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EVALUATION RESULTS OF COMPARISON OF THE NATIONAL STANDARDS OF CAPACITANCE UNIT

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Abstract – Evaluated results of comparisons of national standards of capacitance unit at 10 pF and 100 pF at 1000 Hz of regional metrology organization COOMET are presented. These results used for confirming calibration and measurement capabilities NMIs and establishing of measurement traceability for concrete working standards and measuring instruments.

Keywords: standard, capacitance, traceability**,** evaluation, comparison.

1. INTRODUCTION

The Mutual Recognition Arrangement (MRA) of International Committee for Weights and Measures (CIPM) for national measurement standards and for calibration and measurement certificates issued by national metrology institutes (NMIs) is a response to a growing need for an open, transparent and comprehensive scheme to give users reliable quantitative information on the comparability of national metrology services and to provide the technical basis for wider agreements negotiated for international trade, commerce and regulatory affairs.

A regional metrology organization (RMO) key comparison (KC) is KCs executed in the framework of a RMOs. For a KC carried out by a RMO the link to the KC reference value (RV) is obtained by reference to the results from those institutes which have also taken part in the CIPM KC. A supplementary comparison (SC) is a comparison, usually carried out by an RMO to meet specific needs not covered by KC (e.g. regional needs), for instance measurements of specific artefacts, or measurements of parameters not within the "normal" scope of the Consultative Committees (CC) of CIPM [1].

SCs are normally organized by the RMOs to cover areas or techniques not covered by KCs. The rules for the participation in CIPM and RMO KCs also apply to CIPM and RMO SCs. The differences are: approval is given by the corresponding RMO committee; degrees of equivalence relative to a SC RV may be computed, but this is not mandatory.

For example, the results of EUROMET.EM-S26 comparison are to be linked to the EUROMET.EM-S20 comparison (two SCs). The link is determined from the results of linking NMIs (PTB, Germany and GUM, Poland). GUM did not use the same measurement set-up in both comparisons. Therefore, it was decided to use only the PTB results to determine the link [2].

In this paper results of COOMET.EM-K4, COOMET.EM-S4 [3] and COOMET.EM-S13 comparisons of the national standards of capacitance unit (10 pF and 100 pF) [4–7] are evaluated. SE "Ukrmetrteststandard" (UMTS, Ukraine) was the pilot laboratory in COOMET.EM-K4, COOMET.EM-S4 and COOMET.EM-S13 comparisons.

COOMET.EM-K4 (S4) comparison was conducted in the framework of COOMET 345/UA/05 project from 2006 to 2009. In this comparison take part seven NMIs: UMTS (Ukraine); PTB (Germany); VNIIM (Russia); NMIJ/AIST (Japan); BIM (Bulgaria); KazInMetr (Kazakhstan); BelGIM (Belarus) [8, 9].

COOMET.EM-S13 comparison was conducted in the framework of COOMET 554/UA/12 project from 2012 to 2013. In this comparison take part three NMIs: UMTS (Ukraine); GUM (Poland); BelGIM (Belarus) [10].

In this paper proposed procedure linking of results COOMET.EM-S13 comparison to the COOMET.EM-K4 (S4) comparison for capacitance unit (10 pF and 100 pF) for UMTS and BelGIM.

2. TRAVELLING STANDARDS FOR COMPARISONS

UMTS (Ukraine) would be responsible for providing the travelling standard, coordinating the schedule, collecting and analyzing the comparison data, and preparing the draft report as the pilot laboratory in COOMET.EM-K4 (S4) and COOMET.EM-S13 comparisons.

For COOMET.EM-K4 (S4) and COOMET.EM-S13 comparisons was selected traveling standards are 10 pF and 100 pF Andeen-Hagerling model AH11A fused silica capacitance standards, mounted in a frame model AH1100, which have next manufacturer specifications:

stability is better than 0.3 ppm/year;

temperature coefficient of the capacitance with respect to changes in ambient temperature is less than 0.01 ppm/°C;

hysteresis resulting from temperature cycling is less than 0.05 ppm;

hysteresis resulting from mechanical shock is less than 0.05 ppm;

AC voltage coefficient is less than 0.003 ppm/volt;

DC voltage coefficient is less than 0.0001 ppm/volt;

power line sensitivity is less than 0.0003 ppm per 1% change in power line voltage;

dissipation factor is less than 0.000 003 tan delta;

power voltage ranges: from 85 to 276 volts;

power frequency: from 48 to 440 Hz;
operating temperature range: 10 °C to 40 °C;
maximum allowable applied voltage: 250 volts peak;
operating humidity range: 0 to 85 % relative humidity, non-condensing.

Measurements conditions for COOMET.EM-K4 (S4) and COOMET.EM-S13 comparisons are shown in Table 1.

Table 1. Measurements conditions.

Comparison	COOMET.EM-K4, COOMET.EM-S13	COOMET.EM-S4, COOMET.EM-S13
Standard	Andeen-Hagerling model AH11A	
Capacitance	10 pF	100 pF
Voltage	from 15 V to 100 V	
Temperature	23 °C ± 3 °C	
Relative humidity	between 30% and 70%	
Frequency	1000 Hz* and 1592 Hz	
* only for COOMET.EM-S13		

3. MAIN RESULTS OF COMPARISONS

The RVs x_{ref} are calculated as the mean of participant results with COOMET comparisons data are given by

$$x_{ref} = \sum_{i=1}^{N} \frac{x_i}{u^2(x_i)} \Big/ \sum_{i=1}^{N} \frac{1}{u^2(x_i)} \qquad (1)$$

with associated standard uncertainty

$$u^2(x_{ref}) = 1 \Big/ \sum_{i=1}^{N} \frac{1}{u^2(x_i)}. \qquad (2)$$

RVs of comparisons and its uncertainties are given in Table 2. All the uncertainties quoted in this paper are expanded uncertainties, having a coverage factor k = 2 which provides a level of confidence of approximately 95%.

Table 2. Reference values of comparisons and its uncertainties at 1000 Hz.

Comparison	Capacitance, pF	RV, μF/F	Uncertainties of RV, μF/F
COOMET.EM-K4	10	–0.190	0.246
COOMET.EM-S4	100	0.688	0.270
COOMET.EM-S13	10	0.952	0.411
	100	1.283	0.594

The degrees of equivalence of the i-th NMI and its expanded uncertainties with respect to the comparison reference value is estimated as

$$D_i = x_i - x_{ref}\ , \qquad (3)$$

$$u^2(D_i) = u^2(x_i) + u^2(x_{ref})\text{''}. \qquad (4)$$

The declared uncertainties are judged as confirmed if the following equation is satisfied

$$|D_i| < 2u(D_i). \qquad (5)$$

On the basis of the measurement results of COOMET comparison and corresponding uncertainties $\{x_i,\ u(x_i)\}$, $i = 1,...N$ claimed by comparisons NMIs, the χ^2 criterion value is calculated [11].

$$\chi^2 = \sum_{i=1}^{N} \frac{(x_i - x_{ref})^2}{u^2(x_i)}\ , \qquad (6)$$

where:

x_i – i-th NMI result of the COOMET comparison;

x_{ref} – reference value with transformed COOMET comparison data;

$u(x_i)$ – uncertainty of i-th NMI result of the COOMET comparison;

N – a number participants of the COOMET comparison.

If the criterion value calculated in accordance with the data provided by NMIs doesn't exceed the critical value χ^2 with the coverage level 0.95 and the degrees of freedom

$$\chi^2 = \sum_{i=1}^{N} \frac{(x_i - x_{ref})^2}{u^2(x_i)} \prec \chi^2_{0.95}(N-1), \qquad (7)$$

then the data provided by different NMIs can be acknowledged as consistent, that is the objective confirmation of the announced uncertainties (Table 3).

Table 3 Values for criterion χ^2 for comparisons

Comparison	Capaci-tance, pF	χ^2	$\chi^2_{0,95}(n-1)$
COOMET.EM-K4	10	1.678	11.071
COOMET.EM-S4	100	2.954	
COOMET.EM-S13	10	0.064	5.992
	100	0.241	

NMI that provides maximum E_N criterion is determined

$$\max_i E_N = \frac{|x_i - x_{ref}|}{2\sqrt{u^2(x_i) - u^2(x_{ref})}}. \qquad (8)$$

Further that NMI's data is temporary excluded from the consideration, and the procedure of checking the comparisons data consistency is repeated. The sequential exclusion of data is repeated until the condition (7) is fulfilled.

The maximum E_N criterion and declared uncertainties for degrees of equivalence all NMIs for 10 pF and 100 pF are judged as confirmed by equations (7) and (8) accordingly.

The degrees of equivalence of the NMIs and its expanded uncertainties (k = 2) in COOMET comparisons with respect to the RV for 10 pF and 100 pF at 1000 Hz are also presented in Tables 4 and 5, and Figures 1 and 2.

4. PRACTICAL EVALUATION OF SOME COMPARISON'S RESULTS

The degrees of equivalence for NMIs – UMTS and BelGIM, which took part in COOMET.EM-K4 (S4) and

COOMET.EM-S13 are shown on Table 5 and Figures 3. NMIJ/AIST made measurements only on 1592 Hz.

Table 4. Degrees of equivalence of the NMIs and its expanded uncertainties for 10 pF at 1000 Hz.

NMI	D_i, μF/F	$U(D_i)$, μF/F	E_n
COOMET.EM-K4			
UMTS	0.110	0.365	0.406
PTB	0.040	0.793	0.053
VNIIM	–0.000	0.268	0.000
BIM	0.490	2.307	0.214
BelGIM	–0.040	2.186	0.018
KazInMetr	–0.350	0.660	0.571
COOMET.EM-S13			
UMTS	0.101	1.125	0.262
GUM	–0.052	0.963	0.207
BelGIM	0.162	2.302	0.151

Table 5. Degrees of equivalence of the NMIs and its expanded uncertainties for 100 pF at 1000 Hz.

NMI	D_i, μF/F	$U(D_i)$, μF/F	E_n
COOMET.EM-S4			
UMTS	0.252	0.372	0.985
PTB	–0.088	0.795	0.118
VNIIM	–0.138	0.306	0.958
BIM	0.312	12.097	0.026
BelGIM	0.346	3.991	0.087
KazInMetr	–0.188	0.795	0.251
COOMET.EM-S13			
UMTS	0.122	1.427	0.308
GUM	–0.263	1.552	0.527
BelGIM	0.366	2.352	0.361

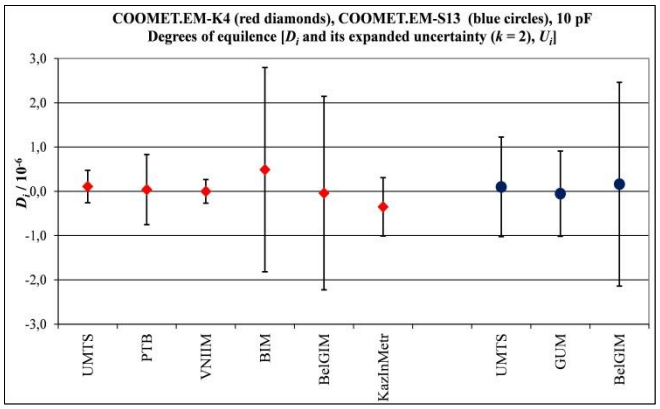

Fig. 1. Degrees of equivalence for 10 pF of the NMIs for COOMET.EM-K4 and COOMET.EM-S13 comparisons.

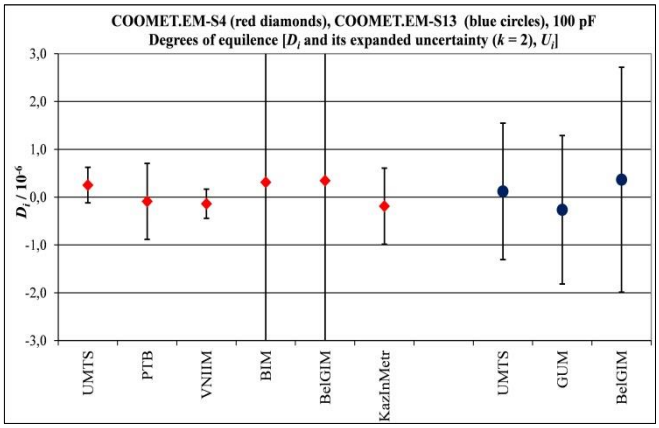

Fig. 2. Degrees of equivalence for 100 pF of the NMIs for COOMET.EM-S4 and COOMET.EM-S13 comparisons.

Table 5. Degrees of equivalence for UMTS and BelGIM and its expanded uncertainties.

NMI	D_i, μF/F	$U(D_i)$, μF/F	Comparison
10 pF			
UMTS	0.110	0.365	COOMET.EM-K4
BelGIM	–0.040	2.186	
UMTS	0.101	1.125	COOMET.EM-S13
BelGIM	0.162	2.302	
100 pF			
UMTS	0.252	0.372	COOMET.EM-S4
BelGIM	0.346	3.991	
UMTS	0.122	1.427	COOMET.EM-S13
BelGIM	0.366	2.352	

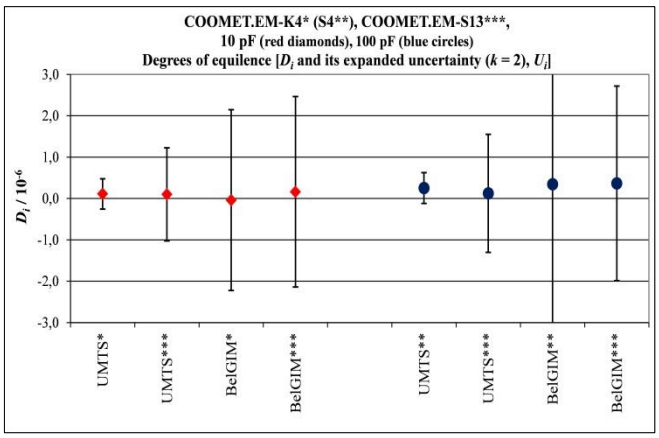

Fig. 3. Degrees of equivalence for UMTS and BelGIM at 10 pF and 100 pF.

The expanded uncertainties of degrees of equivalence of i-th NMI with correlation with the RV for COOMET.EM-K4 and COOMET.EM-S4 comparisons are estimated as

$$U(D_{ci}) = 2\sqrt{u_c^2(x_i) - u_c^2(x_{ref})}\,. \qquad (9)$$

The expanded uncertainties of degrees of equivalence of *i*-th NMI with no such correlation with the RV for COOMET.EM-S13 comparison is estimated as

$$U(D_{nci}) = 2\sqrt{u_c^2(x_i) + u_c^2(x_{ref})}\,. \qquad (10)$$

The expanded uncertainties of degrees of equivalence and recalculated expanded uncertainties of degrees of equivalence by formulas (9) or (10) for UMTS and BelGIM are shown on Table 6.

Table 6. Expanded uncertainties of degrees of equivalence of the NMIs, which took part in all COOMET comparisons

NMI	$U(D_{ci})$, μF/F	$U(D_{nci})$, μF/F	Comparison
10 pF			
UMTS	0.365	0.441	COOMET.EM-K4
BelGIM	2.186	2.200	
UMTS	0.770	1.125	COOMET.EM-S13
BelGIM	2.147	2.302	
100 pF			
UMTS	0.372	0.460	COOMET.EM-S4
BelGIM	3.991	4.001	
UMTS	0.792	1.427	COOMET.EM-S13
BelGIM	2.030	2.352	

Proposed degrees of equivalence for NMIs of COOMET.EM-K4 (10 pF at 1592 Hz) with participants in CCEM-K4 (red), EUROMET.EM-K4 (blue), APMP.EM-K4.1 (green) and COOMET.EM-K4 (brow) are shown on Figure 4.

4. CONCLUSIONS

Results of comparisons of national standards are used for confirming calibration and measurement capabilities NMIs. For each of the joint NMI participants comparisons for equal nominal of quantity can be calculated degrees of equivalence national standards and it uncertainty in term reference value.

Evaluated results of comparisons of national standards of regional metrology organizations are basis for establishing of measurement traceability for concrete working standards and measuring instruments. Presented comparisons of capacitance at 10 pF and 100 pF at 1000 Hz have good agreement between participating laboratories. Measurement traceability is very important for accredited calibration laboratories on national level.

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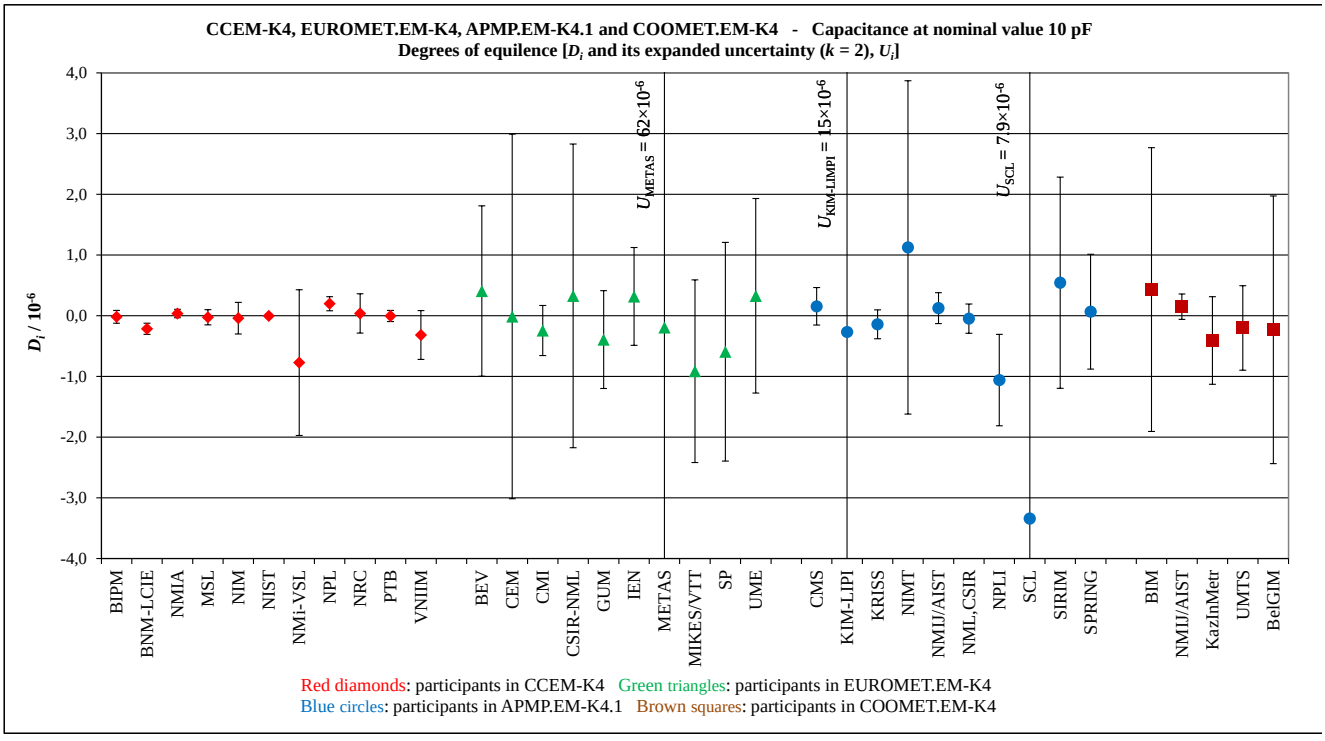

Figure 4. Degrees of equivalence for NMIs with respect to the CCEM-K4 key comparison RV.

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