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Power Frequency Characterization of Resistance Decade Box for Calibrating AC Comparator

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Abstract— To evaluate the accuracy of AC comparators, it was suggested to use the resistance decade box in previous work. In this case, the reactive component of the resistance affects the measurement uncertainty. The results of determining the relationship between the active and reactive components of the P4834 resistance decade box, arising at the power grid frequency, are presented in the paper. Two methods for frequency characterization of this device were applied. The first involves the use of a multifunctional AC comparator which allows operator to measure the components of the electrical conductance, as well as the power factor. The second method requires the use of an AC/DC transfer standard and a stable current source. The use of both methods made it possible to verify the correctness of the data obtained and to evaluate the relative contribution of reactance when using the resistance decade box in a calibration at an industrial frequency.

Index Terms— comparator, frequency, measurement uncertainty, resistance decade box, voltage.

1 Introduction

THE modern calibration devices for current transformers allow to determine the current ratio error and phase displacement at the level of 1 μA/A and 1 μrad, respectively. However, the measurement uncertainty from the use of one of these devices may not be less than 2 μA/A and 8.73 μrad according to the manufacturer's specification [1]. To verify the accuracy of such an alternating current (AC) comparator, a method of determining the reference values using an oscilloscope was proposed earlier [2]. The application of this method with some refinement may allow the measurement uncertainty to be several times smaller than the intrinsic uncertainty of the AC comparator. In accordance with established metrological practice, the ratio between the uncertainty of the standard and the uncertainty of the calibrated device shall be 4 to 1. One of the sources of uncertainty in this method arises when using a resistance decade box (RDB) to determine the difference in currents. In the mentioned method [2], it is stated that the metrological characteristic of RDB should be specified for application at industrial frequency.

Many characteristics of physical processes or objects can be determined analytically or experimentally. For electrical measurement, electrical resistance is often an important feature of objects. Concerning the determination of electrical resistance when direct current (DC) flows through a pair of rectangular conductors, a method of estimating the resistance of the strips was described when the skin depth is small in relation to the thickness of the strips [3]. But when switching to AC, there are influence of frequency-dependent effects on change the value of the resistance of the conductor. A method for calculating frequency-dependent resistance was discussed where skin- and proximity-effects were considered for axially symmetrical conductors [4]. In addition to the cases mentioned, the resistance and internal inductance of a solid cylindrical conductor can also be calculated. Simple formulation was obtained using the Fourier transform method and allowed to build frequency dependence of conductor resistance and internal inductance [5]. The impedance calculation of the cable in the mains was improved by the allocation of circular magnetic fluxes and longitudinal magnetic fluxes [6]. An accuracy of the typical AC resistance calculation methods was also analyzed taking into account fringing-effect losses [7].

As noted, AC resistance can be determined by measurement. In particular, the ratio of two reference resistors of both 100 Ω and 1000 Ω was experimentally determined using a current comparator at low frequency [8]. The specialists of the National Metrology Institute of United Kingdom constructed an automated coaxial AC resistance bridge to solve the problems of daily calibration of electrical resistance measures in the frequency range from 25 Hz to 10 kHz [9]. It is also necessary to mention systems based on the Hall quantum effect to create metrological support for determining the electrical resistance. It was proposed to apply such a system when calibrating the reactance at a frequency of about 1 kHz [10].

2 Materials of Research

2.1 Overview and Purpose

The State Enterprise "Ukrmetrteststandard" (Kyiv, Ukraine) as a calibration laboratory regularly performs the determination of the accuracy of AC comparators. Over the past three years, the accuracy of measuring the ratio error and phase displacement of more than 50 comparators of different types and different manufacturers has been determined. In the previous study, a significant scattering of the measurement results was found when looking for reference values of the same current difference measure [11]. The main contribution to the meas-

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urement uncertainty in the calibration of the current transformer make the burden, the comparator and the connecting conductors. Since reference transformers are subsequently used to calibrate less accurate instrument transformers, their uncertainty is one of the main parts of the uncertainty in calibrating the conventional transformers. The AC comparators are used in both stages of determining the transformation ratio. An AC comparator is a device that measures the difference between two currents (secondary currents of both the calibrated transformer and the standard). Also, this device measures the secondary current of the standard, and the microprocessor calculates the values of two measured values, i.e. ratio error and phase displacement [1].

As mentioned above, when using the method of determining the reference values with the help of an oscilloscope, one should apply RDB. An example of such a device is P4834 decade box, the general view of which is shown in Fig. 1.

Fig. 1. General view of P4834 resistance decade box

The current difference flows through such a resistance creating a voltage drop [12]. Depending on the value of the simulated error of the current transformer, the electrical resistance should be selected so that the voltage drop will be at least 100 mV. This value is necessary to reduce the contribution of electromagnetic interference to the measurement uncertainty. Since the P4834 decade box is mainly used in DC circuits, one need to evaluate an additional uncertainty due to parasitic reactive components at power frequency of 50 or 60 Hz. This is the most relevant frequency, since the vast majority of current transformers is used in industrial power supply systems.

The purpose of this work is to clarify the contribution of RDB to the total measurement uncertainty when applying the method of determining the reference values using an oscilloscope.

To achieve this goal, the following tasks are formulated:

- to determine the ratio between the active and reactive components of the electrical resistance of the P4834 decade box using an electrical conductance meter;
- to determine with high accuracy the magnitude of the voltage difference at the terminals of the P4834 decade box when changing DC by equivalent AC using a precision AC/DC transfer standard;
- to carry out a comparative analysis of the data obtained.

2.2 Methodology

Since the intermediate task is to determine the ratio between the active and reactive components of RDB, it is worth considering some applicable electrical engineering provisions. In general, such a device is used mainly in DC circuits and is characterized by a conventional true value of electrical resistance and uncertainty of this value. In order to use such a means to solve the task of determining the reference values for the calibration of the AC comparator, it is necessary to take into account the additional reactive components that arise when AC flows. In general, the impedance Z of some value of RDB can be represented by the expression

$$Z = R + jX \tag{1}$$

where R is active component of impedance; jX is reactive component of impedance.

If the active and reactive components are arranged in parallel then the impedance value will be determined by the expression

$$|Z| = R \cdot X \big/ \sqrt{R^2 + X^2} \tag{2}$$

In this case, the current will be distributed inversely in proportion to the resistance, for example, as shown in Fig. 2.

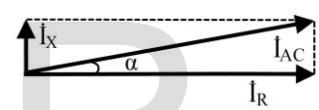

Fig. 2. Phasor sum of AC components through resistance decade box.

The angle α characterizes the phase shift between current and voltage, and the cosine of this angle is determined by the ratio of current through the active component I_R to the current I_{AC} through the P4834 decade box.

The reactive component consists of the inductance of the conductive coils of RDB and the stray capacities. Therefore, to clarify the contribution of an electrical resistance of RDB at an industrial frequency, it was necessary to characterize the total reactive component.

One of the steps for this was to determine the ratio between active and reactive components using the CA507 comparator which has the function of measuring the conductance at an industrial frequency. The design of this device uses a phasor-measuring analog-to-digital converter, which decomposes the measured AC signal into the orthogonal components [1]. According to the specification, the intrinsic uncertainty of measurement of this device in the voltage range from 6 to 30 V will be from 1.3 to 3.5 of microsiemens (μS) depending on the measured active conductance (from 25 to 500 μS). But if one want to determine not the absolute value but the ratio, then the intrinsic uncertainty is not critical. Measurement results which have close values will be shifted to approximately the same value relative to the conventional true value (in the study of the reactive component this is a significant note). The measurements were performed according to the scheme in Fig. 3, and the measurement results were fixed directly in the instrument memory and on the instrument display.

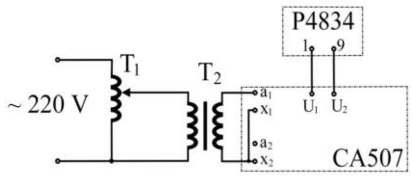

Fig. 3. Measurement scheme for determining the ratio between active and reactive components based on the CA507 comparator

The voltage transmitted to the terminals of the CA507 comparator by means of transformers was measured by this instrument. The voltage was applied to the terminals of the P4834 decade box, which caused current flowing through RDB. The voltage, at which the measurement was made, was 1, 5, 10, 15, and 20 V (at a voltage of 1 and 5 V - for data comparison).

The second step in characterizing the P4834 decade box was to compare the voltage values at the RDB terminals when DC and AC flowed by turns. For accurate comparison of voltage values, it was decided to use a precision Fluke 792A AC/DC transfer standard. Such device is intended for comparing the AC voltage with an equivalent DC voltage. The measurement was carried out according to the scheme shown in Fig. 4.

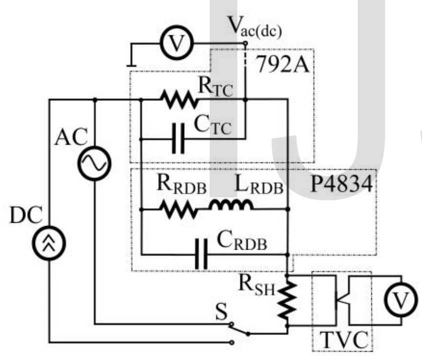

Fig. 4. Measurement scheme for comparison of DC and AC voltages at P4834 terminals based on the 792A AC/DC transfer standard

The precision high-stability Fluke 5720A calibrator was used as the current source. Since the load of such a calibrator should not exceed 1 kΩ for providing the metrological characteristics, precision shunt A40 was used to measure the current accurately. The thermal voltage converter (TVC), whose output was measured using the Agilent 3458A multimeter, was applied as well. The current was defined in two modes, depending on the type of flowing current. The same magnitude of both AC and DC flowed through the precision shunt A40 in turns when the same readouts of the Agilent 3458A multimeter was obtained. The magnitude of both AC and DC was defined on the basis of displaying of the Fluke 5720A calibrator taking into account AC/DC transfer difference of both a precision shunt and a thermal voltage converter. The voltage from the terminals of RDB was transmitted to the input of the 792A AC/DC transfer standard, and the output voltage was measured by a precision DC voltage meter KM300K manufactured by ZIP-Nauchpribor, Russia.

The input circuit of the 792A AC/DC transfer standard has a capacitor and a resistor connected in parallel, and a resistance depends on the input voltage. The current in the circuit is distributed depending on the ratio of the impedances of both RDB and a transfer standard. Table 1 lists the measurement parameters for characterizing the P4834 decade box at an industrial frequency.

TABLE 1
PARAMETERS OF THE MEASUREMENT CIRCUIT WITH USING FLUKE 792A AC/DC TRANSFER STANDARD

Voltage, V	P4834 Current, μA	P4834 Resistance, kΩ	Fluke 792A Resistance, kΩ	Source Current, mA
6.775	1355	5	1.2	7.000
6.750	675	10	1.2	6.300
1.860	93	20	0.42	4.520
0.740	37	20	0.42	1.800
0.720	18.2	40	0.42	1.750
0.108	1.8	60	0.42	0.259

There is a shift of the current phase relative to the voltage due to the presence of a reactive component during AC flowing. Also, the voltage between terminals 1 and 9 of the P4834 decade box varies compared to the value during DC flowing. So, one can determine the relationship between the values of the AC and DC voltages at the terminals of the P4834 decade box by fixing the change in the output voltage of the 792A AC/DC transfer standard depending on the type of current flowing. The Fluke 792A AC/DC transfer standard is characterized by an AC/DC transfer difference δ_{TC} which is the relative difference between the alternating and direct voltage at its input which are connected by the expression

$$V_{AC} = V_{DC} \cdot (1+\delta_{TC}) \quad (3)$$

where V_{DC} is the direct voltage at the input of the transfer standard; V_{AC} is AC voltage at the input of the transfer standard provided the equality of the output signals of both cases.

It is known that the 792A AC/DC transfer standard has a quasi-linear dependence of the output signal on the input voltage [13]

$$V_{ac} = k_{ac} \cdot V_{AC}, \text{ and } V_{dc} = k_{dc} \cdot V_{DC} \quad (4)$$

where k_{ac} and k_{dc} are the conversion factors for AC and DC input voltages which differ due to the presence of reactive components.

If we change the input voltage to the output voltage in expression (3), we can get the ratio

$$V_{AC}/V_{DC} = V_{ac} \cdot k_{dc}/k_{ac} \cdot V_{dc} = k_{dc}/k_{ac} = (1+\delta_{TC}) \quad (5)$$

provided the equality of the output signal for both cases of the input voltage.

The DC, flowing through the P4834 decade box, creates a voltage drop at the terminals

$$V_{DC} = I_{DC} \cdot R \quad (6)$$

When AC is flowing through parallel active and reactive components, the voltage drop is determined by the expression

$$V_{AC} = I_{AC} \cdot R \cdot X \Big/ \sqrt{(R^2 + X^2)} \quad (7)$$

If we divide expression (7) by expression (6), remembering formula (5), we obtain

$$V_{AC}/V_{DC} = V_{ac} \cdot k_{dc} / V_{dc} \cdot k_{ac} = I_{AC} \cdot X / I_{DC} \Big/ \sqrt{\left(R^2 + X^2\right)} \qquad (8)$$

Using formula (5), it is possible to change expression (8)

$$V_{ac}/V_{dc} = I_{AC} \cdot X \Big/ \left[I_{DC} \cdot \sqrt{R^2 + X^2} \cdot \left(1 + \delta_{TC}\right) \right] \qquad (9)$$

The expression (9) is a measurement model that determines the uncertainty of measurement of the output voltage ratio of the 792A AC/DC transfer standard when AC and DC flow in turns. It depends on the uncertainties in the measurement of both DC and AC, the stability of the output signal of the 792A AC/DC transfer standard for both cases, the uncertainty in determining δ_{TC}, and the uncertainty of the values of active resistance and reactance of the P4834 decade box.

3 RESULTS

3.1 Measurement Using CA507 Comparator

The results of the measurement of active and reactive conductance using CA507 comparator are shown in Table 2.

TABLE 2
MEASUREMENT RESULTS WITH USING CA507 COMPARATOR

Voltage, V	Active Conductance, μS	Reactive Conductance, μS	Percentage Ratio of Components	Active Conductance Deviation, μS
1	24.08	2.665	11.06	-0.92
5	25.10	0.554	2.21	0.10
10	25.13	0.235	0.94	0.13
15	25.06	0.216	0.86	0.06
20	25.07	0.138	0.55	0.07
1	48.98	2.712	5.54	-1.02
5	50.09	0.592	1.18	0.09
10	50.23	0.280	0.56	0.23
15	50.19	0.216	0.43	0.19
20	50.19	0.170	0.34	0.19
1	99.58	2.950	2.96	-0.42
5	100.37	0.633	0.63	0.37
10	100.51	0.327	0.32	0.51
15	100.48	0.255	0.25	0.48
20	100.50	0.197	0.20	0.50
1	200.80	0.969	0.48	0.80
5	201.04	0.361	0.18	1.04
10	201.14	0.197	0.10	1.14
15	201.13	0.273	0.14	1.13
20	201.13	0.200	0.10	1.13
1	502.65	1.563	0.31	2.65
5	502.87	0.639	0.13	2.87
10	502.94	0.447	0.09	2.94
15	502.68	0.540	0.11	2.68
20	502.78	0.405	0.08	2.78

Table 2 shows that with increasing measurement voltage minor differences of the reactive component were recorded for all values of active conductance. The percentage ratio of components decreased significantly when the value of a measurand (active conductance) increased. The increase in active conductance deviation is apparently related to both the intrinsic uncertainty of the CA507 comparator and more convenient value to measure the conductance (the CA507 comparator has intrinsic uncertainty of 1 μS in the voltage range from 6 to 30 V).

The dependencies of active conductance deviation on the measurement voltage are graphically presented in Fig. 5.

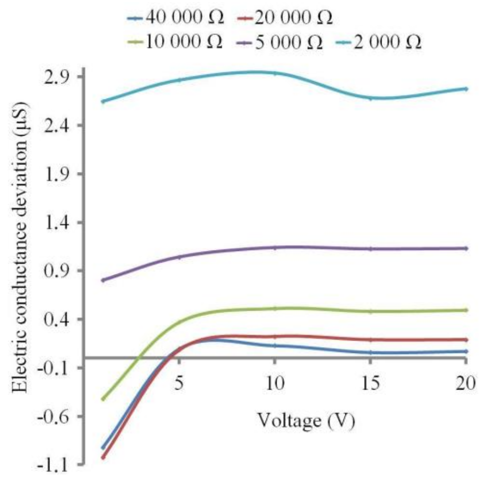

Fig. 5. Active conductance deviation dependencies on both the measurement voltage and the resistance of the Resistance Decade Box

Figure 5 shows that the maximum active conductance deviation relative to the nominal value was fixed for the resistance of 2000 Ω of RDB. It can be seen that the deviation changes almost in proportion to the increase in the measurand. At a voltage of less than 5 V, a noticeable decrease in the measured conductance is visible which is probably a consequence of the influence of electromagnetic interference. However, this effect is less noticeable for smaller values of resistance (i.e. greater conductance). Obviously, this is due to an increase in the current directly measured. It can be seen in Table 2 that the measured values differ less for voltages above 5 V, that is, they can be considered as true enough.

Figure 6 presents the dependencies of reactive conductance on both the measurement voltage and the resistance value of RDB.

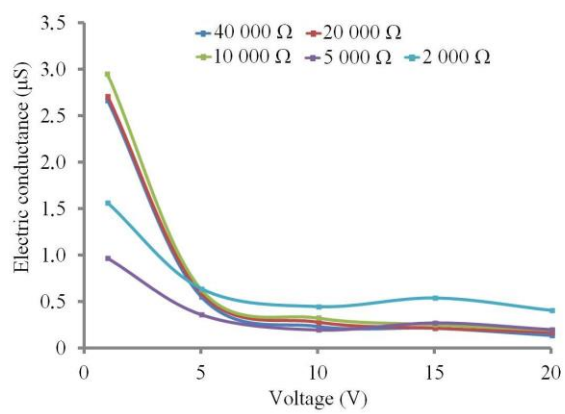

Fig. 6. Reactive conductance obtained depending on both the measurement voltage and the resistance of the Resistance Decade Box

Figure 6 shows that the measured reactive component of RDB had very close values at a voltage greater than 5 V, except 2000 Ω. Although the reactive conductance was obtained almost twice as high for 2000 Ω, but the estimate of the percentage ratio of components was the smallest for this resistance. In the context of the study, the relationship that determines the phase shift of the RDB terminals is of main interest. Given the considerable closeness of the results obtained, it is possible to consider conditionally the reactive component to be unchangeable and almost independent on the value of an active resistance. It looks as if the inductance of the decade coils had a negligible contribution, the parasitic components did not change due to the invariableness of the terminals from which the voltage was transmitted.

An important indicator in the context of the study is the power factor cosφ which characterizes the relationship between the active and reactive components. This parameter was also shown on the CA507 comparator display. We estimated the effect of the reactive component on the phase shift at the given voltage levels by this parameter. The obtained values of cosφ and the corresponding phase shifts are shown in Table 3.

TABLE 3
ASSESSMENT OF INFLUENCE OF REACTIVE COMPONENT OF P4834 DECADE BOX ON PHASE SHIFT APPLYING POWER FACTOR

Characteristic	Value of Resistance Decade Box, kΩ				
	40	20	10	5	2
Average Active Conductance, μS	24.89	49.93	100.29	201.05	502.78
at Voltage of 1 V					
Power Factor	0.9938	0.9984	0.9998	1.0000	1.0000
Phase Shift, °	6.395	3.196	1.208	0	0
at Voltage above 5 V					
Power Factor	1.0000	1.0000	1.0000	1.0000	1.0000
Phase Shift, °	0	0	0	0	0

Table 3 shows that the power factor tended to 1 at a voltage of more than 5 V. That is, when the voltage stated in the specification (above 6 V) was applied, the electromagnetic interference did not distort the measurement result. Since the power factor readout of the CA507 comparator is limited to three decimal places, the contribution of this circumstance to the total measurement uncertainty was 0.0003 when estimating in accordance with GUM 1995 [14]. The corresponding phase shift uncertainty will be about 1.4° for power factor of 0.9997. This uncertainty component should also be taken into account when measuring 1 V. Thus, probably, the greatest effect of the reactive component on the phase shift was noted for the value of 40 kΩ of RDB at a voltage of 1 V. It should be noted that in calibrating the AC comparator, the determination of the current difference magnitude should be performed at different voltages, including 1 V. However, the relative uncertainty decreases for all voltage levels with increasing active conductance (i.e., in decreasing active resistance). However, the minimum uncertainty associated with the least significant digit of the instrument leaves a doubt in measurement (the same 1.4°).

We also estimated the phase shift by the tangent of the angle between current and voltage. Since the reactive conductance was small, the reactance on the contrary was significant. Furthermore, the AC voltage at the RDB terminals decreased within small limits compared to the DC voltage. Therefore, the measured total reactive component, apparently, was parallel to the active component. In the case of a series position, the voltage at the RDB terminals should increase several times. The ratio of reactive conductance to active conductance made it possible to determine the tangent of a given angle. Table 4 shows the calculation of the phase shift values through the tangent for the measured conductance components.

TABLE 4
ASSESSMENT OF INFLUENCE OF REACTIVE COMPONENT OF P4834 DECADE BOX ON PHASE SHIFT APPLYING TANGENT

Voltage, V	Characteristic	Value of Resistance Decade Box, kΩ				
		40	20	10	5	2
1	Tangent	0.1107	0.0554	0.0296	0.0048	0.0031
	Phase shift, °	6.315	3.169	1.697	0.276	0.178
5	Tangent	0.0221	0.0118	0.0063	0.0018	0.0013
	Phase shift, °	1.264	0.677	0.361	0.103	0.073
10	Tangent	0.0094	0.0056	0.0033	0.0010	0.0009
	Phase shift, °	0.536	0.319	0.186	0.056	0.051
15	Tangent	0.0086	0.0043	0.0025	0.0014	0.0011
	Phase shift, °	0.494	0.247	0.145	0.078	0.062
20	Tangent	0.0055	0.0034	0.0020	0.0010	0.0008
	Phase shift, °	0.315	0.194	0.112	0.057	0.046

Table 4 shows that the phase shift did not exceed 0.536° at a voltage of 10 V. At the same time, for the values of 2 kΩ and 5 kΩ of RDB, the phase shift did not exceed 0.276° for all voltage levels. Obviously, the higher the resistance the closer the measured value was to the lower limit of the measurement range, and therefore the confidence in the measurement decreased. The uncertainty due to the least significant digit in such a calculation did not exceed 0.001° when measuring the lowest active conductance value.

3.2 Measurement Using 792A AC/DC Transfer Standard

The results of measuring the voltage change at the terminals of the P4834 decade box are shown in Table 5.

TABLE 5
MEASUREMENT RESULTS WITH USING FLUKE 792A AC/DC TRANSFER STANDARD

P4834 Current, μA	AC Voltage Average Value, V	DC Voltage Average Value, V	AC Average Value, mA	DC Average Value, mA
1355	1.912406	1.912442	6.99985	7.00010
675	1.903502	1.903551	6.30010	6.30009
93	1.498544	1.498573	4.51981	4.52005
37	0.597351	0.597361	1.80071	1.80072
18.2	0.586504	0.586519	1.75060	1.75057
1.8	0.086807	0.086818	0.25931	0.25926

Table 5 shows that the difference between DC and AC did not exceed 0.008 percent. The DC voltage at the terminals of the P4834 decade box exceeded the AC voltage for all measuring points. The input circuit capacitor of the 792A AC/DC transfer standard has 20 pF according to the specification. That is, it has a resistance of about 159 MΩ at a frequency of 50 Hz. Compared to the input resistors with a resistance of 420 Ω or 1200 Ω, it is permissible to consider the input impedance as unchanged, that is, it did not cause redistribution of currents during measurement. This means that the resistance of the P4834 decade box decreased with the AC flow. This is possible if the active and reactive components of RDB were located in parallel. In this case, returning to Fig. 2 and Fig. 4, it can be seen that the current through the active resistance component of the P4834 decade box could be determined by the expression (if the equivalent scheme is represented as parallel active and reactive components)

$$I_R = V_{AC}/R \tag{10}$$

To characterize the P4834 decade box, it is necessary to define a cosine of the angle α as the ratio of I_R to I_{AC}. Remembering that DC and AC were kept equal in measurement, one can get an expression

$$\cos\alpha = I_R/I_{AC} = V_{AC}/\left(R\cdot I_{AC}\right) = V_{AC}/V_{DC} \tag{11}$$

Using expression (5), one can obtain

$$\cos\alpha = \left[V_{ac}\cdot\left(1+\delta_{TC}\right)\right]/V_{dc} \tag{12}$$

Table 6 shows the results of determining the cosine α and the corresponding phase shift depending on the resistance of the P4834 decade box.

TABLE 6
PHASE SHIFT EVALUATION RESULTS WITH USING FLUKE 792A AC/DC TRANSFER STANDARD

Characteristic	Value of Resistance Decade Box, kΩ				
	60	40	20	10	5
Cosine	0.999853	0.999964	0.999977	0.999979	0.999986
Phase Shift, °	0.953	0.491	0.392	0.367	0.299

Table 6 shows that the phase shift between the current through RDB and the voltage at its terminals increased with increasing resistance of the P4834 decade box. This is logically explained by the results obtained. The obtained values of the reactive components in Table 2 had approximately the same small values compared to the active components at a voltage of more than 5 V. But with the increase of active resistance of RDB, the active conductance decreased in proportion. At 60 kΩ, the corresponding conductance is 16.67 µS (the reactive component was measured at the level of 0.2-0.4 µS). With this ratio, the angle in Fig. 2 will be significantly larger than with a ratio of 0.2-0.4 µSm to 500 µS.

3.3 Comparative Analysis of Measurement Results

The obtained phase shifts in both ways did not exceed 1°. At the same time, there was less difference at higher values of active resistance (for 20 kΩ and 40 kΩ). A measurement uncertainty has a large effect on the uniformity of measurement results. We roughly estimated a measurement uncertainty to analyze differences in results.

When using the CA507 comparator, the values of phase shift according to Table 4 were obtained through the ratio of reactive conductance to active conductance. The phase shift in this case was defined as

$$\alpha = \arctan\left(G/B\right) \tag{13}$$

where B and G are active and reactive conductances (input quantities).

In this case, the uncertainty is defined in accordance with GUM 1995 as double root of the sum of the squares of multiplying the sensitivity coefficients by the standard uncertainties [14]

$$U_{CA507} = 2\cdot\sqrt{G^2\cdot u_B^2\bigg/\left(1+\frac{G^2}{B^2}\right)^2\cdot B^4 + u_G^2\bigg/\left(1+\frac{G^2}{B^2}\right)^2\cdot B^2} \tag{14}$$

where u_B and u_G are standard uncertainties of input quantities.

When using the Fluke 792A AC/DC transfer standard, the phase shift values in accordance with Table 6 were obtained through the ratio of the output signals of this instrument when AC and DC flowed through RDB in turns. The angle α in this case was determined by the arccosine of the expression (12). This expression is connected with expression (9), which was analyzed to evaluate a measurement uncertainty. The major contributor to the total uncertainty is the AC estimate. The DC estimate has an order of magnitude less uncertainty. The ratio of the reactance to the sum of the squared resistances under the root at each point is constant and few different from 1. Given the above, in this case, the uncertainty can be estimated by calculating expression (9) in varying the value of AC. Table 7 presents the uncertainty estimation of obtained phase shift assuming AC uncertainty of 0.02 % (using precision ammeter), or 20 µA/A, or 2 µA/A (using precision shunt).

TABLE 7
UNCERTAINTY EVALUATION RESULTS IN MEASURING PHASE SHIFT WITH USING FLUKE 792A AC/DC TRANSFER STANDARD

Uncertainty of Current Measurement, µA/A	Uncertainty of Measurement According to Formula (9), deg., Depending on P4834 Resistance			
	5 kΩ	10 kΩ	20 kΩ	40 kΩ
200	1.090	1.038	0.940	0.776
20	0.310	0.266	0.200	0.126
2	0.071	0.048	0.027	0.014

Table 7 shows that it is possible to achieve an uncertainty of less than 0.1 degrees when using a precision shunt in AC and DC comparison mode.

Figure 7 presents a graphical comparison of the results obtained in two ways. Moreover, the result obtained with the use of precision Fluke A40 shunt instead of precision ammeter is presented. Figure 7 shows that the measurement uncertainty in applying the CA507 comparator is much greater than the uncertainty in applying the scheme of Fig. 4 (this is indicated by the red arrows in the direction of the end of the error bars). It should be noted that the results obtained by the scheme of Fig. 4 are more reliable because the uncertainty estimate is lower. The difference between the results is easily overlapped by the intrinsic uncertainty of the CA507 comparator.

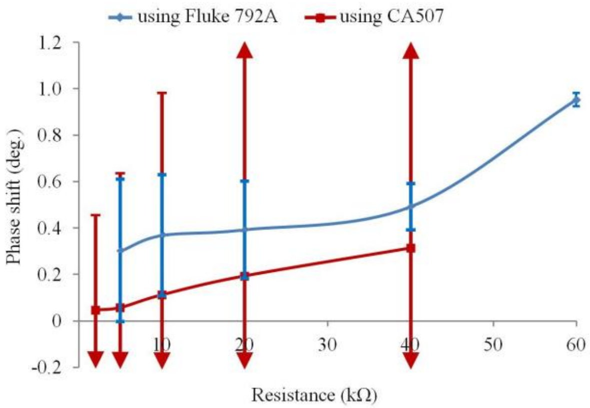

Fig. 7. Comparison of results obtained by means of two methods

In both cases, there is a noticeable tendency to decrease the phase shift while reducing the resistance of the P4834 decade box. When measuring with the CA507 comparator, the point of 60 kΩ was not considered due to the closeness to the lower limit of the active conductance measurement range. The value of 2 kΩ was also not taken into account in the measurement according to Fig. 4, since it did not have a significant effect on the overall result of the study.

Based on the results, we can speak of an increase in the impact of the reactance of the P4834 decade box with increasing its active resistance. Table 7 indicates a tendency to reduce uncertainty with increasing resistance of the P4834 decade box.

4 Conclusions

During metrological characterization of the P4834 decade box at a power frequency, it was found that the maximum phase shift between current and voltage was about 0.5° for rated resistance of 40 kΩ. With a decrease to 5 kΩ, this parameter decreased to approximately 0.3°. Such a phase shift occurred in the presence of a parallel reactive component at the level of units of megaohms. The selected range of resistance values is typical when applying the method with using an oscilloscope to calibrate a unit for characterization of current transformers. The purpose of the work was to clarify the contribution of RDB to the total uncertainty of measurement in the specified method. Since this RDB is used to determine the magnitude of the current difference, the uncertainty of measuring the actual values of the resistance is of great importance. There is also uncertainty of defining the phase shift between the current through RDB and the voltage at its terminals.

To account for the contribution of the phase shift to the total uncertainty, the uncertainty estimates presented in Table 7 can be used. The second option may be to consider the phase shift intervals from 0 to the values of Table 6 as uncertain. The second option may be relevant when such a phase shift does not significantly affect both the results of defining the reference values with using oscilloscope and the corresponding uncertainty estimates.

Two estimate sets of phase shift angles were obtained in the study: using a complex electrical conductance meter and using AC/DC transfer standard. The comparative analysis allowed us to find that the measurement uncertainty estimated for the second method had significantly lower values. Therefore, the results obtained by means of this method are considered to be more reliable.

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