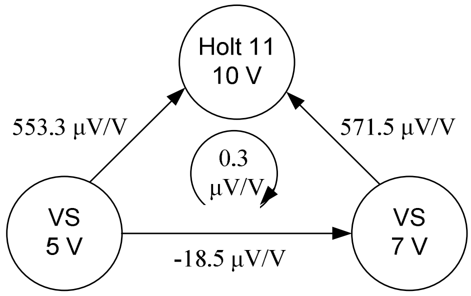

Fig.5. The consistency of AC–DC transfer differences at 1 MHz.

6. Comparison of the results

The AC–DC transfer difference of GUM's Holt 11 standard of input voltage U_N = 10 V was calculated at SUT using results of the performed measurements. The comparison between measured values with values declared by GUM is presented in Fig.6.

The AC–DC transfer difference of this TVC for frequencies above 100 Hz was calculated as the sum of results of performed measurements and theoretically calculated value of AC–DC transfer difference of SUT's reference TVC. At frequencies below 100 Hz, the AC–DC transfer difference of 10 V Holt 11 standard was calculated using the reduced power method [5]. The method is based on the fact that the value of AC–DC transfer difference of a TVC for frequencies below 100 Hz decreases when Joule's power in the TVC heater decreases. Particularly, it was determined that between 10 Hz and 100 Hz and at PMJTC input voltage below 20 % of its nominal value, the AC–DC transfer difference of the PMJTC is close to zero (<1 μV/V). Hence, a TVC of high sensitivity and of higher nominal input voltage than the TVC under test may serve as a standard in this method. At SUT, an additional PMJTC with U_N = 50 V was used for this purpose.

Fig.6. shows a good consistency between AC–DC transfer differences of 10 V Holt 11 standard measured at the SUT and provided by the GUM, especially at frequencies below 500 kHz. The small inconsistency between the comparison results is visible at higher frequencies. It can be partially caused by a different geometry of the tee, which was used at SUT and at PTB.

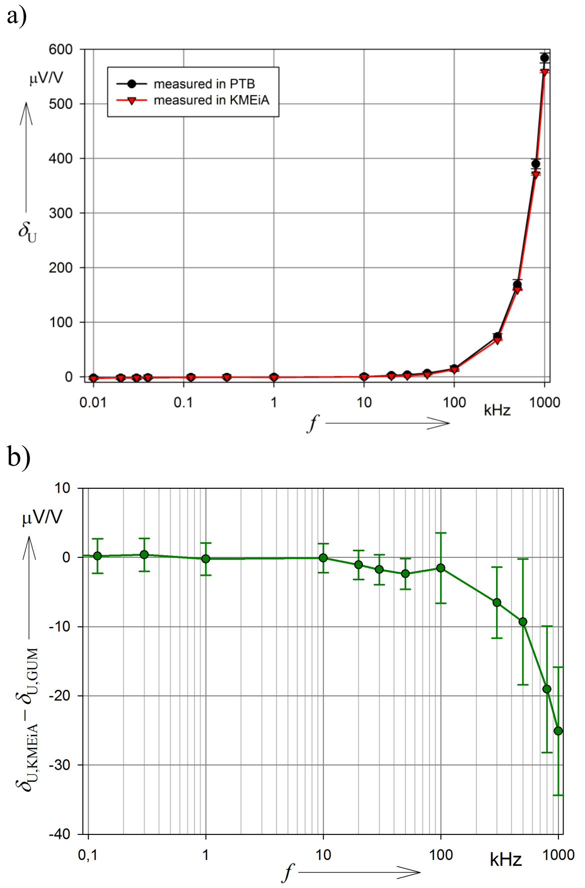

Fig.6. AC–DC transfer of 10 V GUM standard TVC measured at SUT and declared by GUM: a) values of determined AC–DC transfer differences with their uncertainties ($k = 2$)., b) a difference between AC–DC transfer differences measured at SUT and declared by GUM of ($k = 2$).

7. CONCLUSION

The conducted comparison shows a very good consistency of measurements of AC–DC transfer difference of the GUM Holt Model 11 standards performed at SUT with the results of calibration of the TVC performed at PTB. The discrepancy between both results is lower than the combined uncertainty of measurement. The result of this comparison shows correctness of the applied measurement methods, lack of systematic errors in the measurement system and proper estimation of the measurement uncertainty.

REFERENCES

[1] Kampik, M., Grzenik, M., Szutkowski, J., Zawadzki, P. (2018). Bilateral comparison of thermal ac voltage standards. *Przeglad Elektrotechniczny (Electrical Review)*, 94 (11), 63-66. (in Polish)

[2] Kampik, M., Domański, W., Grzenik, M., Majchrzak, K., Musioł, K., Tokarski, J. (2014). System for stabilization of environmental conditions in the Laboratory of AC-DC Standards. *Pomiary Automatyka Kontrola (PAK)*, 2, 73-76. (in Polish)

[3] Grzenik, M., Kampik, M. (2017). Calculable AC voltage standards for 10 kHz-1 MHz frequency range. *IEEE Transactions on Instrumentation and Measurement*, 66 (6), 1372-1378.

[4] Kampik, M., Grzenik, M., Lippert, T., Trinchera, B. (2017). Comparison of a planar thin-film thermal AC voltage standard up to 1 MHz. *IEEE Transactions on Instrumentation and Measurement*, 66 (6), 1379-1384.

[5] Funck, T., Kampik, M., Kessler, E., Klonz, M., Laiz, H., Lapuh, R. (2005). Determination of the AC-DC voltage transfer difference of high-voltage transfer standards at low frequencies. *IEEE Transactions on Instrumentation and Measurement*, 54 (2), 807-809.

[6] Fujiki, H. (2008). Improvement of the voltage dependence of high-voltage AC-DC transfer differences at the NMIJ. *IEEE Transactions on Instrumentation and Measurement*, 57 (9), 1992-1997.

[7] Grzenik, M., Kampik, M. (2018). Determination of frequency-independent component of AC-DC transfer difference of SUT's calculable AC voltage standards. In *2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*. IEEE.

[8] Grzenik, M., Kampik, M. (2019). Determination of AC-DC transfer difference of calculable thermal voltage converters in 1-30 MHz frequency range. *IEEE Transactions on Instrumentation and Measurement*, 68 (6), 2072-2077.

[9] Kampik, M., Grzenik, M., Lippert, T., Rydler, K.-E., Tarasso, V. (2018). Trilateral comparison of a planar thin-film thermal AC voltage standard in frequency range 1 MHz - 30 MHz. In *2018 Conference on Precision Electromagnetic Measurements (CPEM 2018)*. IEEE.

[10] Kampik, M., Tokarski, J., Barwinek, W., Kurczalski, M. (2016). A fast-reversed DC voltage/current source to measure frequency-independent AC-DC transfer difference of thermal voltage converters. *Measurement Automation Monitoring*, 62 (1), 2-6.

[11] Klonz, M., Hammond, G., Inglis, B.D., Sasaki, H., Spiegel, T., Stojanovic, B., Takahashi, K., Zirpel, R. (1995). Measuring thermoelectric effects in thermal converters with a fast reversed DC. *IEEE Transactions on Instrumentation and Measurement*, 44 (2), 379-382.

[12] Kampik, M. (2010). Stanowisko do wzorcowania termicznych przetworników wartości skutecznej napięcia przemiennego. *Przeglad Elektrotechniczny (Electrical Review)*, 86 (1), 239-244. (in Polish)

[13] Grzenik, M., Musioł, K., Kampik, M., Sosso, A. (2017). Investigation of selected AC voltage generators for high-frequency AC-DC transfer. In *2017 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*. IEEE.

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