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INVESTIGATING THE TEMPERATURE DEPENDENCE OF AC/DC TRANSFER STANDARD

The two rounds of investigating the dependence of measurement results of the AC/DC transfer difference on a temperature are yielded during the work. This is one of the important metrological characteristics of precise AC/DC transfer standard Fluke 792A that was varied in a heat chamber in the range of temperature from 15 to 25 °C. The first round has consisted 5 observation cycles which were executed for every point at every defined temperature. There were selected nine observation points depending on frequency and voltage level, and six points depending on measuring temperature. The second round clarifies the dubious results obtained in the first one. As a result of the work, the measurement procedure is described, the uncertainty budget is made up and the temperature dependence of the metrological characteristic under study is determined.

Keywords: *AC/DC transfer difference; temperature dependence; thermocomparator Fluke 792A; measurement procedure; uncertainty.*

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Introduction

The State primary standard of the AC electric voltage from 0.1 to 1000 V is developed and operated in the frequency range from 10 Hz to 1 MHz (DETU 08-07-02) for today in Ukraine. DETU 08-07-02 is intended for the metrological support of precision measuring instruments (MI) in the area of AC voltage measurement, participated in two international comparisons and assigned as the guarantor of the unity of measurements in the state in this direction since the comparison results are linked on the results of comparisons national standards of the leading national metrological institutes of the world [1]. DETU 08-07-02 is a complex of precise MI for measuring, reproducing and converting DC and AC voltages. One of the key elements of this complex is the precision thermoelectric comparator Fluke 792A, which is designed to compare the true RMS value of AC voltage with the equivalent value of DC voltage.

The main metrological characteristic of Fluke 792A is the AC/DC transfer difference (TD) which reflects the relative difference between the values of AC and DC voltages at the input of this MI (the condition is that its output signals are equal at the time of measuring the input signals). The manufacturer's specification of this instrument specifies two temperature ranges for which the acceptable limits of TD are indicated as well as related expanded uncertainty [2]. The temperature ranges are ± 5 °C and ± 12 °C from the calibration temperature which is usually 23 °C. The narrower limits of the measurement uncertainty (UM) values are set for the first range of temperatures, while an insignificantly wider are for the second one. But there is no information about the temperature coefficient of MI in this document. So the question about the temperature dependence of TD of Fluke 792A arises.

Overview of publications

One of the works devoted to the study of temperature instability of reference MIs is the illumination of the features of the use of a precision electric power comparator which is a part of the State primary standard of the electric power and power factor DETU 08-08-02 [3]. Also, the study of the temperature coefficient of AC/DC transfer current shunts was performed for wideband power applications in the temperature range from 20 to 30 °C [4].

The investigation of long-term instability DETU 08-07-02 should be illuminated among the papers concerning to Fluke 792A. The main operation in the method of the research is determining the TD of precision thermoconverter relative to Fluke 792A [5]. It is interesting to study the method of disseminating the unit of volt from DETU 08-07-02 to precision thermoconverters in the part influencing UM with variation of the dynamic characteristics of the measurement process with help of Fluke 792A [6].

With regard to the study of the temperature dependence of Fluke 792A, the website of the International Bureau of Measures and Weights BIPM [7] gives out a technical protocol of key comparison CCEM-K11 and CCEM-K11.1 of voltage transfer difference at low voltages under the auspices of the International Committee of Measures and Weights CIPM [8]. There is information in this document, in the section «The travelling standard…», about the temperature coefficient of Fluke 792A that is frequency dependent. The values of this coefficient are given, in particular, for the range of input voltages up to 220 mV like 0, $1 \cdot 10^{-6}$ and $12 \cdot 10^{-6}$ K^{-1} for frequencies up to 20, 100 and 1000 kHz, respectively. The expanded uncertainty with this is reported like $1 \cdot 10^{-6}$ K^{-1} for frequencies up to 100 kHz and $4 \cdot 10^{-6}$ K^{-1} for a frequency of 1000 kHz. However, the procedure for processing the measurement results (RM) and UM is not covered in this source. The authors did not find the information on the temperature dependence of the TD for the higher input voltage ranges. It follows from the available information [8] that is a lack of temperature dependence of TD for frequencies up to 20 kHz and the presence of a small temperature component of the investigated metrological characteristic at a frequency of 100 kHz relative to the expanded uncertainty at this frequency within 1 K. The additional contribution to the expanded uncertainty will be less than 0.5 % in the case of non-consideration of temperature correction.

Setting goals

For a better understanding of the subject, the technological features of the Fluke 792A working must be considered. For this purpose, Fig. 1 shows four variants of the interrelations of input and output quantities.

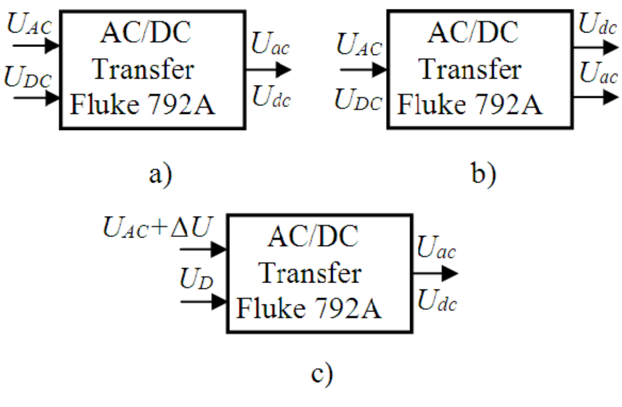

Figure 1 – Interrelations between input and output signals

Variant (a) represents a combination of signals of the investigated thermocomparator when the output signals of the alternating U_{ac} and the direct U_{dc} voltage are equal at the stages of the application of the input alternating U_{AC} and direct U_{DC} voltage, while the condition for determining the TD of the MI is achieved [9].

Variant (b) represents the inverse case when the values of the input voltages coincide, and then it is possible to determine the TD with the opposite sign, taking into account the quasi-linearity of the transmission function of this MI. Such an approach to the definition of this metrological characteristic is realized in the calibration procedure developed by SE «Ukrmetrteststandard» [10] and in the national standard [11].

If the interrelation of input signals is taken off from the state of equality, adding a displacement of the alternating voltage (see variant (c) on Fig. 1), then you can find such value of this input quantity when the output signals will be equal again.

It is worth considering in more detail the process of obtaining information about the actual value of TD of Fluke 792A for the understanding of some nuances.

There is a proportional DC signal at the output of the investigated MI when applying a direct voltage at its input. According to available information [2], it is formed in the measuring path consisting of an input amplifying or dividing unit of electronic components, a measuring unit with an RMS-sensor, an output signal formation unit.

Obviously, the output signal should change as a result of the change in the internal temperature of each element of the measuring path. However, the output signal for applied input AC voltage is formed through the same measuring circuit with the difference that the additional reactive components of the circuit which were in the passive state during the application of input DC voltage. According to the above, the output signal at this operation should also change by approximately the same magnitude, since the difference in the measuring path is only present at the stage before the AC/DC transformation of the signal. The results of the observations set out in [8] indicate a change in the difference between the magnitudes of the output signal at the two specified operations at about 1 uV/V at a frequency of 100 kHz, most likely due to changes in the characteristics of the reactive components.

The effect of temperature on RM of calibration using this standard should be investigated in a wide range of input voltage values to support high-quality precision measurements of the alternating voltage because of Fluke 792A is a part of the DETU 08-07-02. Particularly relevant, this question becomes in the context of the accreditation of the state standards laboratory by international auditors under the auspices of the regional metrological organization COOMET, since the DETU 08-07-02 must be operated in the temperature range from 21 to 23 °C and the temperature of the calibration of Fluke 792A is usually 23 °C.

The above aspects of Fluke 792A application which is a part of DETU 08-07-02 allow to focus an attention on the relevance of the investigation of the temperature dependence of TD of Fluke 792A over a wider range of voltage and to understand the features of the following measurement procedure.

Thus, the purpose of the work is highlighting the measurement procedure, making up the uncertainty budget and determining the temperature dependence of TD of Fluke 792A for taking into account the effect of temperature on the results of disseminating the AC voltage unit to a less accurate MI.

Research method

The basis of research is an assumption about invariability or negligible variation of actual values of deviation Δ_{5720} of output signal of the calibrator Fluke 5720A and deviation of multimeter Agilent 3458A (that is included in total deviation Δ_{Σ}) from the conventional true values of electric voltage in these points on condition of constant connection leads and parameters of surrounding air (first of all, temperature). Furthermore, it is necessary to remember that Fluke 792A converts input signal with some transmission ratio K. An additional condition is an invariability or negligible variation of the internal temperature of mentioned MIs. The last requirement could be satisfied with help of the conditioner (we succeeded to retain a temperature in the range from 22,15 to 22,66 °C during six hours, that is average velocity of temperature variation did not exceed 0,1 °C in one hour).

There was used heat chamber Memmert ICP400 for the creation of necessary temperature level which surrounds investigated MI for determination of temperature dependence of TD of Fluke 792A. The thermocomparator was placed in the determined temperature conditions with adjusting accuracy ±0.1 °C during two hours. There was placed thermohygrometer Testo 608-H1 in a middle of this chamber, in order to avow the displaying of the heat chamber which was calibrated previously. It is interesting to define the dependence of TD of investigated thermocomparator on the surrounding temperature variation in a range from 15 to 25 °C for the scientific and production necessities of the research department of the electric measurements. An interval was selected in two degrees for change fixing of investigated metrological characteristic, that is the determination of TD was executed in six points of one frequency of one magnitude alternating voltage (for research was select frequencies 20 Hz, 1 and 100 kHz in all).

It is possible to research the temperature dependence of TD of investigated thermocomparator using a measuring scheme that is represented in Fig. 2.

The multimeter Agilent 3458A has a function of displaying the value of internal temperature that allows to obtain information about this parameter of MI and to surmise about the internal state of Fluke 5720A. The observation on the time of obtaining the stable temperature inside chassis of multimeter Agilent 3458A in the laboratory of SE «Ukrmetrteststandard» with the volume of air about 65 cubic meters allowed to get conclusion about passing to the quasi-stable internal temperature state during about four hours continuous work, when variation velocity of this parameter does not exceed 0.1 °C and probably, depends on the temperature of surrounding air. The judgment about internal temperature of Fluke 5720A can be formed leaning on state information of multimeter Agilent 3458A, as there is no analogical possibility for the first MI. Then we could assume the possibility of temperature equilibrium achievement approximately in the same temporal borders for both MIs.

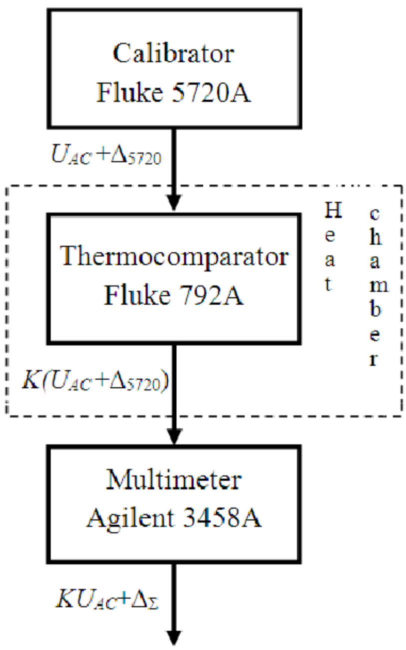

Figure 2 – A measuring scheme for investigating the temperature dependence

The involved MIs were warmed up for at least 150 minutes and Fluke 792A was been in the given temperature conditions for two hours. After that, the output signal of Fluke 792A was measured with the help of multimeter Agilent 3458A when the voltage of the determined value and frequency was applied to the input of the MI. The readout of the multimeter was fixed ten times and, after that, the DC voltage of the positive polarity of the equivalent magnitude was applied to the input of Fluke 792A in the second stage. The readout of the multimeter was fixed ten times and, after that, the voltage polarity was changed to negative and output signal of MI was again recorded 10 times in the third stage. Such manipulations were performed five times for each observation point. Thus, the full information about the TD at any point consisted of 50 observation results of the alternating voltage, 50 observation results of the direct positive and 50 observation results of the direct negative voltage.

Further processing of the measurement data array was carried out according to the formula

$$\overline{U}_j = \frac{\sum_{i=1}^{50} U_{ji}}{50}, \quad (1)$$

where j is a number of observation stage (from 1 to 3);

i is a number of observation result U_j.

The final RM was determined by the formula

$$\delta_{5720} = \frac{2 \cdot \overline{U}_1}{\overline{U}_2 + \overline{U}_3} - 1, \quad (2)$$

where $\overline{U}_1$, $\overline{U}_2$, $\overline{U}_3$ are the average arithmetic values of the multimeter readouts at the measurement of the electrical voltage at the first, second and third stages, respectively, which were calculated by the formula (1).

It should be noted that RM by expression (2) is proportional to the deviation of the RMS value of input AC voltage at the investigated point from the equivalent value of DC voltage without excluding the TD of Fluke 792A itself.

The generally accepted definition of TD requires the application of AC and DC voltages at the input of the thermocomparator when the corresponding output signals acquire equal values (see variant a) of Fig. 1) [9]. The Fluke 792A has a quasi-linear transmission characteristic [2] and consequently, the TD definition will be valid for the same formula with only the opposite sign when the outputs are used instead of the inputs (the condition is that the input signals are equal during the measurements, like in variant b) of Fig. 1), i.e.

$$\delta_{792} = 1 - \frac{2 \cdot U_{ac}}{U_{pdc} + U_{ndc}}, \quad (3)$$

where U_{ac} is the value of the output signal of Fluke 792A when AC voltage is applied to its input;

U_{pdc}, U_{ndc} are the values of the output signals of Fluke 792A when equivalent DC voltages of positive and negative polarity, respectively are applied to its input.

Taking into account the relative deviations of the multimeter Agilent 3458A readouts from the reference values of the standard during calibration, the expression (2) is converted to

$$\delta_{5720} = \frac{2 \cdot (1+\delta_1) \cdot U_{s1}}{(1+\delta_2) \cdot U_{s2} + (1+\delta_3) \cdot U_{s3}} - 1, \quad (4)$$

where U_{s1}, U_{s2}, U_{s3} are conventional true values of voltage for multimeter indications;

δ_1, δ_2, δ_3 are relative deviations of multimeter indications.

The relative deviations of the multimeter Agilent 3458A from the conventional true values are going to be neglected, taking into account the negligibly small difference between its indications in the first, second and third stages which allows equating these deviations.

The arithmetic mean of the output signal in the first stage can be divided into two components in the expression (2): the value of the voltage which can be equated to U_{ac} and proportional to the deviation of Fluke 5720A's output signal ΔU_{ac} and thus

$$\overline{U}_1 = U_{ac} + \Delta U_{ac}. \quad (5)$$

Using the relation (3) can be obtained

$$\overline{U}_1 = (1 - \delta_{792}) \cdot \frac{U_{pdc} + U_{ndc}}{2} + \Delta U_{ac}. \quad (6)$$

When the temperature of the ambient air around Fluke 792A is fixed equal to the temperature of its calibration, then the ratio

$$U_{pdc} + U_{ndc} = U_{s2} + U_{s3} \quad (7)$$

is right.

In this case, the relation (2), taking into account the expression (4), can be converted to

$$\delta_{5720} = \frac{\Delta U_{ac}}{U_{s2} + U_{s3}} - \delta_{792}. \quad (8)$$

Consequently, taking ΔU_{ac} = const, we obtain the direct dependence of RM on TD of investigated Fluke 792A by the formula (2). We can do the conclusion about changing the TD of the investigated MI by varying the temperature of the heat chamber inner air, calculating RM difference using formula (2).

Evaluating the measurement uncertainty

In order to properly evaluate UM in determining the temperature dependence of TD of Fluke 792A one must find the difference of RM by equation (2) at adjacent points 1 and 2, transforming the expression

$$\delta_{792}(T) = \frac{\frac{2 \cdot U_{12}}{U_{22} + U_{32}} - \frac{2 \cdot U_{11}}{U_{21} + U_{31}}}{T_1 - T_2}, \quad (8)$$

where T_1, T_2 are the temperature values in the heat chamber at the measuring points.

The sensitivity coefficients for each input quantity of the functional relationship (8) must be defined as the first partial derivatives in accordance with the Guide to the expression of UM [12].

The absolute value of the sensitivity coefficient for the voltages measured in the first stage is equal to

$$c_1 = \frac{\partial \delta_{792}(T)}{\partial U_{1k}} = \frac{2}{(T_1 - T_2)\cdot(U_{22} + U_{32})}, \quad (9)$$

where k is a notation of the measuring point.

The absolute value of the sensitivity coefficient for the voltages measured at the second and third stages is equal to

$$c_l = \frac{\partial \delta_{792}(T)}{\partial U_{lk}} = \frac{2\cdot U_{1k}}{(T_1 - T_2)\cdot(U_{2k} + U_{3k})^2}, \quad (10)$$

where l is a notation of the second or third stages.

The absolute value of the sensitivity coefficient for the heat chamber inner temperature is equal to

$$c_T = \frac{\partial \delta_{792}(T)}{\partial T_k} = \frac{\dfrac{2\cdot U_{12}}{U_{22}+U_{32}} - \dfrac{2\cdot U_{11}}{U_{21}+U_{31}}}{(T_1 - T_2)^2}. \quad (11)$$

The uncertainty budget is presented in Table 1.

Table 1 – Uncertainty budget when determining the temperature dependence

m	Input quantity	Estimate of input quantity	Standard uncertainty u_m	Contribution to combined uncertainty
1	U_{11}	$\bar{U}_{11}$	u_{11}	$c_1 \cdot u_{11}$
2	U_{12}	$\bar{U}_{12}$	u_{12}	$c_1 \cdot u_{12}$
3	U_{21}	$\bar{U}_{21}$	u_{21}	$c_2 \cdot u_{21}$
4	U_{22}	$\bar{U}_{22}$	u_{22}	$c_2 \cdot u_{22}$
5	U_{31}	$\bar{U}_{31}$	u_{31}	$c_3 \cdot u_{31}$
6	U_{32}	$\bar{U}_{32}$	u_{32}	$c_3 \cdot u_{32}$
7	T_1	$\bar{O}_1;\Delta_1$	u_{T1}; u_T	$c_T \cdot u_{T1}$; $c_T \cdot u_T$
8	T_2	$\bar{O}_2;\Delta_2$	u_{T2} ; u_T	$c_T \cdot u_{T2}$; $c_T \cdot u_T$
Output quantity		Measurement result	Combined standard uncertainty	Expanded uncertainty
$\delta_{792}(T)$		Equation (8)	u_{2comb}	$k \cdot u_{2comb}$ ($k \approx 2$)

There is used the symbol u in Table 1. In general, it is the type A uncertainty for the corresponding input quantity, but also it notes the type B uncertainty for the correction of the thermohygrometer indication when it is used the subscript T.

Combined standard uncertainty is determined by the formula

$$u_{2comb} = \sqrt{\sum_{m=1}^{8} c_m^2 \cdot u_m^2}\ . \quad (12)$$

Measurement results and uncertainty of defining the temperature dependence

The measurements were made to determine the temperature dependence when the electrical voltage of 0.2, 2 and 5 V at a frequency of 20 Hz, 1 and 100 kHz were applied. As noted above, the temperature points of measurement were chosen 15, 17, 19, 21, 23 and 25 °C.

The determination of temperature dependence took place in two rounds. In the first round, a complete cycle of measurements was carried out at all points starting at a temperature of 15 °C.

In the second round, a clarification of the dubious RMs was made. The results that had values significantly different from the overall consecutive RM were attributed as the dubious RMs.

RM of the first round of the study is presented in Tables 2-4.

Table 2 – Average values of measured input quantities and RM for voltage 0.2 V

T, °C	Output signal value, V, depending on the input voltage			RM, uV/V
	alternating	positive direct	negative direct	
at frequency 20 Hz				
15	1.795153	1.795197	1.795220	-30.9
17	1.795089	1.795142	1.795151	-32.0
19	1.795038	1.795097	1.795089	-30.6
21	1.795003	1.795075	1.795034	-28.7
23	1.794910	1.794986	1.794947	-31.5
25	1.794858	1.794951	1.794885	-33.4
at frequency 1 kHz				
15	1.795202	1.795189	1.795214	0.3
17	1.795140	1.795139	1.795146	-1.4
19	1.795088	1.795093	1.795086	-0.8
21	1.795025	1.795049	1.795010	-2.5
23	1.794977	1.795000	1.794962	-2.2
25	1.794910	1.794944	1.794883	-1.9
at frequency 100 kHz				
15	1.795184	1.795186	1.795213	-8.6
17	1.795123	1.795133	1.795145	-8.9
19	1.795082	1.795099	1.795092	-7.5
21	1.795010	1.795044	1.795006	-8.4
23	1.794962	1.794995	1.794958	-8.1
25	1.794897	1.794941	1.794880	-7.5

In general, the dependencies of RM on temperature which were obtained in the first round of the study seems to have close to the direct lines with peak emissions at some points.

The results of the investigation at a voltage of 0.2 V for a better visual perception are converted to a graphical form in Fig. 3.

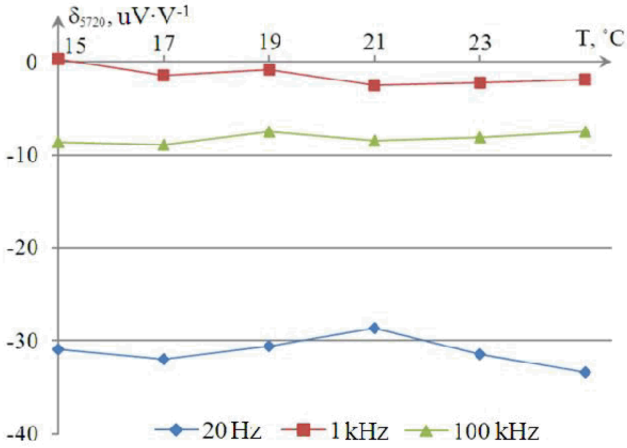

Figure 3 – RM dependence for input voltage 0.2 V

The results of the study on voltage 2 V for Table 3 have been converted to a graphical form in Fig. 4.

Table 3 – Average values of measured input quantities and RM for voltage 2 V

T, °C	Output signal value, V, depending on the input voltage			RM, uV/V
	alternating	positive direct	negative direct	
at frequency 20 Hz				
15	1.694307	1.694362	1.694373	-35.7
17	1.694305	1.694300	1.694312	-0.6
19	1.694212	1.694264	1.694274	-33.6
21	1.694109	1.694162	1.694174	-34.8
23	1.693996	1.694051	1.694061	-35.4
25	1.693914	1.693967	1.693973	-33.1
at frequency 1 kHz				
15	1.694384	1.694362	1.694371	10.3
17	1.694322	1.694299	1.694311	10.0
19	1.694283	1.694261	1.694272	9.7
21	1.694210	1.694188	1.694200	9.4
23	1.694158	1.694135	1.694147	10.0
25	1.694070	1.694048	1.694057	10.3
at frequency 100 kHz				
15	1.694204	1.694363	1.694374	-97.1
17	1.694342	1.694300	1.694312	21.2
19	1.694101	1.694260	1.694271	-97.1
21	1.694029	1.694188	1.694200	-97.4
23	1.693977	1.694134	1.694147	-96.5
25	1.693887	1.694046	1.694056	-96.8

The nature of the temperature dependencies shown in Fig. 3 indicates the inappropriateness of introducing a temperature correction to RM obtained with the application of the thermocomparator in the range of a given temperature.

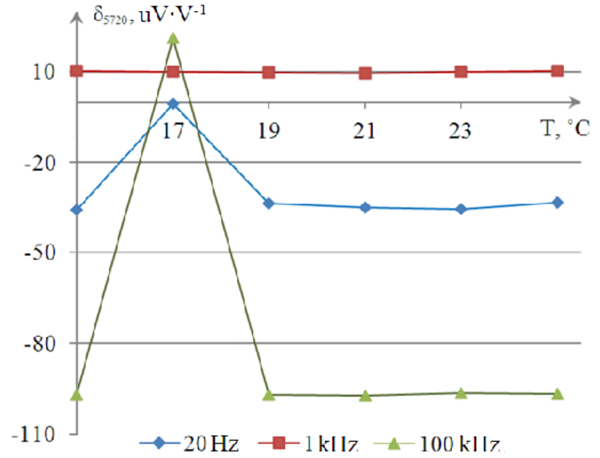

Figure 4 – RM dependence for input voltage 2 V

As can be seen in Fig. 4, during the first round of research recorded jump-off offset of RMs at a temperature of 17 °C at frequencies of 20 Hz and 100 kHz which causes distrust of these RMs.

Table 4 – Average values of measured input quantities and RM for voltage 5 V

T, °C	Output signal value, V, depending on the input voltage			RM, uV/V
	alternating	positive direct	negative direct	
at frequency 20 Hz				
15	1.426868	1.426910	1.426921	-33.3
17	1.426843	1.426877	1.426888	-27.7
19	1.426822	1.426863	1.426873	-32.2
21	1.426782	1.426825	1.426837	-34.3
23	1.426675	1.426719	1.426731	-35.0
25	1.426701	1.426750	1.426756	-36.4
at frequency 1 kHz				
15	1.426905	1.426910	1.426920	-7.0
17	1.426872	1.426877	1.426888	-7.4
19	1.426854	1.426859	1.426869	-7.0
21	1.426809	1.426814	1.426826	-7.5
23	1.426778	1.426783	1.426795	-7.7
25	1.426751	1.426756	1.426767	-7.4
at frequency 100 kHz				
15	1.426937	1.426909	1.426920	15.8
17	1.427000	1.426878	1.426888	82.0
19	1.426917	1.426858	1.426868	37.8
21	1.426756	1.426814	1.426825	-44.3
23	1.426725	1.426783	1.426794	-44.5
25	1.426692	1.426752	1.426763	-45.9

The results of the study on voltages 5 V for Table 4 have been converted to a graphical form in Fig. 5.

As can be seen from Tables 2-4, the spin-off deviations were fixed at a temperature of 17 °C at a voltage of 2 V at a frequency of 20 Hz and 100 kHz and 5 V at a frequency of 20 Hz. Another problem point was the temperature of 19 °C for a frequency of 100 kHz at a voltage of 5 V. Moreover, the displacement at all points occurred in one positive direction. RMs got to a roughly straight line on a frequency of 1 kHz at all observation points and at any given temperature.

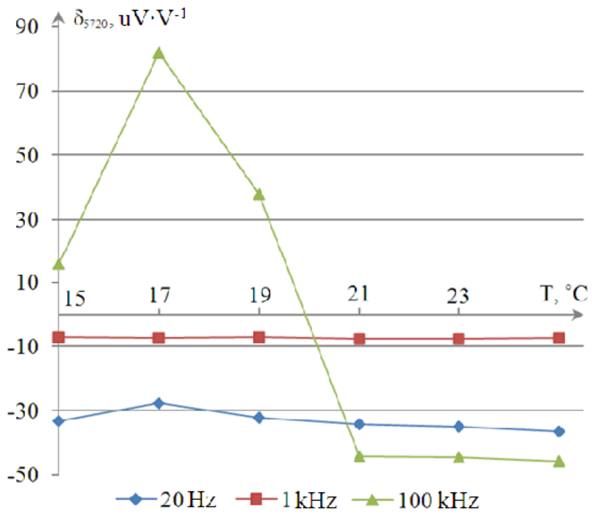

Figure 5 – RM dependence for input voltage 5 V

During the second round, a refinement of jump-off RM offset was made. The refinement was carried out for three values of temperature, two values of frequency and two values of electric voltage. The process was constructed in such a way that observation took place practically throughout the whole period of temperature change in the heat chamber. It was accidental, but the MI was maintained for two hours at a temperature of 15 °C at the beginning.

Periodic measurements were made in accordance with the expressions (1) and (2) in a random manner starting with this temperature and to a temperature different from laboratory to several degrees. It was noted that there was no repetition of previous results at a frequency of 100 kHz for both voltage values in contrast to the frequency of 1 kHz where the repetition occurred. With regard to the frequency of 20 Hz, the results of the second round indicate a straightforward temperature dependence despite the isolated cases of RM deviation.

During the second round of observations, some of the regularities of the Fluke 5720A functioning were noted. It was observed that the output signal of said MI during the observation period took some number of certain values at a frequency of 100 kHz. There were recorded several cases of jump-off RM offset during one measurement stage and after some time the return of RM to the previous value. Since the measurement scheme involves three MIs, this state of affairs may be explained by changes in the internal parameters of some of them. The RM offset was recorded almost entirely at a frequency of 100 kHz which is the evidence of the version about the internal state change of the Fluke 5720A.

The values of RM that were periodically repeated during the first and second rounds for voltage 2 V at frequency of 100 kHz: -97.2; -39.5; -20.5; +21.3 uV/V.

The values of RM that were periodically repeated during the first and second rounds for voltage 5 V at frequency of 100 kHz: -45.6; +15.8; +38.1; +81.6 uV/V.

Throughout the time of observation, a small short-term displacement of the multimeter readings periodically arose which was noticeable at all stages of the measurement. It may have been the effect of internal noise of the Fluke 792A or the multimeter. The materials from previous experimental studies were used in order to take into account the short-term instability of Fluke 5720A [13].

Another factor influencing the RMs is the drift of the output signal of Fluke 792A whose contribution to the combined standard uncertainty has been estimated in accordance with [6] at a level lower than 0.1 uV/V. In general, this agrees with the data of the manufacturer [2].

The final results of determining the temperature dependence of Fluke 792A are presented in Table 5.

Table 5 – The temperature-related change of TD, and the corresponding UM

Temperature range	TD change, $uV \cdot V^{-1} \cdot K^{-1}$	UM, $uV \cdot V^{-1} \cdot K^{-1}$
for voltage 0.2 V and frequency 20 Hz		
15 - 17	0.55	2.62
17 - 19	-0.70	
19 - 21	-0.95	
21 - 23	1.40	
23 - 25	0.95	
Mean	0.25	
for voltage 0.2 V and frequency 1 kHz		
15 - 17	0.85	1.23
17 - 19	-0.30	
19 - 21	0.85	
21 - 23	-0.15	
23 - 25	-0.15	
Mean	0.22	

Continuation of Table 5

Temperature range	TD change, uV·V^{-1}·K^{-1}	UM, uV·V^{-1}·K^{-1}
for voltage 0.2 V and frequency 100 kHz		
15 - 17	0.15	
17 - 19	-0.70	
19 - 21	0.45	1.12
21 - 23	-0.15	
23 - 25	-0.30	
Mean	-0.11	
for voltage 2 V and frequency 20 Hz		
15 - 17	-0.75	
17 - 19	-0.30	1.97
19 - 21	0.60	
21 - 23	0.30	
for voltage 2 V and frequency 20 Hz		
23 - 25	-1.15	1.97
Mean	-0,26	
for voltage 2 V and frequency 1 kHz		
15 - 17	0.15	
17 - 19	0.15	
19 - 21	0.15	0.96
21 - 23	-0.30	
23 - 25	-0.15	
Mean	0.00	
for voltage 2 V and frequency 100 kHz		
15 - 17	-0.10	
17 - 19	0.10	
19 - 21	0.15	1.09
21 - 23	-0.45	
23 - 25	0.15	
Mean	-0.03	
for voltage 5 V and frequency 20 Hz		
15 - 17	-2.80	
17 - 19	2.25	
19 - 21	1.05	2.01
21 - 23	0.35	
23 - 25	0.70	
Mean	0.31	
for voltage 5 V and frequency 1 kHz		
15 - 17	0.20	
17 - 19	-0.20	
19 - 21	0.25	1.28
21 - 23	0.10	
23 - 25	-0.15	
Mean	0.04	
for voltage 5 V and frequency 100 kHz		
15 - 17	0.35	
17 - 19	0.30	
19 - 21	-0.45	1.15
21 - 23	0.10	
23 - 25	0.70	
Mean	0.20	

As can be seen from the table, the average values of the temperature coefficient of the investigated MI do not exceed 0.32 uV·V^{-1}·K^{-1}. In view of UM values and the dispersion of RM, it can be stated that there is no temperature dependence or that it is negligibly small.

Discussions

The authors are inclined to consider the suspicious RMs obtained in the first round as a contribution of the Fluke 5720A. Another voltage source, the calibrator Fluke 5522A, was used during the work to test such an assumption. However, this instrument is considered less accurate and we felt it when it was applied. For example, the scattering of the RM of the output signal of Fluke 792A at a frequency of 100 kHz was an order of magnitude higher than the same characteristic of the initially selected source (type A uncertainty is 4-5 times greater). In addition, the value of the RM obtained in accordance with expression (2) reached +290 uV/V at a voltage of 2 V. Also, the drift of the output direct voltage of Fluke 5522A was estimated to be three times larger than an analogic characteristic of the first voltage source. These circumstances did not allow the use of Fluke 5522A as an alternative source.

Another argument which proves in favor of the previous thesis is the absence of a similar problem phenomenon at a frequency of 1 kHz and has a less clear expression for a frequency of 20 Hz.

A disappointing disadvantage of the study is the lack of technical possibility of the application of the above methodology at a frequency of 1000 kHz since the calibrator Fluke 5720A is deprived of a repeating stable output signal of this frequency.

The authors suppose that the results of the study, in general, are considered to avow about inappropriateness to introduce a temperature correction to the treatment of RM during the transfer of the unit of AC voltage. Since the expanded uncertainty attributed to Fluke 792A during calibration has a minimum of 9 and 4 uV/V at frequencies of 20 Hz and 1 kHz, and the estimated mean values of the temperature coefficient for these frequencies for the corresponding voltage are -0.26 and 0.03 uV/V·K^{-1}, respectively.

Conclusions

The obtained results allow us to state the absence or negligently small degree of influence of the temperature coefficient on the displacement of the TD of Fluke 792A in the temperature range of 15 to 25 °C for three variants of the configuration of the measuring path (with amplifying or dividing the input signal or without scaling).

The measurement procedure of the TD of Fluke 792A temperature dependence research has been proposed and analyzed, as well as the uncertainty sources have been determined and the uncertainty budget has been compiled in the determination of the temperature characteristic.

A number of characteristic values of the output signal of Fluke 5720A are noted, which, obviously, is a constructive feature of specific specimen or type of MI in whole.

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ДОСЛІДЖЕННЯ ТЕМПЕРАТУРНОЇ ЗАЛЕЖНОСТІ ЕТАЛОНУ AC/DC ПЕРЕХОДУ

У складі Державного первинного еталону одиниці електричної змінної напруги є прецизійний термокомпаратор Fluke 792A. Цей прецизійний засіб вимірювальної техніки призначений для різночасового компарування діючого значення змінної напруги з еквівалентним значенням постійної напруги. Найбільше впливає на сумарну невизначеність зазначеного державного еталону Fluke 792A, тобто стандартна невизначеність при вимірюванні його похибки компарування напруги.

У технічній документації цього термокомпаратору відсутня інформація про температурну залежність метрологічних характеристик, що призводить до виникнення додаткових запитань щодо невизначеності за температури, відмінної від температури калібрування. Головною проблемою, що вирішується в дослідженні, є підтвердження метрологічної простежуваності результатів вимірювання змінної напруги при калібруванні прецизійних засобів вимірювальної техніки відносно державного еталону одиниці цієї фізичної величини в діапазоні температури застосування.

Робота з дослідження залежності результатів вимірювання похибки компарування напруги від температури виконувалася у два раунди. Ця важлива метрологічна характеристика термокомпаратору Fluke 792A варіювалася в діапазоні температур від 15 до 25 °C у тепловій камері. Перший раунд складався з 5 циклів спостереження, які виконувалися для кожної точки за кожної визначеної температури. Кожен цикл спостереження складався з трьох етапів почергового подання напруги різного роду чи полярності на вхід термокомпаратору Fluke 792A.

Похибка компарування напруги визначалась опосередковано через змінення відхилення вихідного сигналу змінної напруги високоточного калібратору Fluke 5720A від його ж еквівалентного сигналу постійної напруги. Було обрано дев'ять точок спостереження залежно від частоти та рівня напруги та шість точок залежно від температури при вимірюванні. Другий раунд уточнює сумнівні результати, отримані в першому.

На етапі планування дослідження було розроблено метод та описана процедура вимірювання. За результатами аналізу чинників, котрі впливають на точність вимірювання, був складений бюджет невизначеності. Після виконання експериментальних робіт визначена температурна залежність досліджуваної метрологічної характеристики.

Ключові слова: *похибка компарування; температурна залежність; термокомпаратор Fluke 792A; методика вимірювання; невизначеність.*

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ИССЛЕДОВАНИЕ ТЕМПЕРАТУРНОЙ ЗАВИСИМОСТИ ЭТАЛОНА AC/DC ПЕРЕХОДА

Работа по исследованию зависимости результатов измерений погрешности компарирования от температуры выполнялась в два раунда. Одна из важных метрологических характеристик высокоточного эталона AC/DC преобразования Fluke 792A варьировалась в диапазоне температур от 15 до 25 °C в тепловой камере. Первый раунд состоял из 5 циклов наблюдения, которые выполнялись для каждой точки при каждой определенной температуре. Были выбраны девять точек наблюдения в зависимости от частоты и уровня напряжения и шесть точек в зависимости от температуры при измерении. Второй раунд уточняет сомнительные результаты, полученные в первом. Результатами работы является описанная процедура измерения, составленный бюджет неопределенности и определенная температурная зависимость исследуемой метрологической характеристики.

Ключевые слова: *погрешность компарирования; температурная зависимость; термокомпаратор Fluke 792A; методика измерения; неопределенность.*