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Final Report

Euromet Project 599

"COMPARISON OF VOLTAGE RATIO STANDARDS"

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Abstract

Seven European national metrology institutes and one commercial laboratory participated in this international comparison of instrument voltage transformers in the range of primary voltage 5 kV up to 22 kV.

Two instrument voltage transformers (IVT) with transformation ratios (5 and 10) kV/100 V and 22 kV/100 V served as transfer standards. The measured quantities were the voltage ratio error and the phase displacement. The measurements were performed at a frequency of 50 Hz and with a burden of $B = 1$ VA at unity power factor. The errors of the transfer standards were measured with (40, 60, 80, 100 and 120) % of the rated value of the primary voltage.

By result processing it was supposed that results of individual laboratories are not correlated. The comparison reference values (CRVs) and their uncertainties were calculated as weighted means. The consistency of the CRVs was checked using the χ^2 test and Birge ratio. The confidence coefficient E of individual laboratories was calculated for CRVs, which did not pass the Birge ratio test. Results of laboratories with $E > 1{,}5$ were not included in the calculation of the corrected CRVs.

The differences from the CRVs and their uncertainties presented in tables and graphs are the results of the comparison. The good results of this comparison prove the good calibration capabilities of the participants in the field of instrument transformers.

1. Introduction

AC voltage ratio is one of two basic parameters in the area of metrology of instrument transformers and it is very important for the measurement of electric energy. In trade with electric energy, the accuracy of measurement has to be ensured within given limits. To support the many transformer manufacturers relying on national standards as a source of traceability, the comparison of these standards at the European level is of great importance.

The relevant quantity for the measurement of high AC voltage is the ratio of the primary and secondary voltage for an instrument transformer, which is a complex value. The errors of this ratio are given as the ratio error and the phase displacement. These two quantities are the subject of this international comparison.

The Euromet project No. 599 titled “Comparison of voltage ratio standards” started in the beginning of June 2000 with participants from eight European countries including the Czech Metrology Institute (CMI) in Prague as pilot laboratory.

The participating laboratories were asked to follow their usual measurement procedure corresponding to their best measurement capabilities taking into account the allowed time frame for the comparison.

2. Participants

The participants and their affiliation, the eight institutes involved, are listed in Table 1 in order of the transfer standard circulation:

R. Styblíková, K. Draxler	CMI, Czech Metrology Institute, V Botanice 4, 150 72 Prague 5, Czech Republic
J. Gašparovič	SEPS LPT, Slovak electricity transmission system, 919 24 Križovany nad Dudváhom, Slovak Republic
J. Gellén, A. Boros, I. Szunyogh	OMH, National Office of Measures, Nemetvölgyi ut 37-39, 1124 Budapest XII, Hungary
W. Waldmann	BEV, Federal Office of Metrology and Surveying, Arltgasse 35, 1160 Vienna, Austria
B. Paczek	GUM, Central Office of Measures, Elektoralna 2, 00-139 Warsaw, Poland
E-P. Suomalainen	MIKES-HUT, Helsinki University of Technology, High Voltage Institute, Otakaari 5L, 02150 ESPOO, Finland
B. Jeckelmann, R. Kämpfer	METAS, Swiss Federal Office of Metrology and Accreditation, Lindenweg 50, 3003 Bern-Wabern, Switzerland
R. Martin Berjano, F. Garnacho Vecino	LCOE, Laboratorio Central Oficial de Electrotecnia, José Gutiérrez Abascal 2, 28006 Madrid, Spain

Table 1

3. Measured quantities

The measured quantities were the voltage ratio error ε_U and the phase displacement δ_U. The voltage ratio error ε_U is defined as:

$$\varepsilon_U = \frac{U_S\, k_U - U_P}{U_P} \quad . \qquad (1)$$

The phase displacement δ_U is defined as the phase difference between the secondary voltage U_S and the primary voltage U_P; it is considered as positive when the secondary voltage phasor U_S leads the primary voltage phasor,

ε_U:	voltage ratio error [% or ppm],
δ_U:	phase displacement [' or µrad],
U_P:	actual value of the primary voltage [V],
U_S:	actual value of the secondary voltage [V],
k_U:	transformation ratio [-],
B:	burden [VA],
cos β	power factor of burden for sinusoidal waveforms [-].

4. Transfer standards

Standard Voltage Transformer Tettex 4823:

rated primary voltage: (5 and 10) kV
rated secondary voltage: 100 V
rated burden: B = 1 VA real
ser. number: 141'925
accuracy: ± 0.03 %; ± 1.5'
weight: approx. 20 kg

Standard Voltage Transformer Tettex 4820:

rated primary voltage: 22 kV
rated secondary voltage: (100 and 110) V
rated burden: B = 1 VA real
ser. number: 141'885
accuracy: ± 0.03 %; ± 1.5'
weight: approx. 50 kg

5. Organization of the comparison

The transfer standards were transported in two wooden containers, screwed to the bottom and hold in place by styrofoam. It was not necessary to transport the standards personally because they are rather robust devices. Due to the well-constructed transport containers, no damage of the transfer standards occurred during the comparison measurement.

The time schedule of the comparison is apparent from Table 2. The transfer standards were transported around the participating laboratories according to the planed schedule up to September 2001 when they arrived at the CMI in Prague where a second set of measurements was performed. At this point, the Spanish laboratory became interested in this project and the transfer standards were transported to Spain in June 2002. The transformers came back to the pilot laboratory at the end of July 2002 where a further set of measurements was scheduled. These measurements had to be postponed due to serious damages in the pilot laboratory after the flood in August 2002.

CMI Prague, Czech Republic	June 2000
SEPS LPT Krizovany, Slovak Republic	July 2000
OMH Budapest, Hungary	August 2000
BEV Vienna, Austria	September 2000
GUM Warsaw, Poland	June 2001
MIKES-HUT Helsinki, Finnland	July 2001
METAS Bern, Switzerland	August 2001
CMI Prague, Czech Republic	September 2001
LCOE Madrid, Spain	July 2002
CMI Prague, Czech Republic	August 2002

Table 2

6. Measurement methods and conditions

The measurements of the ratio error ε_U and phase displacement δ_U were performed at a frequency of 50 Hz and with a burden of $B = 1$ VA at unity power factor. The errors of the transfer standards were measured with (40, 60, 80, 100 and 120) % of the rated value U_R of the primary voltage.

The participating laboratories performed the measurements according to three basic set-ups.

Method 1: Comparison with a standard transformer

The principle of this method lies in the comparison of a transfer standard with a standard instrument voltage transformer by means of a transformer test set for error evaluation.

Method 2: Comparison with a standard capacitive divider

The principle of this method lies in the comparison of a transfer standard with a standard capacitive divider by means of a transformer test set for error evaluation.

Method 3: Error evaluation by means of standard capacitors and comparator bridge

The ratio of the VT is measured by standard capacitors connected to a current comparator (CC) bridge. Currents through the standard capacitors are compared by means of a CC-bridge. After the CC-bridge is balanced, readings for the ratio and phase displacement are taken.

The participating laboratories and the methods used for the comparison measurements are given in Table 3.

Laboratory	**Method**	**t [°C]**	**Burden B [VA]; cos β**	**f [Hz]**
CMI	1	23,0 ± 0,5	B = (1 ± 0,002) VA; cos β = (1 ± 0,002)	50 ± 0,05
SEPS LPT	2	23,0 ± 1,0	B = 1 VA; cos β = 1	50 ± 0,05
OMH	1	23,0 ± 2,0	B = 1 VA; cos β = 1	50
BEV	1	22,0 ± 2,0	B = 1 VA; cos β = 1	50
GUM	1	22,0	B = 1 VA; cos β = 1	49,95 ± 0,04
MIKES-HUT	3	26,0 ± 1,0	B = (1 ± 0,003) VA; cos β = (1 ± 0,001)	50
METAS	1	23,0 ± 1,0	B = 1 VA; cos β = 1	50
LCOE	1	23 ± 2,0	B = 1 VA; cos β = 1	50

Table 3

7. Used standards and equipment

Austria - BEV

- MWB NUZG 35 standard IVT for ratios (5; 10; 22) kV/100 V
- Zera system for instrument transformer testing for ratios (5; 10) kV/100 V
- Tettex 2767 automatic transformer test set for ratio 22 kV/100 V

Czech Republic - CMI

- Tettex 4820 standard IVT for ratios (5; 10; 22) kV/100 V
- Tettex 2767 automatic transformer test set

Finland - MIKES-HUT

- Micafil PG1 standard capacitor, 100 pF/200 kV
- Tettex 3320 standard capacitors, 1 nF/2 kV; 10 nF/2 kV
- Tettex 2809 current comparator bridge

Hungary - OMH

- standard IVT MWB NUZG 35 for ratios (5; 10; 22) kV/100 V
- voltage transformer measuring bridge VTT, man. TU Budapest

Poland - GUM

- Siemens VT0155 standard IVT for ratios (5; 10; 22) kV/100 V
- Tettex 2767 automatic transformer test set

Slovak Republic - SEPS LPT

- Tettex NVDD 3 standard IVT for ratios (5; 10) kV/100 V
- Tettex 4854b capacitive and electronic divider for ratio 22 kV/100 V
- Tettex 2767 automatic transformer test set

Spain - LCOE

- Tettex 4829A standard IVT for ratios (5; 10; 22) kV/100 V
- Tettex 2767 automatic transformer test set

Switzerland - METAS

- METAS standard IVT for ratios (5; 10; 22) kV/100 V
- MWB TAB 79U voltage transformer test system

8. Traceability

Each participant supplied a statement of traceability for the used standard. Table 4 shows if the measurements are traceable to their own national standards or to another national laboratory.

Laboratory	**Traceable to own national standards**	**Traceable to other national standards**
CMI	x	
SEPS LPT		x
OMH	x	x
BEV	x	
GUM		x
MIKES-HUT	x	
METAS	x	x
LCOE	x	

Table 4

9. Results of measurement

9. 1. Method of results evaluation

The participating laboratories reported the measurement results including uncertainties to the pilot laboratory CMI in Prague, where they were evaluated according to [1]. The pilot laboratory calculated the resulting comparison reference value (CRV) as the weighted mean according to the formula

$$\varepsilon_r = \frac{\sum_{L=1}^{n} \varepsilon_L u^{-2}(\varepsilon_L)}{\sum_{L=1}^{n} u^{-2}(\varepsilon_L)} \quad , \qquad \delta_r = \frac{\sum_{L=1}^{n} \delta_L u^{-2}(\delta_L)}{\sum_{L=1}^{n} u^{-2}(\delta_L)} \quad , \qquad (2)$$

where ε_r, δ_r are reference values for the ratio error and phase displacement,
ε_L, δ_L, results of ratio error and phase displacement of each participating laboratory,
$u(\varepsilon_L)$, $u(\delta_L)$ standard deviations (standard uncertainties) of the ratio error and phase displacement results as reported by the individual laboratories,
n is the number of participating laboratories.

The standard uncertainties of the CRV for the ratio error $u(\varepsilon_r)$ and the phase displacement $u(\delta_r)$ are given by the formulae

$$u(\varepsilon_r) = \frac{1}{\sqrt{\sum_{L=1}^{n} u^{-2}(\varepsilon_L)}} \quad , \qquad u(\delta_r) = \frac{1}{\sqrt{\sum_{L=1}^{n} u^{-2}(\delta_L)}} \quad . \qquad (3)$$

The expanded uncertainties of the reference values for the ratio error $U(\varepsilon_r)$ and the phase displacement $U(\delta_r)$ for a coverage factor $k = 2$ (95 % confidence level) are

$$U(\varepsilon_r) = 2\, u(\varepsilon_r), \quad U(\delta_r) = 2\, u(\delta_r). \tag{4}$$

The differences of the participant's results to the comparison reference values are given as

$$\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r \;\;, \qquad \Delta(\delta_L) = \delta_L - \delta_r \,. \tag{5}$$

The uncertainties of these differences are

$$u(\Delta\varepsilon_L) = \sqrt{u^2(\varepsilon_L) - u^2(\varepsilon_r)} \;,\; u(\Delta\delta_L) = \sqrt{u^2(\delta_L) - u^2(\delta_r)} \tag{6}$$

and the expanded uncertainties of these differences ($k = 2$) are given as

$$U(\Delta\varepsilon_L) = 2u(\Delta\varepsilon_L), \qquad U(\Delta\delta_L) = 2u(\Delta\delta_L) \;. \tag{7}$$

The credibility of the reference value and its uncertainty is characterized by the χ^2 test, given by

$$\chi^2_{obs} = \sum_{L=1}^{n} \frac{(\varepsilon_L - \varepsilon_r)^2}{u^2\,(\varepsilon_L)} \;. \tag{8}$$

The well known Birge ratio is related to the χ^2 as follows:

$$\chi^2 = R_B^2 .(n-1) \tag{9}$$

The consistency is usually regarded as satisfactory if the probability of having a χ^2 greater than the observed one is smaller than 5 %. For 7 degrees of freedom (n = 8), the corresponding upper value for the observed χ^2-test is 14,067 (deduced from the χ^2-test distribution function). This corresponds to a value of 1,42 for the Birge ratio.
Combining equations (8) and (9). the Birge ratio may be expressed as

$$R_B = \sqrt{\frac{\chi^2}{n-1}} \quad = \quad \sqrt{\frac{\sum_{L=1}^{n} u^{-2}(\varepsilon_L).(\varepsilon_L - \varepsilon_r)^2}{n-1}} \tag{10}$$

9. 2. Procedure for result evaluation

1) The CRVs ε_r and δ_r and their standard uncertainties $u(\varepsilon_r)$ and $u(\delta_r)$ were calculated according to (2) and (3). These results are given in Tables 5 and 6 .
2) The χ^2-test and Birge ratio R_B were calculated for the individual CRVs and these results are given in Table 7. The CRVs with $R_B > 1{,}42$ are underlined.
3) The confidence coefficients were calculated for all laboratories where $R_B > 1{,}42$ according to the following formulae

$$E_n(\varepsilon_L) = \frac{|\Delta\varepsilon_L|}{2u(\Delta\varepsilon_L)}, \qquad E_n(\delta_L) = \frac{|\Delta\delta_L|}{2u(\Delta\delta_L)}. \tag{11}$$

These confidence coefficients are given in Table 8. Laboratories with $E_n > 1{,}5$ are underlined.

4) The results of the laboratories with confidence coefficient $E_n > 1{,}5$ were not included in the calculation of the corrected CRVs. Final reference values calculated without these laboratories are given in Tables 9 and 10. Outlier results are underlined.

5) The χ^2-test and Birge ratios R_B for the final reference values were calculated and the results are given in Table 11. It is obvious that all final reference values fulfill the required criterion $R_B < 1{,}42$.

6) The resulting differences between the results of the individual laboratories and the final CRVs calculated according to (5) and their expanded uncertainties calculated according to (6) and (7) are given in Tables 12 and 13.

Note: As the outliers (underlined) are no longer correlated with the CRV, the formulae for the uncertainties $U(\Delta\varepsilon_L)$ and $U(\Delta\delta_L)$ change for the outliers; they become:

$$U(\Delta\varepsilon_L) = 2\sqrt{u^2(\varepsilon_L) + u^2(\varepsilon_r)}, \qquad U(\Delta\delta_L) = 2\sqrt{u^2(\delta_L) + u^2(\delta_r)}$$

7) Graphical results from Tables 12 and 13 are shown in Graphs in Fig. 1 - 30.

10. Final remarks

Eight European laboratories participated in this international comparison of AC voltage ratio standards up to 22 kV at a frequency of 50 Hz. Three different measurement methods were used during the comparison: comparison with a standard transformer, comparison with a capacitive divider and current comparator bridge with standard capacitors. The reference values and their uncertainties were calculated as weighted means according to the above mentioned formulae. The consistency of the CRVs was checked using the χ^2 test and Birge ratio. The confidence coefficient E of individual laboratories was calculated for CRVs, which did not pass the Birge ratio test. Results of laboratories with $E > 1{,}5$ were not included in the calculation of the corrected CRVs.

By result processing it was supposed that results of individual laboratories are not correlated. There is no direct traceability between national standards of participating laboratories in this comparison.

Traceability of national standards of some laboratories on PTB was not taken in to account. The correlated component of resulting uncertainty of individual national standards represents only uncertainty of PTB standards. Other components (burden and its power factor, transformer test set, adjusting of measured voltage etc.) are not correlated.

Test measurements have shown that the temperature coefficient of the transport transformers is very low (smaller than 1 ppm/°C) and therefore no correction needs to be applied even for the laboratories measuring at 22°C or 26°C. Individual laboratories included the temperature influence in to their result uncertainties.

The differences from the CRVs and their uncertainties presented in tables and graphs are the results of the comparison.

The good results of this comparison prove the good calibration capabilities of the participants in the field of instrument transformers.

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References

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RATIO ERROR

		results and standard uncertainties of individual laboratories																reference values		
		CMI		**SEPS LPT**		**BEV**		**OMH**		**GUM**		**METAS**		**MIKES-HUT**		**LCOE**		weighted mean ε_r [ppm]	$u(\varepsilon_r)$ [ppm]	$U(\varepsilon_r)$ [ppm]
k_U [kV/V]	U_N [%]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]			
5/100	40	-343	18	-355	50	-346	23	-425	17	-334	17	-361	12	-360	30	-372	35	-363	7	14
	60	-40	18	-57	50	-47	23	-119	17	-41	17	-67	12	-71	30	-64	35	-65	7	14
	80	141	18	109	50	135	23	71	17	140	17	118	12	114	30	124	35	119	7	14
	100	273	18	240	50	263	23	208	17	267	17	246	12	245	30	249	35	249	7	14
	120	364	18	329	50	363	23	304	17	360	17	337	12	338	30	345	35	342	7	14
10/100	40	-420	18	-434	50	-442	19	-467	17	-425	15	-436	12	-435	20	-452	35	-438	6	13
	60	-201	18	-205	50	-217	19	-240	17	-204	15	-213	12	-215	20	-221	35	-215	6	13
	80	-73	18	-89	50	-92	19	-114	17	-79	15	-90	12	-85	20	-92	35	-89	6	13
	100	4	18	-17	50	-20	19	-36	17	-9	15	-19	12	-16	20	-18	35	-16	6	13
	120	-4	18	-16	50	-8	19	-30	17	9	15	-12	12	-11	20	-12	35	-9	6	13
22/100	40	-86	18	-72	50	-94	21	-104	16	-107	15	-91	13	-116	40	-131	48	-97	7	14
	60	-53	18	-102	50	-53	21	-63	16	-65	15	-49	13	-73	40	-73	48	-58	7	14
	80	-21	18	-110	50	-27	21	-32	16	-41	15	-24	13	-49	40	-50	48	-32	7	14
	100	-17	18	-100	50	-14	21	-25	16	-30	15	-12	13	-37	40	-38	48	-22	7	14
	120	-23	18	-66	50	-20	21	-22	16	-33	15	-11	13	-39	40	-26	48	-23	7	14

Table 5. Results and uncertainties of individual laboratories, reference values and their uncertainty for ratio error

PHASE DISPLACEMENT

		results and standard uncertainties of individual laboratories																reference values		
		CMI		**SEPS LPT**		**BEV**		**OMH**		**GUM**		**METAS**		**MIKES-HUT**		LCOE		weighted mean δ_L [']	$u(\delta_r)$ [']	$U(\delta_r)$ [']
k_U [kV/V]	U_N [%]	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']			
5/100	40	0,513	0,055	0,555	0,15	0,469	0,08	0,498	0,06	0,44	0,09	0,420	0,039	0,527	0,06	0,440	0,12	0,4714	0,0227	0,045
	60	0,235	0,055	0,281	0,15	0,168	0,08	0,213	0,06	0,16	0,09	0,140	0,039	0,245	0,06	0,200	0,12	0,1907	0,0227	0,045
	80	0,096	0,055	0,150	0,15	-0,041	0,08	0,113	0,06	0,02	0,09	0,000	0,039	0,087	0,06	0,030	0,12	0,0476	0,0227	0,045
	100	0,013	0,055	0,068	0,15	-0,149	0,08	0,038	0,06	-0,08	0,09	-0,090	0,039	-0,003	0,06	-0,040	0,12	-0,0403	0,0227	0,045
	120	-0,042	0,055	0,019	0,15	-0,225	0,08	-0,062	0,06	-0,12	0,09	-0,130	0,039	-0,069	0,06	-0,050	0,12	-0,0972	0,0227	0,045
10/100	40	0,944	0,055	1,356	0,15	1,156	0,065	0,942	0,055	1,07	0,09	1,050	0,039	1,123	0,06	1,050	0,12	1,0455	0,0220	0,044
	60	0,795	0,055	1,169	0,15	0,969	0,065	0,863	0,055	0,92	0,09	0,890	0,039	0,965	0,06	0,940	0,12	0,8991	0,0220	0,044
	80	0,790	0,055	1,087	0,15	0,823	0,065	0,835	0,055	0,85	0,09	0,810	0,039	0,885	0,06	0,830	0,12	0,8314	0,0220	0,044
	100	0,902	0,055	1,061	0,15	0,804	0,065	0,825	0,055	0,84	0,09	0,800	0,039	0,867	0,06	0,840	0,12	0,8412	0,0220	0,044
	120	0,989	0,055	1,149	0,15	0,865	0,065	0,863	0,055	0,92	0,09	0,900	0,039	0,955	0,06	0,960	0,12	0,9133	0,0220	0,044
22/100	40	-0,146	0,055	-0,864	0,15	-0,085	0,065	-0,358	0,055	-0,10	0,09	-0,170	0,04	-0,154	0,06	-0,160	0,16	-0,1955	0,0223	0,045
	60	-0,244	0,055	-0,913	0,15	-0,192	0,065	-0,361	0,055	-0,21	0,09	-0,260	0,04	-0,257	0,06	-0,250	0,16	-0,2767	0,0223	0,045
	80	-0,302	0,055	-0,949	0,15	-0,231	0,065	-0,351	0,055	-0,27	0,09	-0,320	0,04	-0,315	0,06	-0,320	0,16	-0,3217	0,0223	0,045
	100	-0,308	0,055	-0,970	0,15	-0,258	0,065	-0,533	0,055	-0,28	0,09	-0,350	0,04	-0,335	0,06	-0,310	0,16	-0,3689	0,0223	0,045
	120	-0,339	0,055	-1,038	0,15	-0,278	0,065	-0,495	0,055	-0,27	0,09	-0,340	0,04	-0,322	0,06	-0,330	0,16	-0,3664	0,0223	0,045

Table 6. Results and uncertainties of individual laboratories, reference values and their uncertainty for phase displacement

		ratio error						**phase displacement**					
		reference values			**CHI-square test and Birge ratio**			**reference values**			**CHI-square test and Birge ratio**		
k_U [kV/V]	**U_N [%]**	weighted mean ε_r [ppm]	**u(ε_r)** [ppm]	**U(ε_r)** [ppm]	CHI^2	CHI^2/n-1	**R_B**	weighted mean δ_L [']	**u(δ_r) [']**	**U(δ_r) [']**	CHI^2	CHI^2/n-1	**R_B**
5/100	40	-363	7	14	18,21	2,60	1,61	0,4714	0,0227	0,045	3,87	0,55	0,74
	60	-65	7	14	14,85	2,12	1,46	0,1907	0,0227	0,045	3,87	0,55	0,74
	80	119	7	14	11,67	1,67	1,29	0,0476	0,0227	0,045	5,69	0,81	0,90
	100	249	7	14	9,37	1,34	1,16	-0,0403	0,0227	0,045	7,21	1,03	1,02
	120	342	7	14	8,85	1,26	1,12	-0,0972	0,0227	0,045	5,62	0,80	0,90
10/100	40	-438	6	13	5,19	0,74	0,86	1,0455	0,0220	0,044	15,90	2,27	1,51
	60	-215	6	13	3,56	0,51	0,71	0,8991	0,0220	0,044	9,81	1,40	1,18
	80	-89	6	13	3,61	0,52	0,72	0,8314	0,0220	0,044	4,64	0,66	0,81
	100	-16	6	13	3,13	0,45	0,67	0,8412	0,0220	0,044	4,82	0,69	0,83
	120	-9	6	13	3,19	0,46	0,67	0,9133	0,0220	0,044	8,77	1,25	1,12
22/100	40	-97	7	14	2,24	0,32	0,57	-0,1955	0,0223	0,045	34,31	4,90	2,21
	60	-58	7	14	1,94	0,28	0,53	-0,2767	0,0223	0,045	23,26	3,32	1,82
	80	-32	7	14	3,98	0,57	0,75	-0,3217	0,0223	0,045	20,17	2,88	1,70
	100	-22	7	14	3,80	0,54	0,74	-0,3689	0,0223	0,045	30,71	4,39	2,09
	120	-23	7	14	2,23	0,32	0,56	-0,3664	0,0223	0,045	29,81	4,26	2,06

Table 7. Reference values, their uncertainty and CHI-square test

k_U [kV/V]	**error**	**U_N [%]**	**CMI**	**SEPS LPT**	**BEV**	**OMH**	**GUM**	**METAS**	**MIKES HUT**	**LCOE**
5/100	ratio error	40	0,61	0,08	0,40	1,98	0,94	0,12	0,06	0,13
5/100	ratio error	60	0,76	0,08	0,43	1,72	0,78	0,08	0,10	0,02
22/100	phase displacement	40	0,49	2,25	0,91	1,61	0,55	0,39	0,37	0,11
22/100	phase displacement	60	0,33	2,14	0,69	0,84	0,38	0,25	0,18	0,08
22/100	phase displacement	80	0,20	2,11	0,74	0,29	0,30	0,03	0,06	0,01
22/100	phase displacement	100	0,61	2,03	0,91	1,63	0,51	0,29	0,30	0,19
22/100	phase displacement	120	0,27	2,26	0,72	1,28	0,55	0,40	0,40	0,12

Table 8. Confidence coefficients for results with $R_B > 1,42$; outllier identification

RATIO ERROR

		results and standard uncertainties of individual laboratories																reference values		
		CMI		**SEPS LPT**		**BEV**		**OMH**		**GUM**		**METAS**		**MIKES-HUT**		**LCOE**		weighted mean ε_r [ppm]	$u(\varepsilon_r)$ [ppm]	$U(\varepsilon_r)$ [ppm]
k_U [kV/V]	U_N [%]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]	ε_L [ppm]	$u(\varepsilon_L)$ [ppm]			
5/100	40	-343	18	-355	50	-346	23	-425	17	-334	17	-361	12	-360	30	-372	35	-351	7	15
	60	-40	18	-57	50	-47	23	-119	17	-41	17	-67	12	-71	30	-64	35	-55	7	15
	80	141	18	109	50	135	23	71	17	140	17	118	12	114	30	124	35	119	7	14
	100	273	18	240	50	263	23	208	17	267	17	246	12	245	30	249	35	249	7	14
	120	364	18	329	50	363	23	304	17	360	17	337	12	338	30	345	35	342	7	14
10/100	40	-420	18	-434	50	-442	19	-467	17	-425	15	-436	12	-435	20	-452	35	-438	6	13
	60	-201	18	-205	50	-217	19	-240	17	-204	15	-213	12	-215	20	-221	35	-215	6	13
	80	-73	18	-89	50	-92	19	-114	17	-79	15	-90	12	-85	20	-92	35	-89	6	13
	100	4	18	-17	50	-20	19	-36	17	-9	15	-19	12	-16	20	-18	35	-16	6	13
	120	-4	18	-16	50	-8	19	-30	17	9	15	-12	12	-11	20	-12	35	-9	6	13
22/100	40	-86	18	-72	50	-94	21	-104	16	-107	15	-91	13	-116	40	-131	48	-97	7	14
	60	-53	18	-102	50	-53	21	-63	16	-65	15	-49	13	-73	40	-73	48	-58	7	14
	80	-21	18	-110	50	-27	21	-32	16	-41	15	-24	13	-49	40	-50	48	-32	7	14
	100	-17	18	-100	50	-14	21	-25	16	-30	15	-12	13	-37	40	-38	48	-22	7	14
	120	-23	18	-66	50	-20	21	-22	16	-33	15	-11	13	-39	40	-26	48	-23	7	14

Table 9. Corrected reference values for ratio error without outliers (outliers underlined)

PHASE DISPLACEMENT

		results and standard uncertainties of individual laboratories																reference values		
		CMI		SEPS LPT		BEV		OMH		GUM		METAS		MIKES-HUT		LCOE				
k_U [kV/V]	U_N [%]	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	δ_U [']	$u(\delta_L)$ [']	weighted mean δ_L [']	$u(\delta_r)$ [']	$U(\delta_r)$ [']
5/100	40	0,513	0,055	0,555	0,15	0,469	0,08	0,498	0,06	0,440	0,09	0,420	0,039	0,527	0,06	0,440	0,12	0,4714	0,0227	0,045
	60	0,235	0,055	0,281	0,15	0,168	0,08	0,213	0,06	0,160	0,09	0,140	0,039	0,245	0,06	0,200	0,12	0,1907	0,0227	0,045
	80	0,096	0,055	0,150	0,15	-0,041	0,08	0,113	0,06	0,020	0,09	0,000	0,039	0,087	0,06	0,030	0,12	0,0476	0,0227	0,045
	100	0,013	0,055	0,068	0,15	-0,149	0,08	0,038	0,06	-0,080	0,09	-0,090	0,039	-0,003	0,06	-0,040	0,12	-0,0403	0,0227	0,045
	120	-0,042	0,055	0,019	0,15	-0,225	0,08	-0,062	0,06	-0,120	0,09	-0,130	0,039	-0,069	0,06	-0,050	0,12	-0,0972	0,0227	0,045
10/100	40	0,944	0,055	1,356	0,15	1,156	0,065	0,942	0,055	1,070	0,09	1,050	0,039	1,123	0,06	1,050	0,12	1,0455	0,0220	0,044
	60	0,795	0,055	1,169	0,15	0,969	0,065	0,863	0,055	0,920	0,09	0,890	0,039	0,965	0,06	0,940	0,12	0,8991	0,0220	0,044
	80	0,790	0,055	1,087	0,15	0,823	0,065	0,835	0,055	0,850	0,09	0,810	0,039	0,885	0,06	0,830	0,12	0,8314	0,0220	0,044
	100	0,902	0,055	1,061	0,15	0,804	0,065	0,825	0,055	0,840	0,09	0,800	0,039	0,867	0,06	0,840	0,12	0,8412	0,0220	0,044
	120	0,989	0,055	1,149	0,15	0,865	0,065	0,863	0,055	0,920	0,09	0,900	0,039	0,955	0,06	0,960	0,12	0,9133	0,0220	0,044
22/100	40	-0,146	0,055	-0,864	0,15	-0,085	0,065	-0,358	0,055	-0,100	0,09	-0,170	0,04	-0,154	0,06	-0,160	0,16	-0,1446	0,0247	0,049
	60	-0,244	0,055	-0,913	0,15	-0,192	0,065	-0,361	0,055	-0,210	0,09	-0,260	0,04	-0,257	0,06	-0,250	0,16	-0,2623	0,0226	0,045
	80	-0,302	0,055	-0,949	0,15	-0,231	0,065	-0,351	0,055	-0,270	0,09	-0,320	0,04	-0,315	0,06	-0,320	0,16	-0,3075	0,0226	0,045
	100	-0,308	0,055	-0,970	0,15	-0,258	0,065	-0,533	0,055	-0,280	0,09	-0,350	0,04	-0,335	0,06	-0,310	0,16	-0,3195	0,0247	0,049
	120	-0,339	0,055	-1,038	0,15	-0,278	0,065	-0,495	0,055	-0,270	0,09	-0,340	0,04	-0,322	0,06	-0,330	0,16	-0,3512	0,0226	0,045

Table 10. Corrected reference values for phase displacement without outliers (outliers underlined)

		ratio error						phase displacement					
		reference values			CHI-square test and Birge ratio			reference values			CHI-square test and Birge ratio		
k_U [kV/V]	**U_N [%]**	weighted mean ε_r [ppm]	**u(ε_r)** [ppm]	**U(ε_r)** [ppm]	CHI^2	CHI^2/n-1	**R_B**	weighted mean δ_L [']	**u(δ_r) [']**	**U(δ_r) [']**	CHI^2	CHI^2/n-1	**R_B**
5/100	40	-351	7	15	2,40	0,40	0,63	0,4714	0,0227	0,045	3,87	0,55	0,74
	60	-55	7	15	2,88	0,48	0,69	0,1907	0,0227	0,045	3,87	0,55	0,74
	80	119	7	14	11,67	1,67	1,29	0,0476	0,0227	0,045	5,69	0,81	0,90
	100	249	7	14	9,37	1,34	1,16	-0,0403	0,0227	0,045	7,21	1,03	1,02
	120	342	7	14	8,85	1,26	1,12	-0,0972	0,0227	0,045	5,62	0,80	0,90
10/100	40	-438	6	13	5,19	0,74	0,86	1,0455	0,0220	0,044	15,90	2,27	1,51
	60	-215	6	13	3,56	0,51	0,71	0,8991	0,0220	0,044	9,81	1,40	1,18
	80	-89	6	13	3,61	0,52	0,72	0,8314	0,0220	0,044	4,64	0,66	0,81
	100	-16	6	13	3,13	0,45	0,67	0,8412	0,0220	0,044	4,82	0,69	0,83
	120	-9	6	13	3,19	0,46	0,67	0,9133	0,0220	0,044	8,77	1,25	1,12
22/100	40	-97	7	14	2,24	0,32	0,57	-0,1446	0,0247	0,049	1,53	0,31	0,55
	60	-58	7	14	1,94	0,28	0,53	-0,2623	0,0226	0,045	4,86	0,81	0,90
	80	-32	7	14	3,98	0,57	0,75	-0,3075	0,0226	0,045	2,29	0,38	0,62
	100	-22	7	14	3,80	0,54	0,74	-0,3195	0,0247	0,049	1,77	0,35	0,59
	120	-23	7	14	2,23	0,32	0,56	-0,3512	0,0226	0,045	9,31	1,55	1,25

Table 11. CHI-square test for corrected results (corrected results underlined)

		differences of the participants results to the reference value and their uncertainties															
		CMI		SEPS LPT		BEV		OMH		GUM		METAS		**MIKES-HUT**		LCOE	
k_U [kV/V]	**U_N [%]**	$\varepsilon_L - \varepsilon_r$ [ppm]	$U(\Delta\varepsilon_L)$ [ppm]	$\varepsilon_L - \varepsilon_r$ [ppm]	$U(\Delta\varepsilon_L)$ [ppm]	$\varepsilon_L - \varepsilon_r$ [ppm]	$U(\Delta\varepsilon_L)$ [ppm]	$\varepsilon_L - \varepsilon_r$ [ppm]	$U(\Delta\varepsilon_L)$ [ppm]	$\varepsilon_L - \varepsilon_r$ [ppm]	$U(\Delta\varepsilon_L)$ [ppm]	$\varepsilon_L - \varepsilon_r$ [ppm]	$U(\Delta\varepsilon_L)$ [ppm]	$\varepsilon_L - \varepsilon_r$ [ppm]	$U(\Delta\varepsilon_L)$ [ppm]	$\varepsilon_L - \varepsilon_r$ [ppm]	$U(\Delta\varepsilon_L)$ [ppm]
5/100	40	8	32	-4	99	6	42	-74	37	17	31	-10	19	-9	58	-21	68
	60	15	32	-2	99	8	42	-64	37	14	31	-12	19	-16	58	-9	68
	80	22	32	-10	99	16	43	-48	31	21	31	-1	20	-5	58	5	69
	100	24	32	-9	99	14	43	-41	31	18	31	-3	20	-4	58	0	69
	120	22	32	-13	99	21	43	-38	31	18	31	-5	20	-4	58	3	69
10/100	40	18	33	4	99	-5	36	-29	30	13	28	2	20	3	38	-14	69
	60	14	33	10	99	-2	36	-25	30	11	28	2	20	0	38	-6	69
	80	16	33	0	99	-2	36	-25	30	10	28	-1	20	4	38	-3	69
	100	21	33	-1	99	-3	36	-20	30	7	28	-3	20	0	38	-2	69
	120	6	33	-7	99	2	36	-21	30	18	28	-3	20	-2	38	-3	69
22/100	40	11	32	25	99	4	40	-7	29	-10	27	6	22	-19	79	-34	94
	60	5	32	-44	99	5	40	-5	29	-7	27	9	22	-15	79	-15	94
	80	11	32	-78	99	5	40	0	29	-9	27	8	22	-17	79	-18	94
	100	5	32	-78	99	8	40	-3	29	-8	27	10	22	-15	79	-16	94
	120	-1	32	-43	99	3	40	1	29	-10	27	12	22	-16	79	-3	94

Table 12. Differences between results of individual laboratories and reference value and their uncertainties for ratio error

		differences of the participants results to the reference value and their uncertainties															
		CMI		SEPS LPT		BEV		OMH		GUM		METAS		**MIKES-HUT**		LCOE	
k_U [kV/V]	**U_N [%]**	δ_L - δ_R [']	U ($\Delta\delta_L$) [']	δ_L - δ_R [']	U ($\Delta\delta_L$) [']	δ_L - δ_R [']	U ($\Delta\delta_L$) [']	δ_L - δ_R [']	U ($\Delta\delta_L$) [']	δ_L - δ_R [']	U ($\Delta\delta_L$) [']	δ_L - δ_R [']	U ($\Delta\delta_L$) [']	δ_L - δ_R [']	U ($\Delta\delta_L$) [']	δ_L - δ_R [']	U ($\Delta\delta_L$) [']
5/100	40	0,041	0,100	0,084	0,297	-0,003	0,153	0,027	0,111	-0,031	0,174	-0,051	0,063	0,056	0,111	-0,031	0,236
	60	0,045	0,100	0,090	0,297	-0,023	0,153	0,022	0,111	-0,031	0,174	-0,051	0,063	0,054	0,111	0,009	0,236
	80	0,048	0,100	0,102	0,297	-0,088	0,153	0,066	0,111	-0,028	0,174	-0,048	0,063	0,039	0,111	-0,018	0,236
	100	0,054	0,100	0,108	0,297	-0,109	0,153	0,078	0,111	-0,040	0,174	-0,050	0,063	0,037	0,111	0,000	0,236
	120	0,055	0,100	0,116	0,297	-0,127	0,153	0,035	0,111	-0,023	0,174	-0,033	0,063	0,028	0,111	0,047	0,236
10/100	40	-0,102	0,101	0,310	0,297	0,111	0,122	-0,104	0,101	0,024	0,175	0,004	0,064	0,077	0,112	0,004	0,236
	60	-0,104	0,101	0,270	0,297	0,070	0,122	-0,036	0,101	0,021	0,175	-0,009	0,064	0,066	0,112	0,041	0,236
	80	-0,042	0,101	0,256	0,297	-0,008	0,122	0,004	0,101	0,019	0,175	-0,021	0,064	0,054	0,112	-0,001	0,236
	100	0,060	0,101	0,220	0,297	-0,037	0,122	-0,016	0,101	-0,001	0,175	-0,041	0,064	0,026	0,112	-0,001	0,236
	120	0,076	0,101	0,236	0,297	-0,049	0,122	-0,050	0,101	0,007	0,175	-0,013	0,064	0,042	0,112	0,047	0,236
22/100	40	-0,001	0,098	-0,719	0,304	0,060	0,120	-0,213	0,121	0,045	0,173	-0,025	0,063	-0,009	0,109	-0,015	0,306
	60	0,019	0,100	-0,651	0,303	0,070	0,122	-0,099	0,100	0,052	0,174	0,002	0,066	0,005	0,111	0,012	0,307
	80	0,006	0,100	-0,641	0,303	0,076	0,122	-0,043	0,100	0,038	0,174	-0,012	0,066	-0,007	0,111	-0,012	0,307
	100	0,011	0,098	-0,651	0,304	0,061	0,120	-0,213	0,121	0,039	0,173	-0,031	0,063	-0,016	0,109	0,009	0,306
	120	0,013	0,100	-0,687	0,303	0,073	0,122	-0,144	0,100	0,081	0,174	0,011	0,066	0,029	0,111	0,021	0,307

Table 13. Differences between results of individual laboratories and reference value and their uncertainties for phase displacement

5 kV/100 V 40 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) [ppm]
CMI	8	32
SEPS LPT	-4	99
BEV	6	42
OMH	-74	37
GUM	17	31
METAS	-10	19
MIKES-HUT	-9	58
LCOE	-21	68
ref. value	0	15

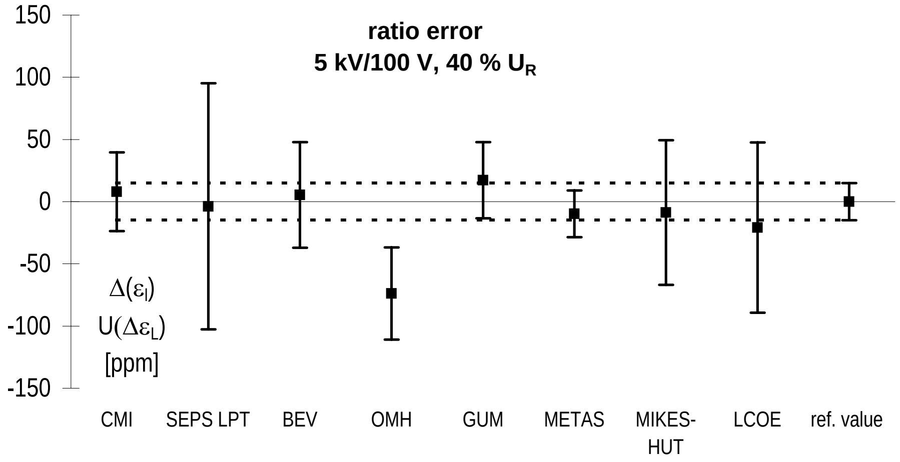

Fig. 1. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 5 kV/100 V at 40 % U_R

5 kV/100 V 60 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) [ppm]
CMI	15	32
SEPS LPT	-2	99
BEV	8	42
OMH	-64	37
GUM	14	31
METAS	-12	19
MIKES-HUT	-16	58
LCOE	-9	68
ref. value	0	15

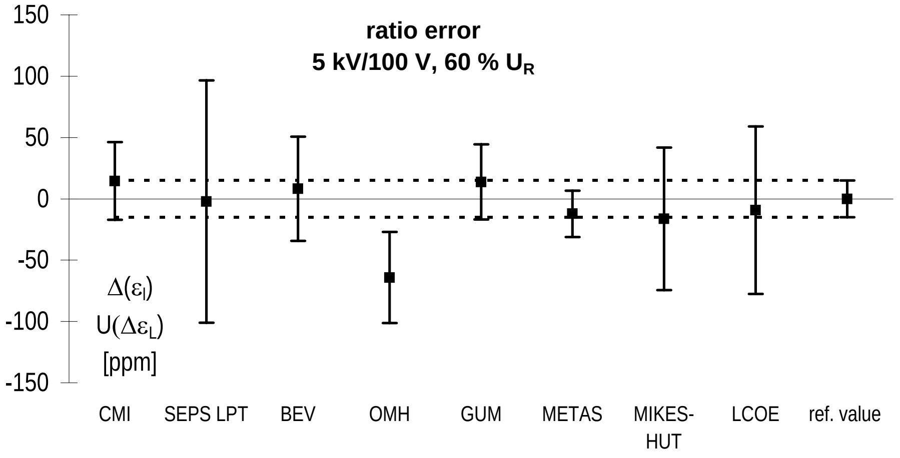

Fig. 2. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 5 kV/100 V at 60 % U_R

5 kV/100 V 80 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) [ppm]
CMI	22	32
SEPS LPT	-10	99
BEV	16	43
OMH	-48	31
GUM	21	31
METAS	-1	20
MIKES-HUT	-5	58
LCOE	5	69
ref. value	0	14

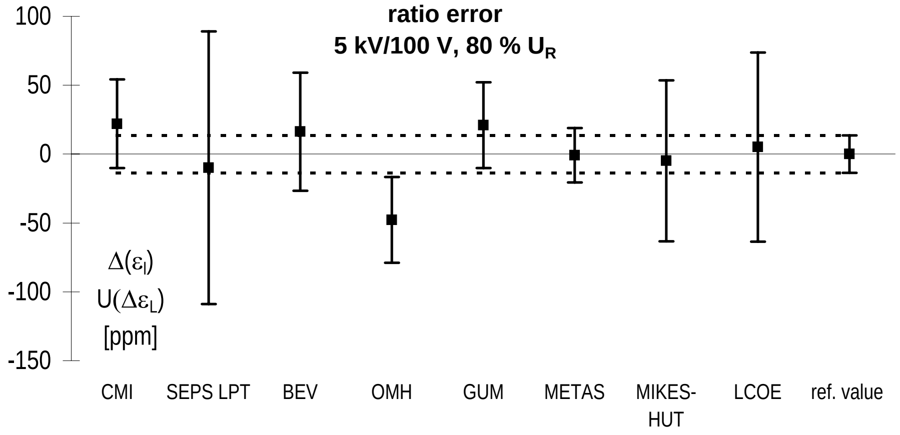

Fig. 3. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 5 kV/100 V at 80 % U_R

5 kV/100 V 100 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	24	32
SEPS LPT	-9	99
BEV	14	43
OMH	-41	31
GUM	18	31
METAS	-3	20
MIKES-HUT	-4	58
LCOE	0	69
ref. value	0	14

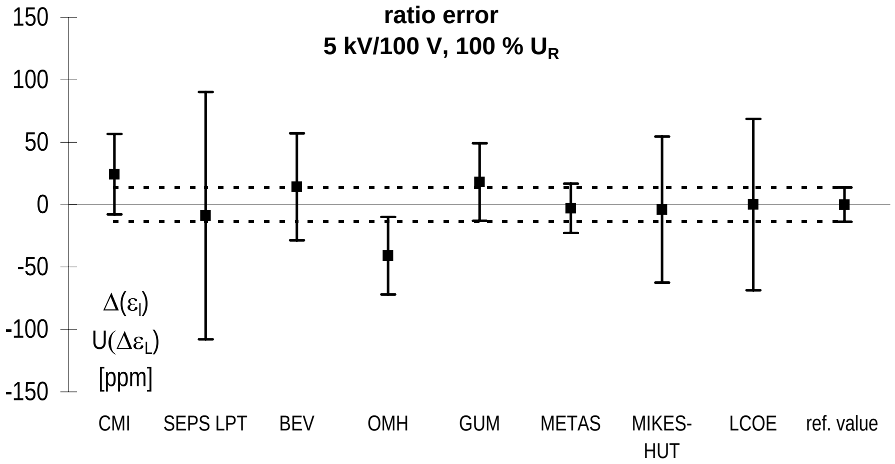

Fig. 4. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 5 kV/100 V at 100 % U_R

5 kV/100 V 120 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	22	32
SEPS LPT	-13	99
BEV	21	43
OMH	-38	31
GUM	18	31
METAS	-5	20
MIKES-HUT	-4	58
LCOE	3	69
ref. value	0	14

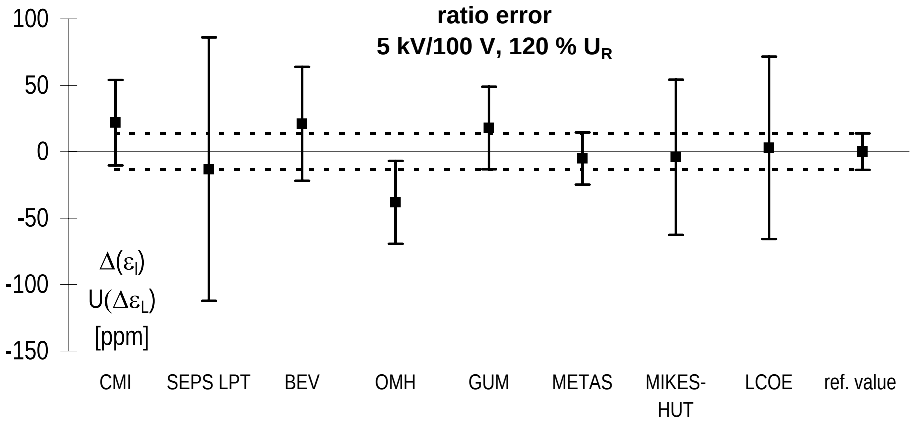

Fig. 5. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 5 kV/100 V at 120 % U_R

10 kV/100 V 40 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	18	33
SEPS LPT	4	99
BEV	-5	36
OMH	-29	30
GUM	13	28
METAS	2	20
MIKES-HUT	3	38
LCOE	-14	69
ref. value	0	13

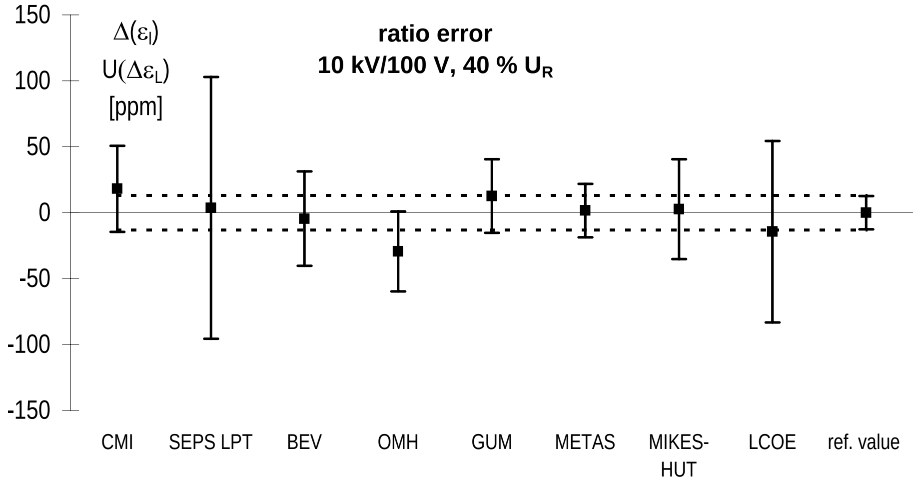

Fig. 6. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 10 kV/100 V at 40 % U_R

10 kV/100 V 60 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	14	33
SEPS LPT	10	99
BEV	-2	36
OMH	-25	30
GUM	11	28
METAS	2	20
MIKES-HUT	0	38
LCOE	-6	69
ref. value	0	13

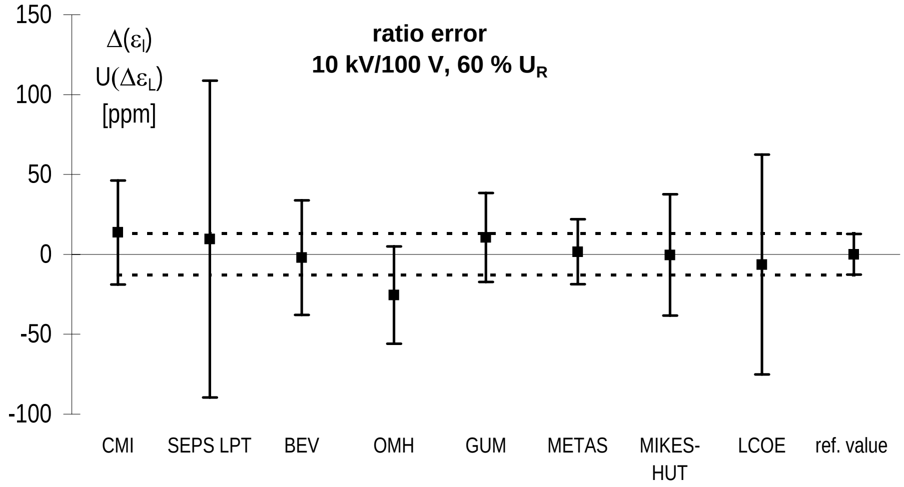

Fig. 7. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 10 kV/100 V at 60 % U_R

10 kV/100 V 80 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	16	33
SEPS LPT	0	99
BEV	-2	36
OMH	-25	30
GUM	10	28
METAS	-1	20
MIKES-HUT	4	38
LCOE	-3	69
ref. value	0	13

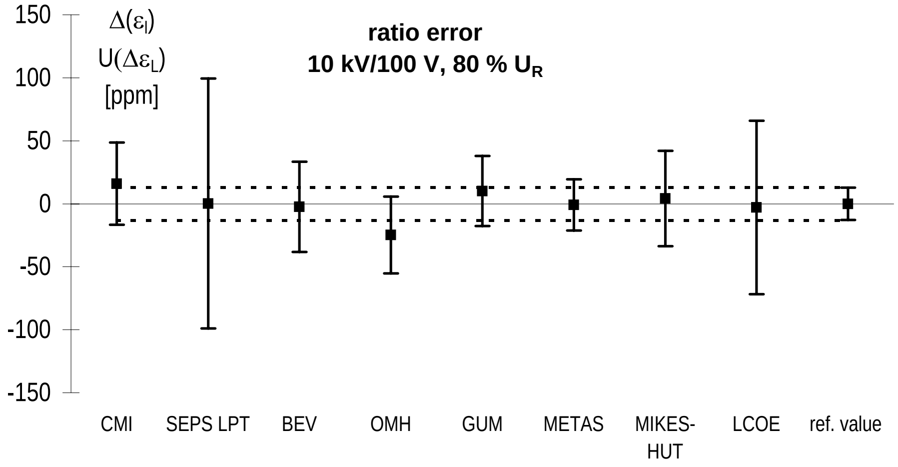

Fig. 8. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 10 kV/100 V at 80 % U_R

10 kV/100 V 100 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) [ppm]
CMI	21	33
SEPS LPT	-1	99
BEV	-3	36
OMH	-20	30
GUM	7	28
METAS	-3	20
MIKES-HUT	0	38
LCOE	-2	69
ref. value	0	13

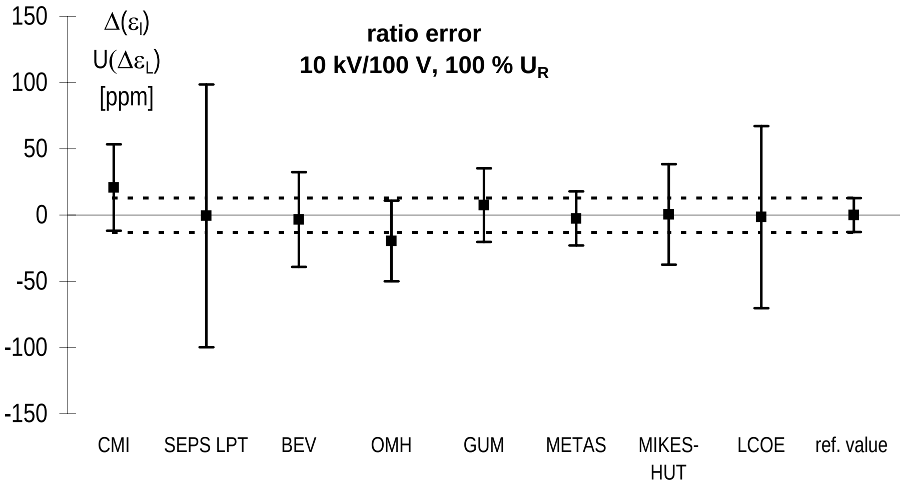

Fig. 9. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 10 kV/100 V at 100 % U_R

10 kV/100 V 120 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) [ppm]
CMI	6	33
SEPS LPT	-7	99
BEV	2	36
OMH	-21	30
GUM	18	28
METAS	-3	20
MIKES-HUT	-2	38
LCOE	-3	69
ref. value	0	13

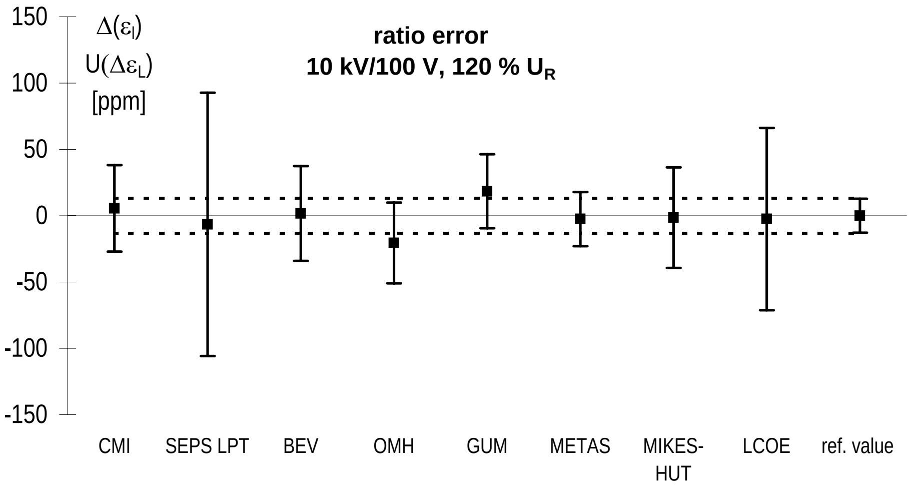

Fig. 10. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 10 kV/100 V at 120 % U_R

22 kV/100 V 40 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	11	32
SEPS LPT	25	99
BEV	4	40
OMH	-7	29
GUM	-10	27
METAS	6	22
MIKES-HUT	-19	79
LCOE	-34	94
ref. value	0	14

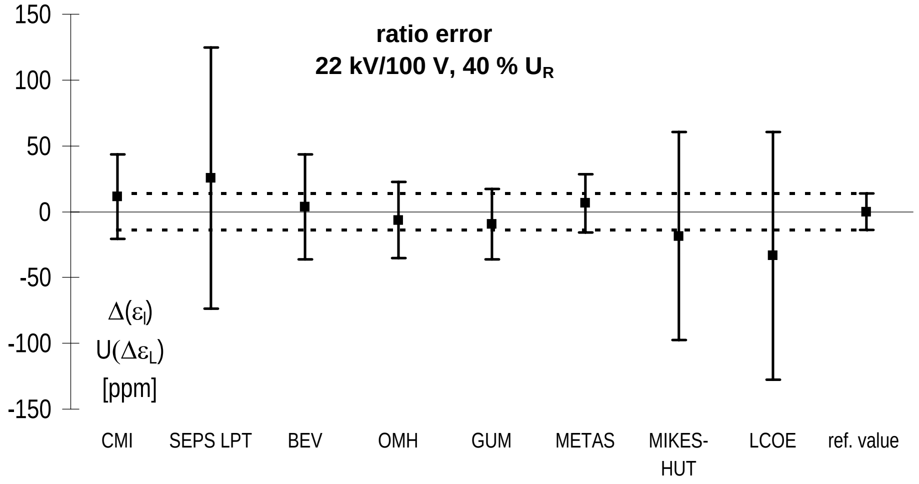

Fig. 11. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 22 kV/100 V at 40 % U_R

22 kV/100 V 60 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	5	32
SEPS LPT	-44	99
BEV	5	40
OMH	-5	29
GUM	-7	27
METAS	9	22
MIKES-HUT	-15	79
LCOE	-15	94
ref. value	0	14

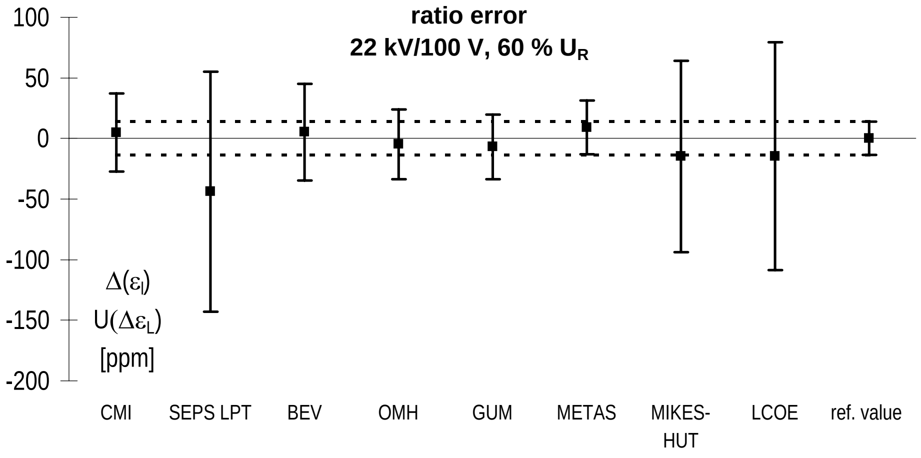

Fig. 12. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 22 kV/100 V at 60 % U_R

22 kV/100 V 80 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	11	32
SEPS LPT	-78	99
BEV	5	40
OMH	0	29
GUM	-9	27
METAS	8	22
MIKES-HUT	-17	79
LCOE	-18	94
ref. value	0	14

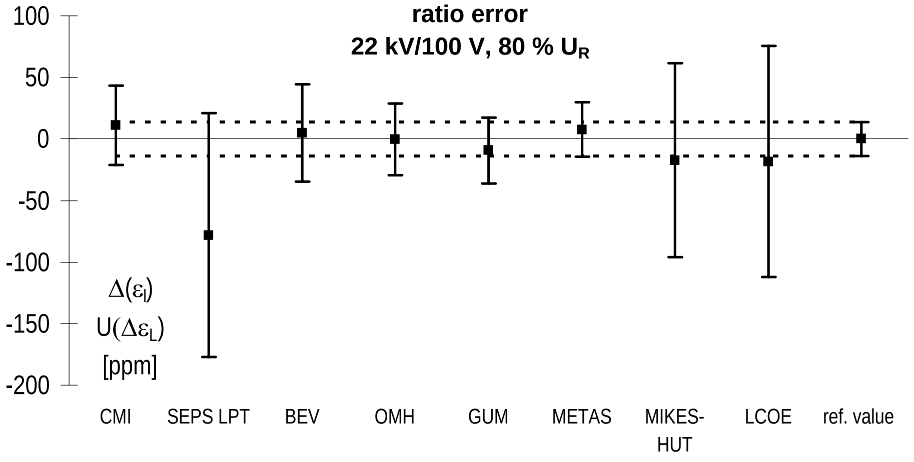

Fig. 13. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 22 kV/100 V at 80 % U_R

22 kV/100 V 100 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	5	32
SEPS LPT	-78	99
BEV	8	40
OMH	-3	29
GUM	-8	27
METAS	10	22
MIKES-HUT	-15	79
LCOE	-16	94
ref. value	0	14

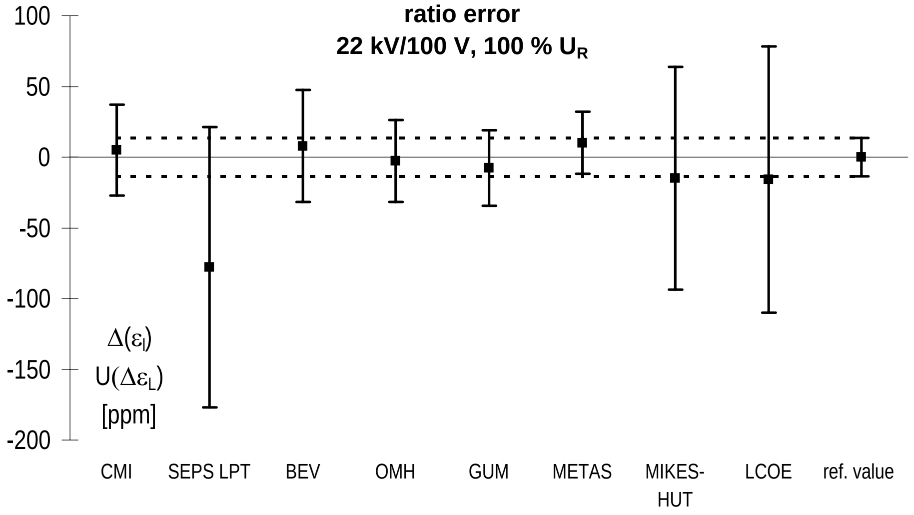

Fig. 14. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 22 kV/100 V at 100 % U_R

22 kV/100 V 120 %	$\Delta\varepsilon_L$ [ppm]	U ($\Delta\varepsilon_L$) **[ppm]**
CMI	-1	32
SEPS LPT	-43	99
BEV	3	40
OMH	1	29
GUM	-10	27
METAS	12	22
MIKES-HUT	-16	79
LCOE	-3	94
ref. value	0	14

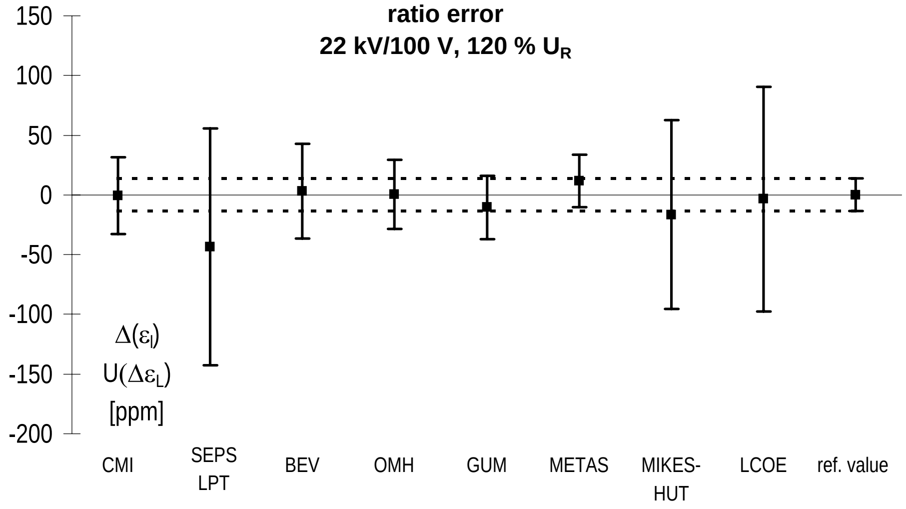

Fig. 15. Differences $\Delta(\varepsilon_L) = \varepsilon_L - \varepsilon_r$ and their uncertainties for 22 kV/100 V at 120 % U_R

5 kV/100 V 40 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,041	0,100
SEPS LPT	0,084	0,297
BEV	-0,003	0,153
OMH	0,027	0,111
GUM	-0,031	0,174
METAS	-0,051	0,063
MIKES-HUT	0,056	0,111
LCOE	-0,031	0,236
ref. value	0,000	0,045

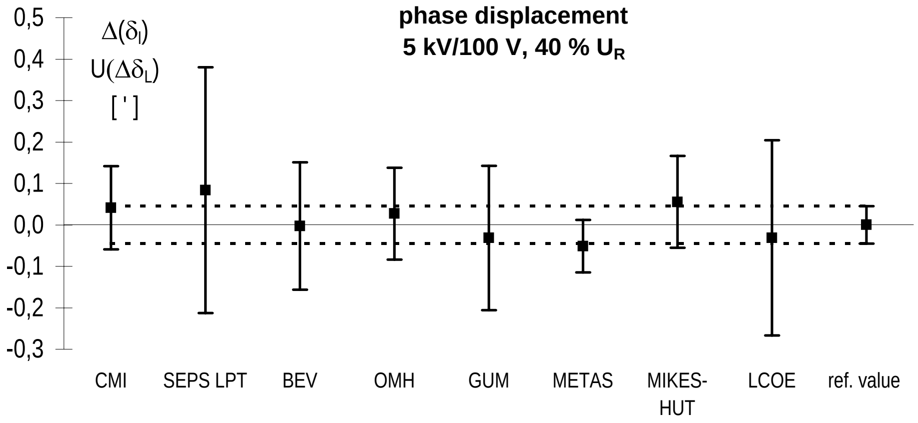

Fig. 16. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 5 kV/100 V at 40 % U_R

5 kV/100 V 60 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,045	0,100
SEPS LPT	0,090	0,297
BEV	-0,023	0,153
OMH	0,022	0,111
GUM	-0,031	0,174
METAS	-0,051	0,063
MIKES-HUT	0,054	0,111
LCOE	0,009	0,236
ref. value	0,000	0,045

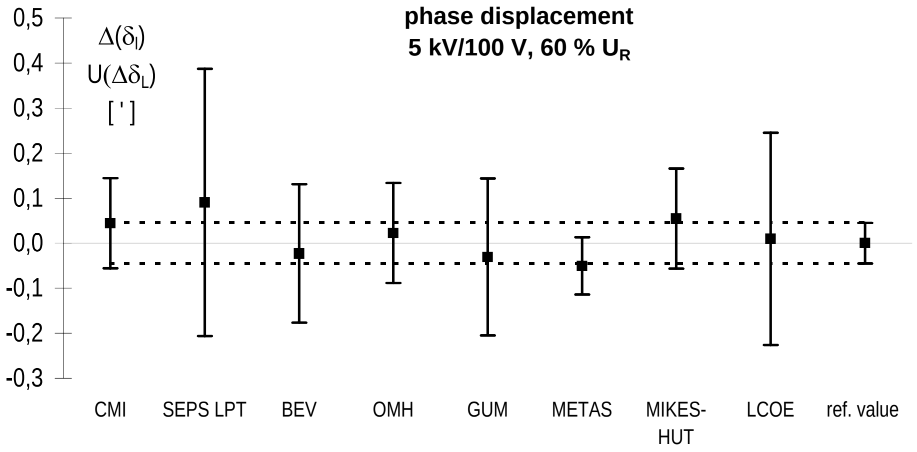

Fig. 17. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 5 kV/100 V at 60 % U_R

5 kV/100 V 80 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,048	0,100
SEPS LPT	0,102	0,297
BEV	-0,088	0,153
OMH	0,066	0,111
GUM	-0,028	0,174
METAS	-0,048	0,063
MIKES-HUT	0,039	0,111
LCOE	-0,018	0,236
ref. value	0,000	0,045

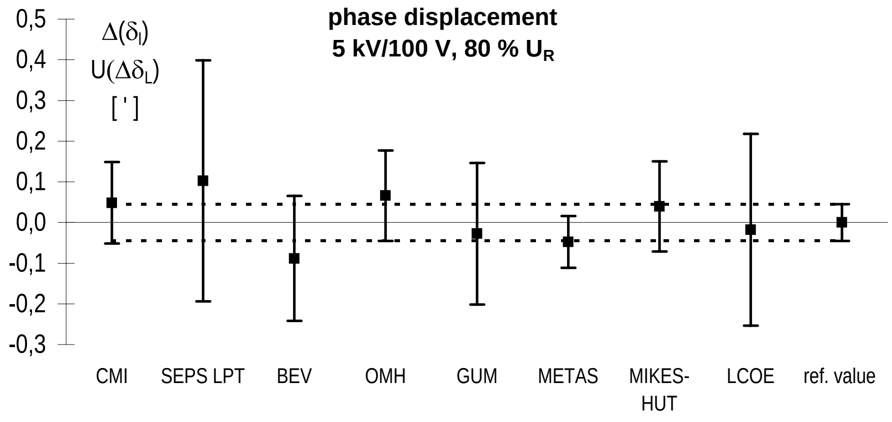

Fig. 18. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 5 kV/100 V at 80 % U_R

5 kV/100 V 100 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,054	0,100
SEPS LPT	0,108	0,297
BEV	-0,109	0,153
OMH	0,078	0,111
GUM	-0,040	0,174
METAS	-0,050	0,063
MIKES-HUT	0,037	0,111
LCOE	0,000	0,236
ref. value	0,000	0,045

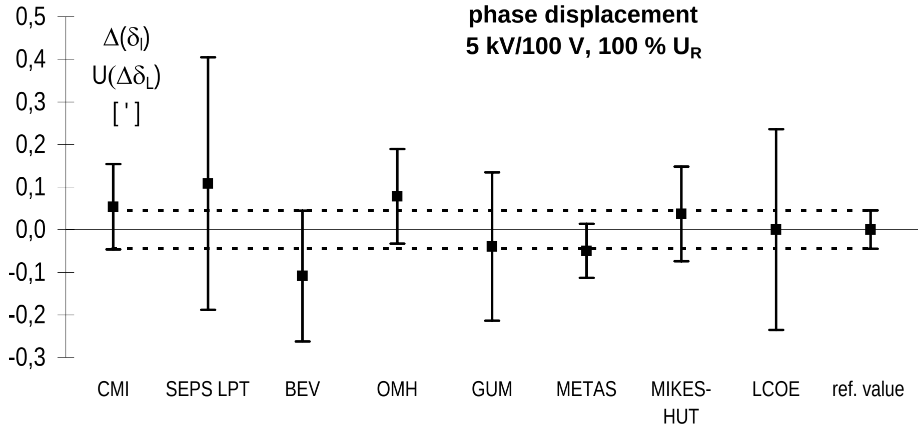

Fig. 19. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 5 kV/100 V at 100 % U_R

5 kV/100 V 120 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,055	0,100
SEPS LPT	0,116	0,297
BEV	-0,127	0,153
OMH	0,035	0,111
GUM	-0,023	0,174
METAS	-0,033	0,063
MIKES-HUT	0,028	0,111
LCOE	0,047	0,236
ref. value	0,000	0,045

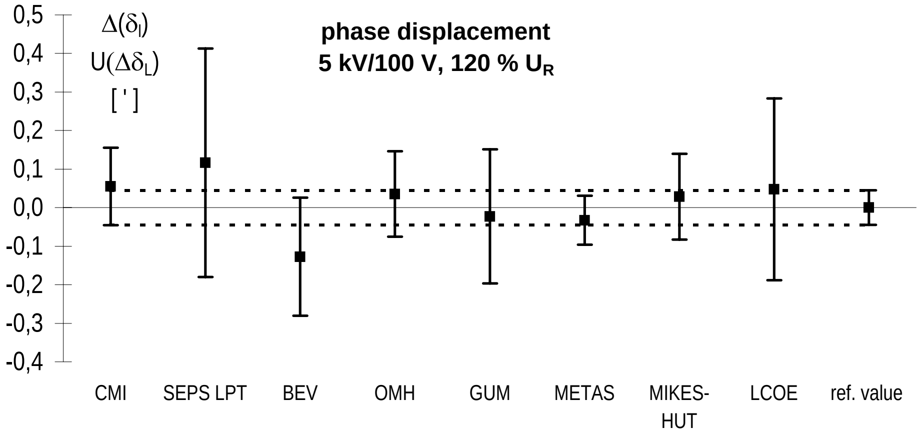

Fig. 20. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 5 kV/100 V at 120 % U_R

10 kV/100 V 40 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	-0,102	0,101
SEPS LPT	0,310	0,297
BEV	0,111	0,122
OMH	-0,104	0,101
GUM	0,024	0,175
METAS	0,004	0,064
MIKES-HUT	0,077	0,112
LCOE	0,004	0,236
ref. value	0,000	0,044

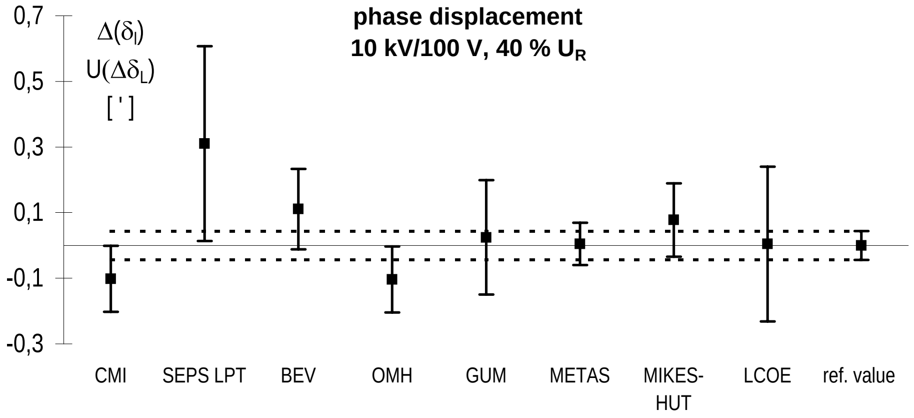

Fig. 21. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 10 kV/100 V at 40 % U_R

10 kV/100 V 60 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	-0,104	0,101
SEPS LPT	0,270	0,297
BEV	0,070	0,122
OMH	-0,036	0,101
GUM	0,021	0,175
METAS	-0,009	0,064
MIKES-HUT	0,066	0,112
LCOE	0,041	0,236
ref. value	0,000	0,044

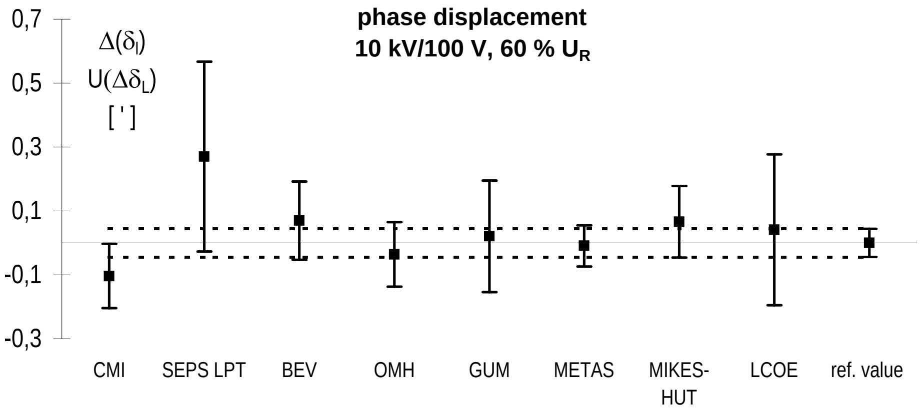

Fig. 22. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 10 kV/100 V at 60 % U_R

10 kV/100 V 80 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	-0,042	0,101
SEPS LPT	0,256	0,297
BEV	-0,008	0,122
OMH	0,004	0,101
GUM	0,019	0,175
METAS	-0,021	0,064
MIKES-HUT	0,054	0,112
LCOE	-0,001	0,236
ref. value	0,000	0,044

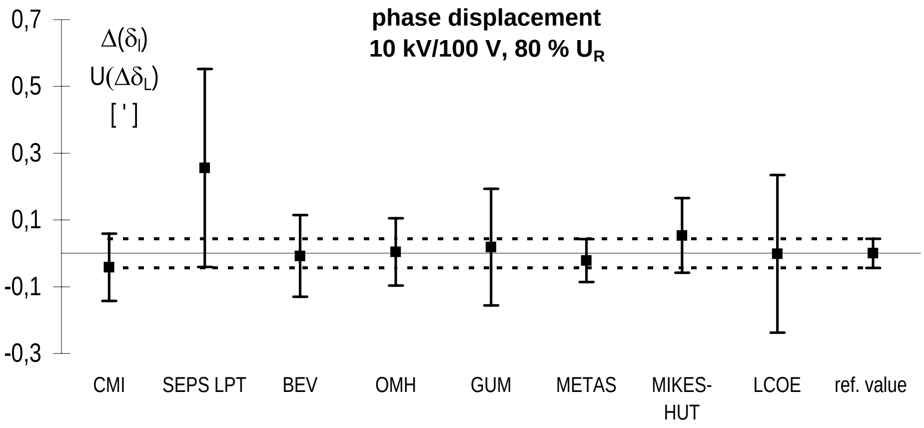

Fig. 23. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 10 kV/100 V at 80 % U_R

10 kV/100 V 100 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,060	0,101
SEPS LPT	0,220	0,297
BEV	-0,037	0,122
OMH	-0,016	0,101
GUM	-0,001	0,175
METAS	-0,041	0,064
MIKES-HUT	0,026	0,112
LCOE	-0,001	0,236
ref. value	0,000	0,044

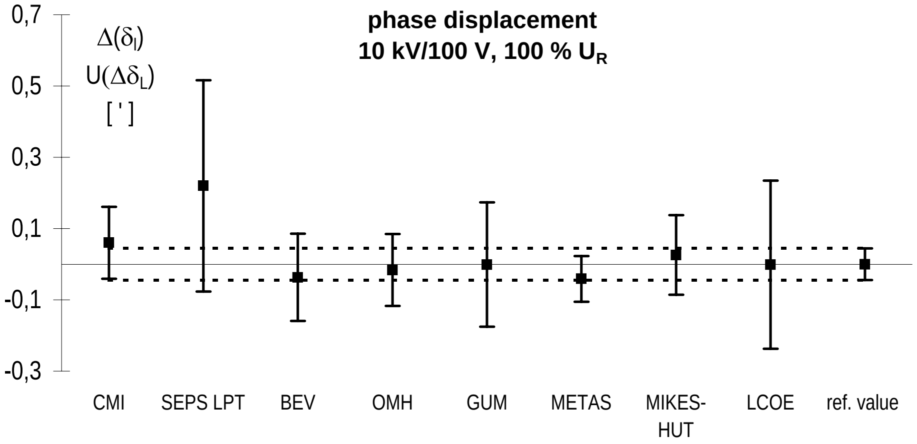

Fig. 24. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 10 kV/100 V at 100 % U_R

10 kV/100 V 120 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,076	0,101
SEPS LPT	0,236	0,297
BEV	-0,049	0,122
OMH	-0,050	0,101
GUM	0,007	0,175
METAS	-0,013	0,064
MIKES-HUT	0,042	0,112
LCOE	0,047	0,236
ref. value	0,000	0,044

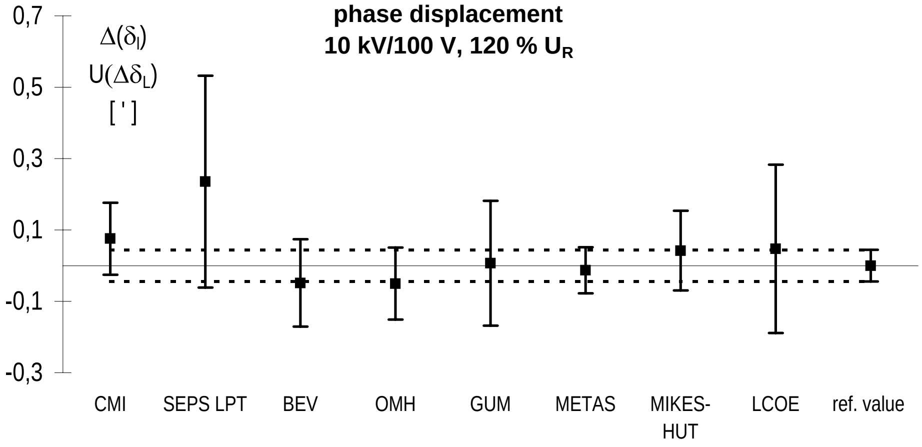

Fig. 25. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 10 kV/100 V at 120 % U_R

22 kV/100 V 40 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	-0,001	0,098
SEPS LPT	-0,719	0,304
BEV	0,060	0,120
OMH	-0,213	0,121
GUM	0,045	0,173
METAS	-0,025	0,063
MIKES-HUT	-0,009	0,109
LCOE	-0,015	0,306
ref. value	0,000	0,049

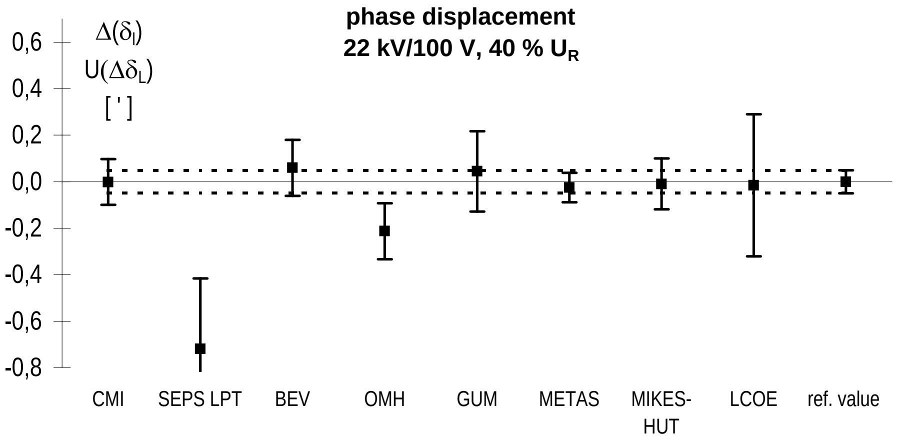

Fig. 26. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 22 kV/100 V at 40 % U_R

22 kV/100 V 60 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,019	0,100
SEPS LPT	-0,651	0,303
BEV	0,070	0,122
OMH	-0,099	0,100
GUM	0,052	0,174
METAS	0,002	0,066
MIKES-HUT	0,005	0,111
LCOE	0,012	0,307
ref. value	0,000	0,045

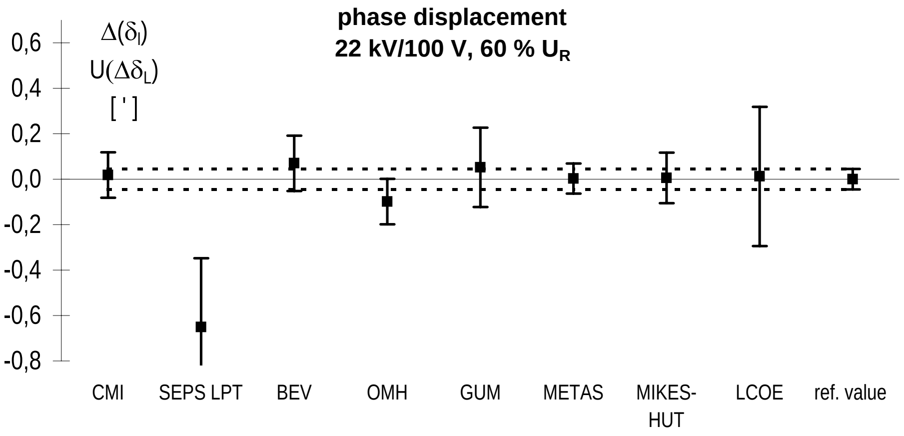

Fig. 27. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 22 kV/100 V at 60 % U_R

22 kV/100 V 80 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,006	0,100
SEPS LPT	-0,641	0,303
BEV	0,076	0,122
OMH	-0,043	0,100
GUM	0,038	0,174
METAS	-0,012	0,066
MIKES-HUT	-0,007	0,111
LCOE	-0,012	0,307
ref. value	0,000	0,045

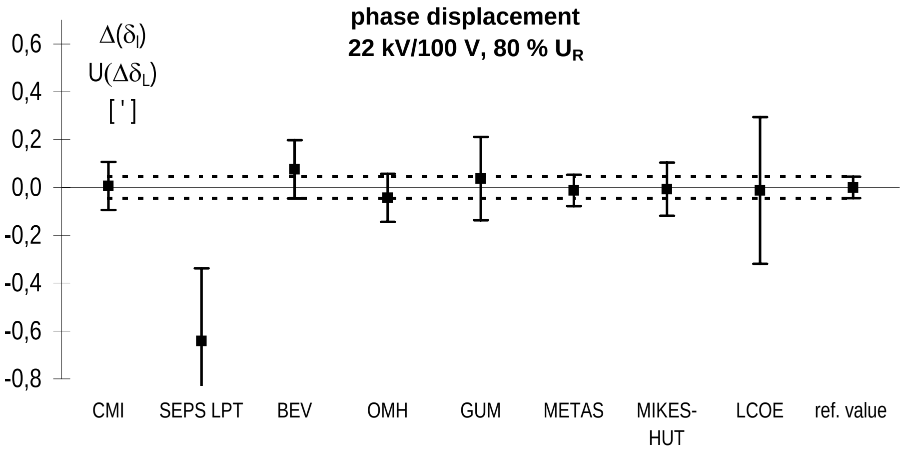

Fig. 28. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 22 kV/100 V at 80 % U_R

22 kV/100 V 100 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,011	0,098
SEPS LPT	-0,651	0,304
BEV	0,061	0,120
OMH	-0,213	0,121
GUM	0,039	0,173
METAS	-0,031	0,063
MIKES-HUT	-0,016	0,109
LCOE	0,009	0,306
ref. value	0,000	0,049

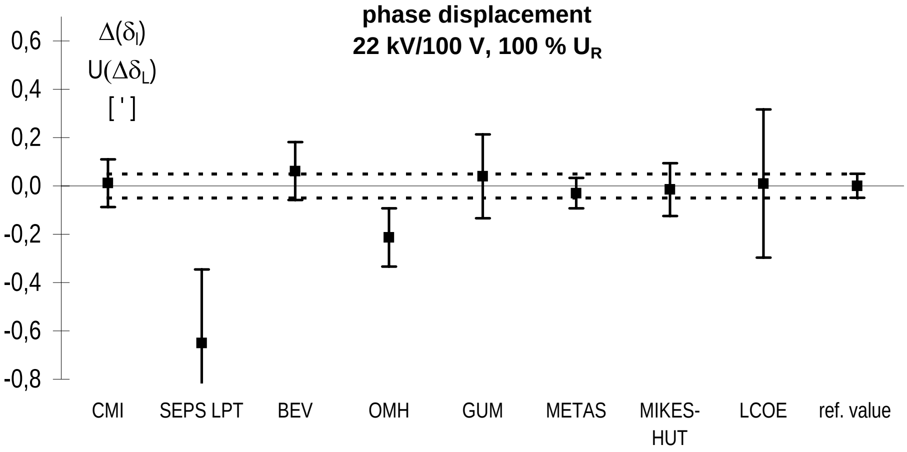

Fig. 29. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 22 kV/100 V at 100 % U_R

22 kV/100 V 120 %	$\Delta\delta_L$ [']	U ($\Delta\delta_L$) [']
CMI	0,013	0,100
SEPS LPT	-0,687	0,303
BEV	0,073	0,122
OMH	-0,144	0,100
GUM	0,081	0,174
METAS	0,011	0,066
MIKES-HUT	0,029	0,111
LCOE	0,021	0,307
ref. value	0,000	0,045

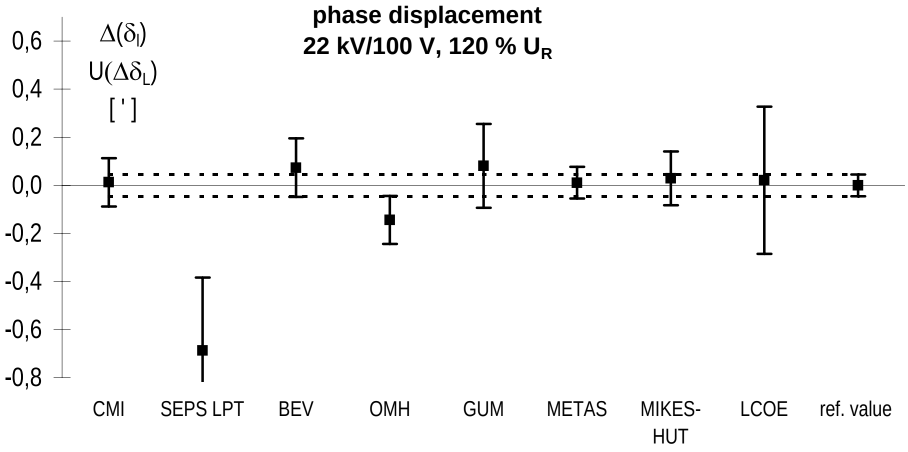

Fig. 30. Differences $\Delta(\delta_L) = \delta_L - \delta_r$ and their uncertainties for 22 kV/100 V at 120 % U_R