Supplementary Comparison EURAMET.EM-S19
EURAMET Project No. 688

Bilateral Comparison of Measurements of Current Transformers (CTs) Between BIM and UME

Final Report

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January 2011

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Abstract

This report presents the results of a bilateral comparison on current transformer measurements between BIM (Bulgarian Institute of Metrology) and UME (TÜBİTAK Ulusal Metroloji Enstitüsü / NMI of Turkey). The comparison was registered as EURAMET project no 688 and EURAMET.EM-S19 in the BIPM Key Comparison Database. The aim of this project is comparison of AC current ratio standards of UME and BIM at 50Hz between 5A/5A and 1000A/5A current ratios. Main targets of the comparison are to demonstrate equivalence of metrological practice and to check the correctness of the calibration results. The results of the measurements showed a good agreement between BIM and UME both for the ratio errors and phase displacements.

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Introduction

A supplementary comparison was organized between UME, Turkey and BIM, Bulgaria, in the field of current transformer measurements. This comparison was registered as EURAMET project no 688 and EURAMET.EM-S19 in the BIPM Key Comparison Database.

The aim of this project is comparison of AC current ratio standards of UME and BIM at 50Hz between 5A/5A and 1000A/5A current ratios. Main targets of the comparison are to demonstrate equivalence of metrological practice and to check the correctness of the calibration results.

Current transformer measurements performed by UME and BIM, support a large number of measurements made in the electrical generation, supply and distribution industries in their own countries and they also support transformer manufacturers who rely on national standards as a source of traceability. The current ratio errors and phase angle errors of each ratio of the uncompensated current transformer transfer standard were determined at a defined frequency, burden and power factor, using each participant's standard measuring method and equipment.

Participants

<u>BIM (formerly NCM)</u>

Name : Bulgarian Institute of Metrology, National Centre of Metrology
Address : General Directorate "National Centre of Metrology"
Section "Electric Energy Measurements"
52-B G.M. Dimitrov Blvd.
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<u>UME</u>

Name : TÜBİTAK Ulusal Metroloji Enstitüsü (NMI of Turkey)
Address : TÜBİTAK UME
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41470 Kocaeli
Country : Turkey
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Comparison Schedule

The participating institutes and measurement dates are listed in the following table.

Acronym	National Metrology Institute	Country	Dates of Measurements
BIM	Bulgarian Institute of Metrology	Bulgaria	April 2003 (I) October 2003 (II)
UME	TÜBİTAK Ulusal Metroloji Enstitüsü	Turkey	June 2003

Table 1. List of participants and measurement dates

Note: Second measurement results of BIM (October 2003) were taken into account while calculating the comparison results.

Traveling Standard

The traveling standard was an uncompensated multi-ratio current transformer provided by BIM.

Manufacturer/Model	: I-512, Russia		
Serial Number	: 21/1980		
Transformation Ratios	: Primary currents	: from 0,5 A up to 3000A	
	Secondary currents	: 1A and 5A	
Class and Rating	: Class 0,05 at 5VA, 50Hz		
Weight	: 106 kg		

Measurements

Each participating laboratory was asked to make measurements under their normal laboratory conditions using the following guidelines:

Transformation ratios	: 1000A, 500A, 200A, 100A, 50A, 20A, 10A, 5A / 5A
Burden	: 5VA, cos $\beta = 1$
Test frequency	: 50Hz
Temperature	: (23 ± 1) °C
Rated current	: 120%, 100%, 50%, 20%, 10%, and 5% (2% optional)

Symbols and Definitions

The symbols and definitions stated are in accordance with IEC 60044-1:2003-2 [1].

ε_X Current error: the error which a transformer introduces into the measurement of a current and which arises from the fact that the actual transformation ratio is not equal to the rated transformation ratio.
The current error expressed in per cent is given by the formula:

$$Current\ error\ \% = \frac{(K_n I_s - I_p) \times 100}{I_p}$$

where,
K_n is the rated transformation ratio;
I_p is the actual primary current;
I_s is the actual secondary current when I_p is flowing, under the conditions of measurement.

Z_B Burden: The impedance of the secondary circuit in ohms and power-factor. The burden is usually expressed as the apparent power in volt-amperes absorbed at a specified power-factor and at the rated secondary current.

δ_X Phase displacement: The difference in phase between the primary and secondary current vectors, the direction of the vectors being so chosen that the angle is zero for a perfect transformer. The phase displacement is said to be positive when the secondary current vector leads the primary current vector. It is usually expressed in minutes or centiradians.

Measurement Conditions and Methods

Each laboratory's measuring conditions and method of calibration are listed in the following table.

Laboratory	Method	Temperature ºC	Burden		Frequency Hz
			VA	Cos β	
BIM	Note 1	23 ± 1	5 ± 3%	1	50
UME	Note 2,3	23 ± 1	5 ± 1%	1	50 ± 0,2

Table 2. Reference conditions in the laboratories during the measurements

Note 1: Comparison against standard current transformer with errors measured on commercial test set.

Note 2: Comparison with compensated current comparator [2].

Note 3: Comparison against electronically compensated current comparator with errors measured on commercial test set.

The following table details the type of standard and/or instrument used by each participant in the measurement of the transfer standard.

Lab.	Standard			Bridge		
	Passive CCC	Elect. CCC	Transformer	Passive	Elect.	Homemade
UME	✓	✓			✓	✓
BIM			✓	✓		

Table 3. Types of standard used by participants

Legend
Lab. : Laboratory
CCC : Compensated current comparator
Elect. : Electronic

For more details of calibration methods, see APPENDIX A1.

Traceability

Each participant supplied a statement of traceability to the SI. The following table shows if traceability is to their own national standards or if their traceability is to another national laboratory.

Laboratory	Traceable to own National Standards	Traceable to other National Standards
BIM		SP (Sweden)
UME	✓	

Table 4. Traceability

Uncertainty Budget

Table 5 shows a typical uncertainty budget used by UME in the calculation of its uncertainty values. The uncertainty budget given shows the contributions associated with the measurements made on ratio 5A/5A at I/I_n=100%, at a burden of 5VA, unity power factor, at a frequency of 50Hz and an ambient temperature of 23˚C. The uncertainty budgets supplied by BIM contained most of the principle contributions listed below.

For more details of uncertainty budgets of each NMI, see APPENDIX A2.

Quantity	Standard Uncertainty (ppm)	Type	Probability Distribution	Sensitivity Coefficient	Uncertainty Contribution (ppm)
Calibration of bridge and comparator	16.0	B	normal	1	16.0
Error in the bridge	5.8	B	rectangular	1	5.8
Error due to frequency setting	1.2	B	rectangular	1	1.2
Resolution of test set	0.3	B	rectangular	1	0.3
Error due to burden setting	0.6	B	rectangular	1	0.6
Error due to temperature	1.2	B	rectangular	1	1.2
Circuit configuration	1.0	B	normal	1	1.0
Error due to current setting	0.6	B	rectangular	1	0.6
Repeatability	10	A	normal	1	10
Combined uncertainty					19.8
Expanded uncertainty (U) (k=2)					**39.7**

Table 5. Uncertainty budget of UME for the current error measurement on ratio 5A/5A at I/I_n=100%

The contributions for the “Calibration of the bridge and comparator” and “Error in the bridge” take into account any error of the test set and standard comparator used in calibration of the transfer standard.

The contribution for the error due to the burden setting takes into account the fact that the actual burden was either too high or too low. The change in ε_X and δ_X for a change in VA was calculated and then the error included in the budget.

The contribution for the error due to the current setting covers any inaccuracy in the setting of the applied current, I/I_n.

The value for repeatability is the standard deviation of the mean for each individual set of measurements.

For all measurements made by UME and BIM, the reported expanded uncertainties are based on a standard uncertainty multiplied by a coverage factor of k=2, which for a normal distribution provides a level of confidence of approximately 95 % [3].

Measurement Results

The results obtained from the comparison, are displayed in two ways. The first is a set of graphs showing the current error and phase displacement comparison results for all ratios at I/I_n=120%, 100%, 20%, 10% and 5%. Following the graphs is a set of tables displaying the results supplied by UME and BIM for both current error and phase displacement. Each participant's individual expanded uncertainty is also included in the tables. Although the phase displacement values of BIM are given in min, they are displayed as µrad in the following graphs and tables.

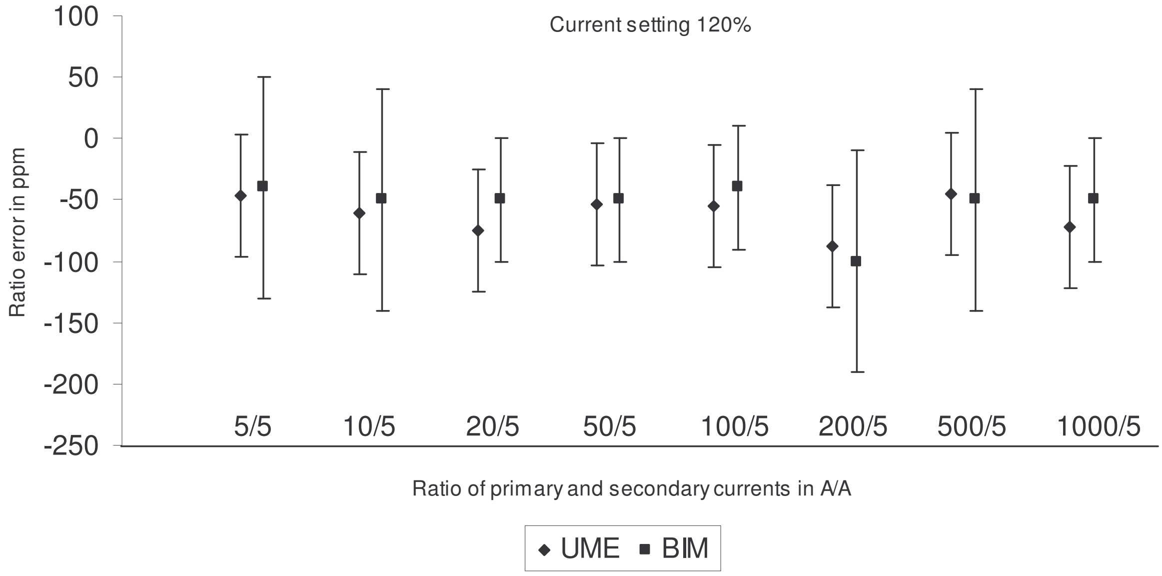

Figure 1. The current error comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=120%.

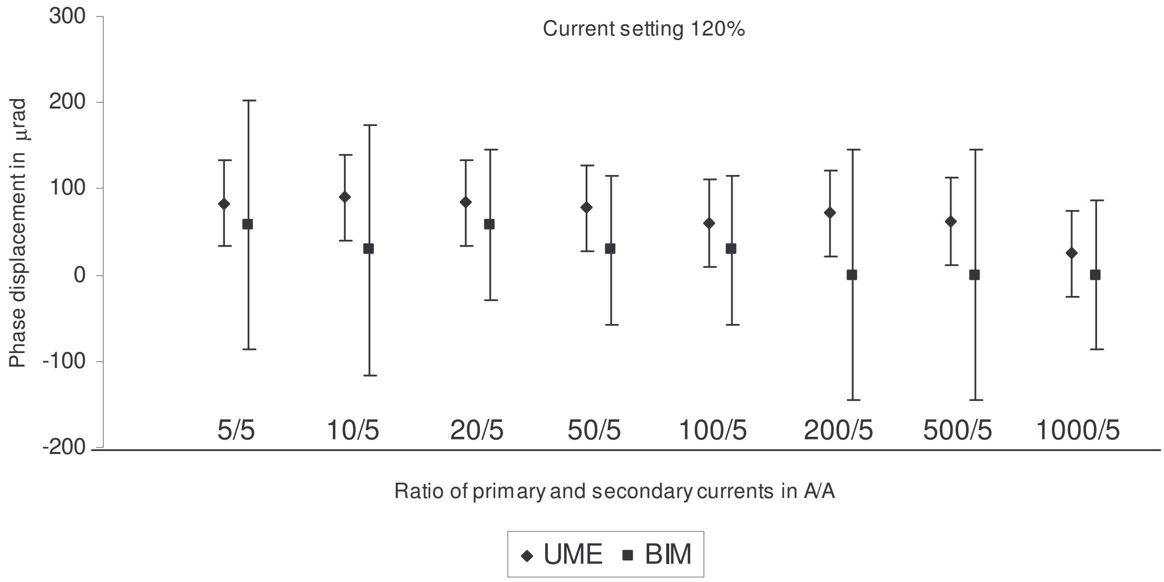

Figure 2. The phase displacement comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=120%.

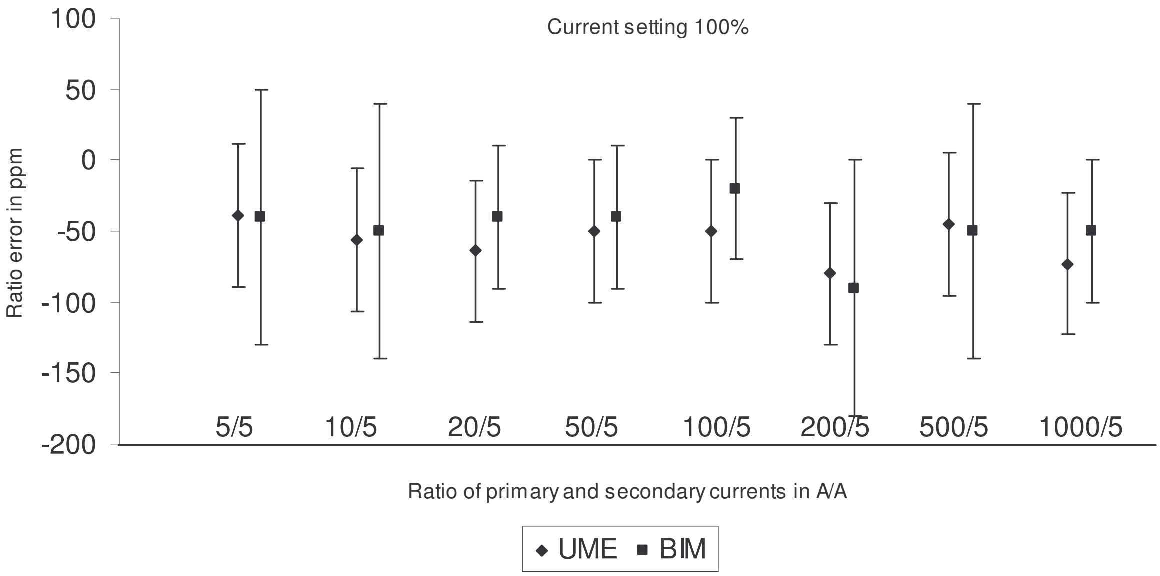

Figure 3. The current error comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=100%.

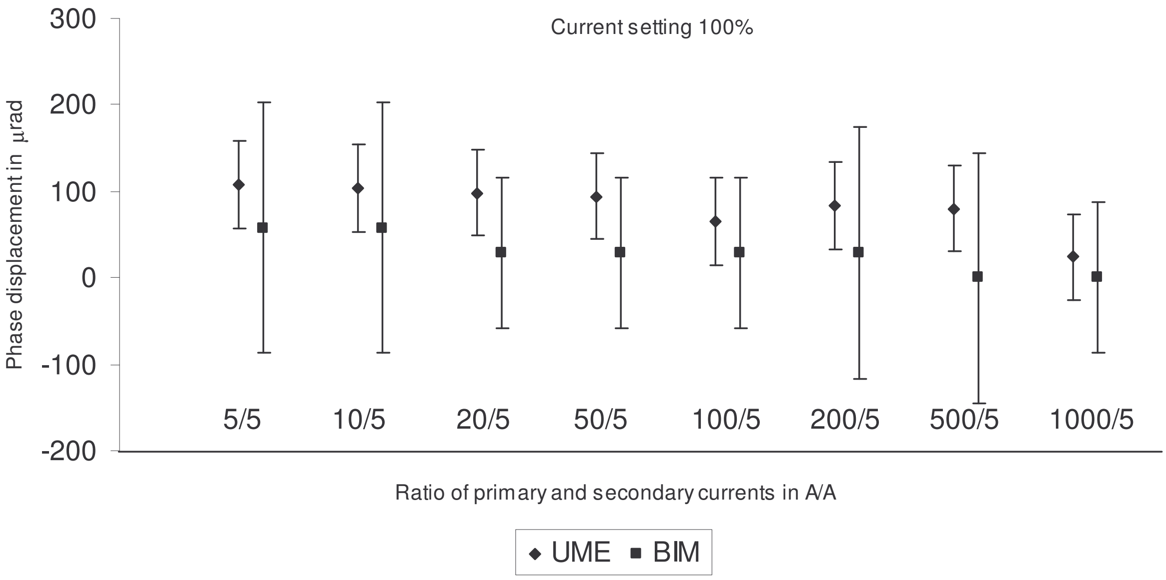

Figure 4. The phase displacement comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=100%.

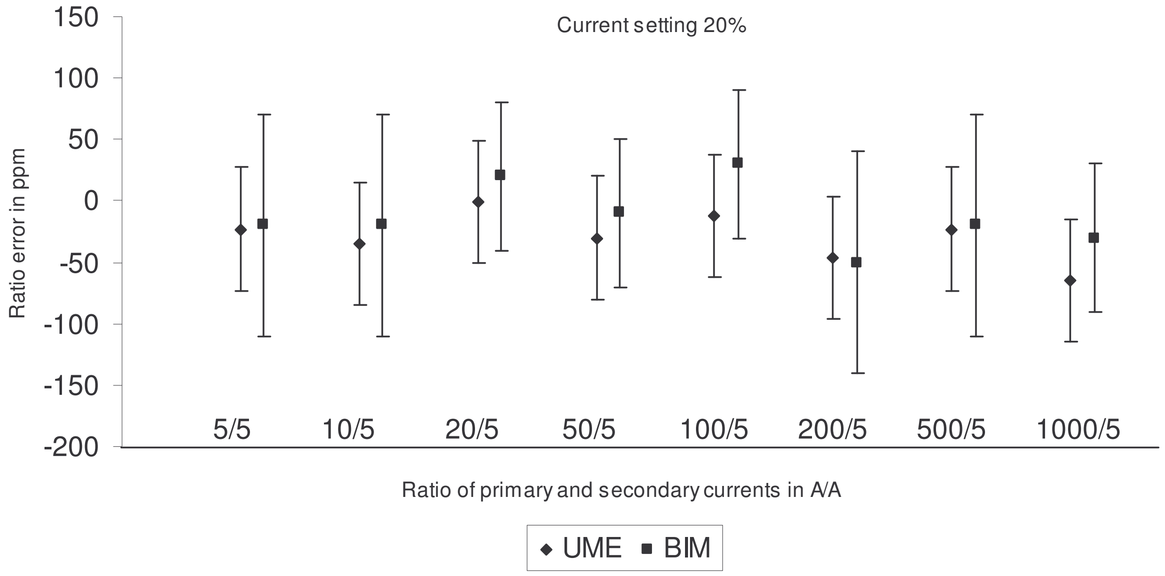

Figure 5. The current error comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=20%.

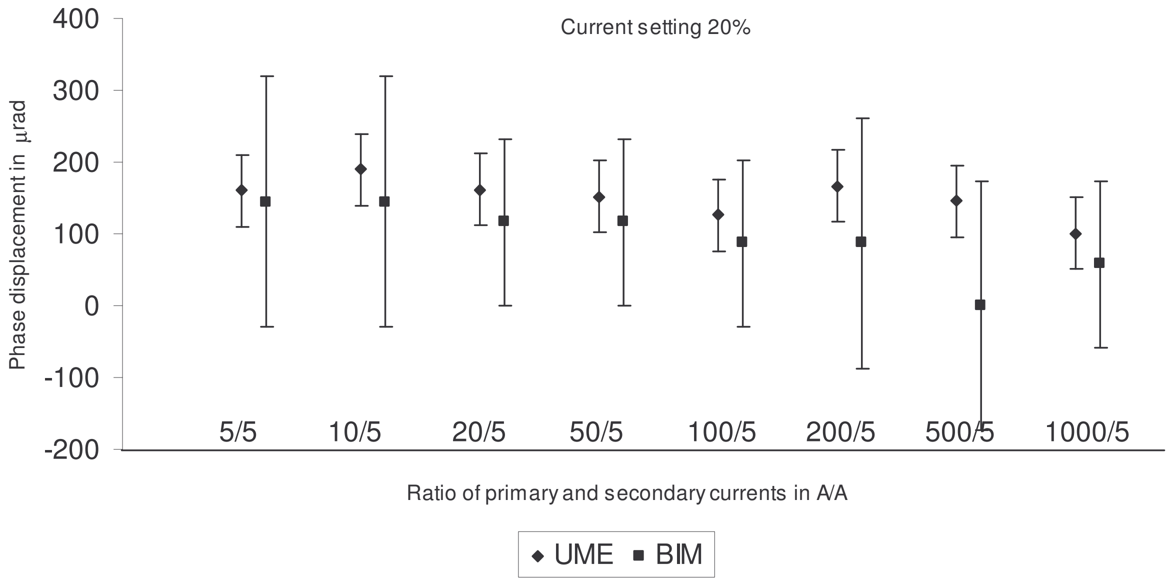

Figure 6. The phase displacement comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=20%.

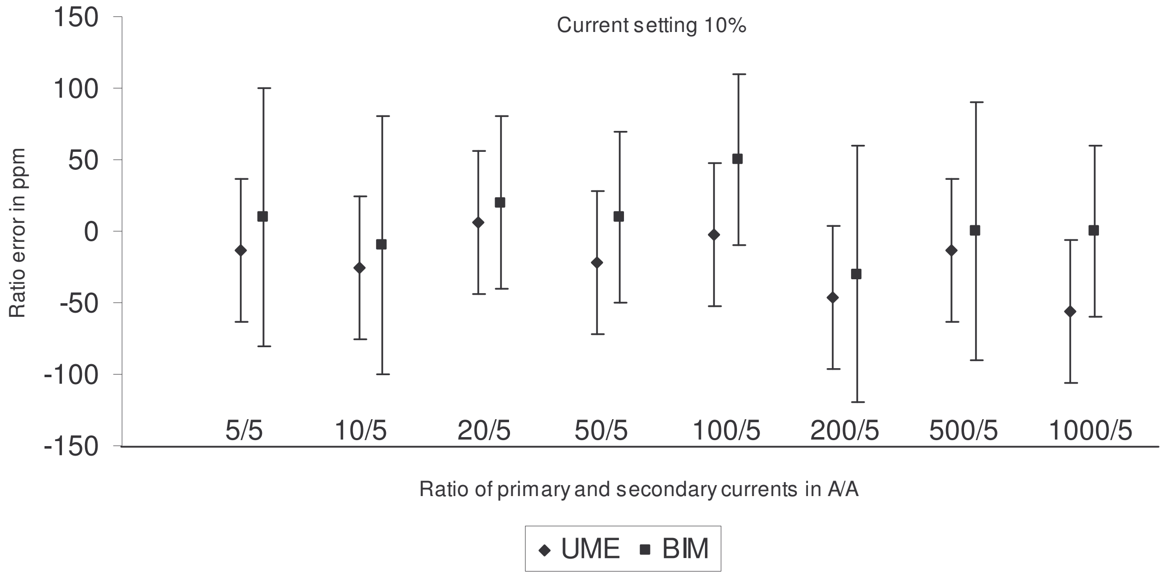

Figure 7. The current error comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=10%.

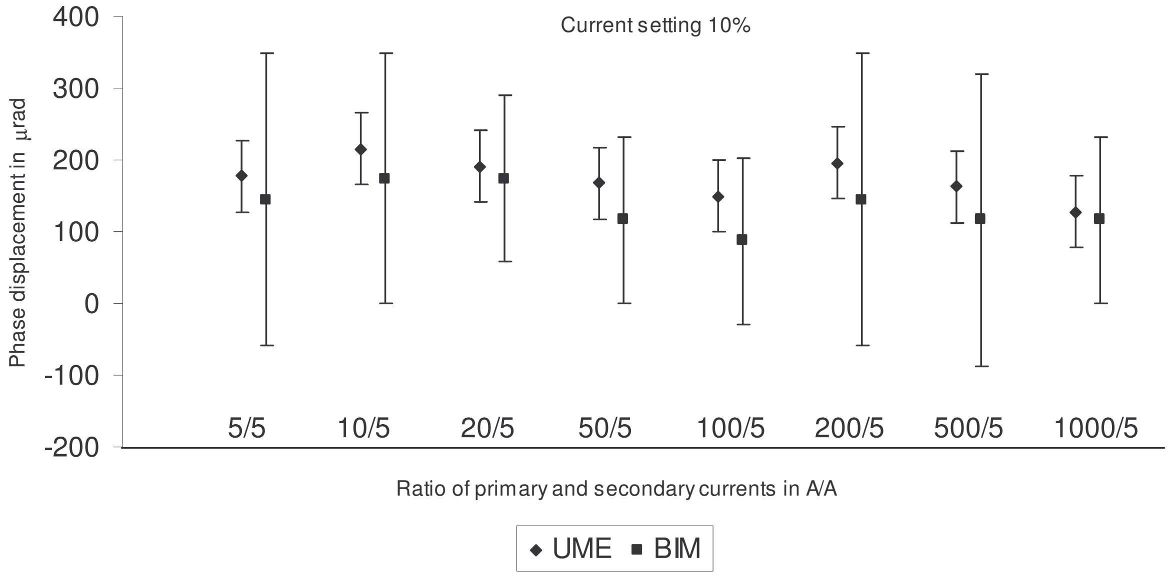

Figure 8. The phase displacement comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=10%.

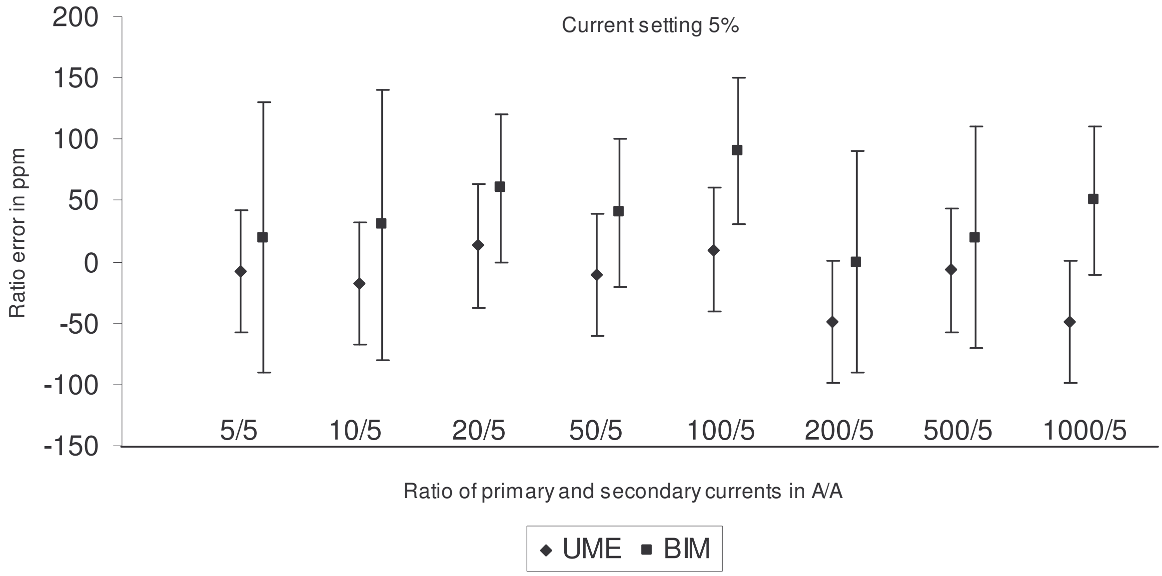

Figure 9. The current error comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=5%.

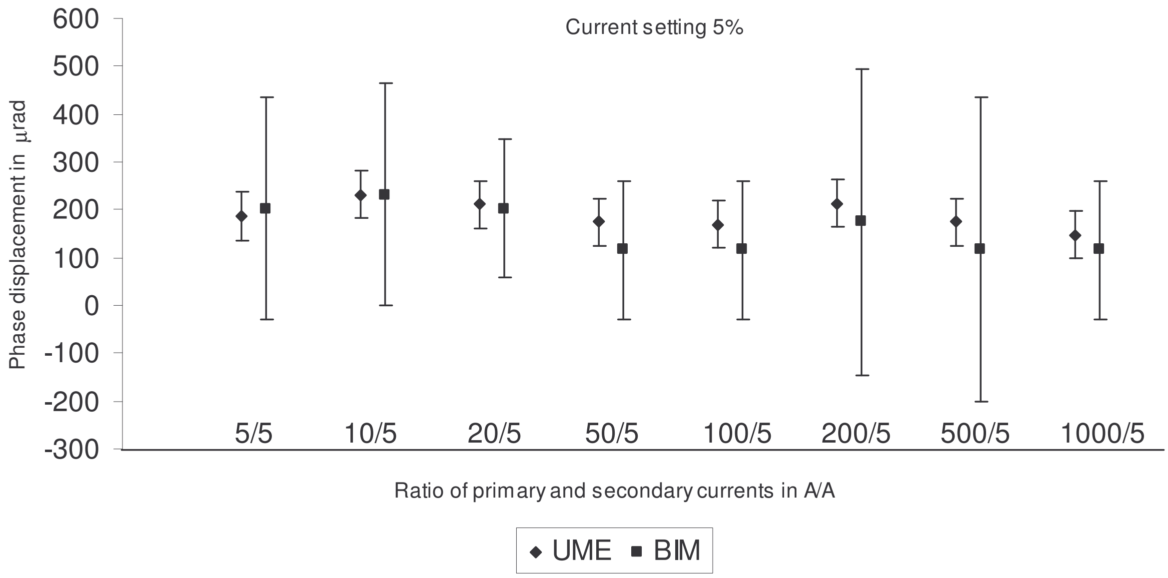

Figure 10. The phase displacement comparison results and expanded uncertainties U_i (k = 2) for all ratios, at I/I_n=5%.

I/In %	5A/5A				10A/5A				20A/5A				50A/5A			
	UME		BIM		UME		BIM		UME		BIM		UME		BIM	
	ε_X	U	ε_X	U	ε_X	U	ε_X	U	ε_X	U	ε_X	U	ε_X	U	ε_X	U
120	-47	50	-40	90	-61	50	-50	90	-75	50	-50	50	-54	50	-50	50
100	-39	50	-40	90	-56	50	-50	90	-64	50	-40	50	-50	50	-40	50
50	-36	50	-	-	-49	50	-	-	-24	50	-	-	-43	50	-	-
20	-23	50	-20	90	-35	50	-20	90	-1	50	20	60	-30	50	-10	60
10	-14	50	10	90	-26	50	-10	90	6	50	20	60	-22	50	10	60
5	-8	50	20	110	-18	50	30	110	13	50	60	60	-11	50	40	60
2	30	50	-	-	-10	50	-	-	21	50	-	-	10	50	-	-

I/In %	100A/5A				200A/5A				500A/5A				1000A/5A			
	UME		BIM		UME		BIM		UME		BIM		UME		BIM	
	ε_X	U	ε_X	U	ε_X	U	ε_X	U	ε_X	U	ε_X	U	ε_X	U	ε_X	U
120	-55	50	-40	50	-88	50	-100	90	-45	50	-50	90	-72	50	-50	50
100	-50	50	-20	50	-80	50	-90	90	-45	50	-50	90	-73	50	-50	50
50	-30	50	-	-	-58	50	-	-	-39	50	-	-	-77	50	-	-
20	-12	50	30	60	-46	50	-50	90	-23	50	-20	90	-65	50	-30	60
10	-3	50	50	60	-46	50	-30	90	-14	50	0	90	-56	50	0	60
5	10	50	90	60	-49	50	0	90	-7	50	20	90	-49	50	50	60
2	35	50	-	-	-63	50	-	-	-2	50	-	-	-40	50	-	-

Table 6. Current error comparison results with each participant's individual expanded uncertainty

ε_X, is the current error value for each point supplied by each participant in ppm.
U, is the expanded uncertainty for each point supplied by each participant in ppm.
-, indicates that the point was not reported.

I/I_n %	5A/5A				10A/5A				20A/5A				50A/5A			
	UME		BIM		UME		BIM		UME		BIM		UME		BIM	
	δ_X	U	δ_X	U	δ_X	U	δ_X	U	δ_X	U	δ_X	U	δ_X	U	δ_X	U
120	83	50	58	145	90	50	29	145	84	50	58	87	78	50	29	87
100	108	50	58	145	104	50	58	145	98	50	29	87	94	50	29	87
50	129	50	-	-	143	50	-	-	125	50	-	-	120	50	-	-
20	160	50	145	174	190	50	145	174	162	50	116	116	152	50	116	116
10	177	50	145	203	215	50	174	174	191	50	174	116	168	50	116	116
5	186	50	203	232	232	50	232	232	211	50	203	145	174	50	116	145
2	120	50	-	-	242	50	-	-	223	50	-	-	170	50	-	-

I/I_n %	100A/5A				200A/5A				500A/5A				1000A/5A			
	UME		BIM		UME		BIM		UME		BIM		UME		BIM	
	δ_X	U	δ_X	U	δ_X	U	δ_X	U	δ_X	U	δ_X	U	δ_X	U	δ_X	U
120	60	50	29	87	72	50	0	145	62	50	0	145	25	50	0	87
100	65	50	29	87	83	50	29	145	80	50	0	145	24	50	0	87
50	91	50	-	-	118	50	-	-	115	50	-	-	55	50	-	-
20	126	50	87	116	166	50	87	174	146	50	0	174	101	50	58	116
10	150	50	87	116	196	50	145	203	163	50	116	203	127	50	116	116
5	169	50	116	145	214	50	174	319	175	50	116	319	147	50	116	145
2	185	50	-	-	221	50	-	-	178	50	-	-	164	50	-	-

Table 7. Phase displacement comparison results with each participant's individual expanded uncertainty

δ_X, is the phase displacement value for each point supplied by each participant in μrad.
U, is the expanded uncertainty for each point supplied by each participant in μrad.
-, indicates that the point was not reported.

Reference value and degrees of equivalence

For all current ratios in the range from 5A/5A to 1000A/5A, UME participated in the supplementary comparison EUROMET.EM-S11 with 15 participants [4]. However, the measurement system of UME used in this comparison is a new one; therefore, there are no results available from previous comparisons. For this reason, only the degrees of equivalence between the two laboratories are determined for all ratios.

The degree of equivalence, D_{ij} (*i* is rated transformation ratio and *j* is excitation current), between two laboratories is found from the differences of the measurement results, X_i:

$$D_{ij}(\varepsilon) = \varepsilon_{BIM} - \varepsilon_{UME}$$

$$D_{ij}(\delta) = \delta_{BIM} - \delta_{UME}$$

with relevant uncertainties $u(D_{ij})$ are give by:

$$u[D_{ij}(\varepsilon)] = \sqrt{[u(\varepsilon_{BIM})]^2 + [u(\varepsilon_{UME})]^2}$$

$$u[D_{ij}(\delta)] = \sqrt{[u(\delta_{BIM})]^2 + [u(\delta_{UME})]^2}$$

It is assumed that there is no significant correlation between the results of BIM and UME.

The expanded (k=2) uncertainties $U(D_{ij})$ are:

$$U[D_{ij}(\varepsilon)] = 2 \cdot u[D_{ij}(\varepsilon)]$$

$$U[D_{ij}(\delta)] = 2 \cdot u[D_{ij}(\delta)]$$

The degrees of equivalence are given in the following figures and tables.

Conclusion

A project on a bilateral comparison of AC current ratio standards of UME and BIM at 50Hz between 5A/5A and 1000A/5A current ratios was performed. Main targets of the comparison were to demonstrate equivalence of metrological practice and to check the correctness of the calibration results. The measurements of the bilateral comparison were carried out according to the agreed time table. The results of the measurements showed a good agreement between BIM and UME both for the ratio errors and phase displacements within the stated uncertainties.

References

[1] IEC 60044-1:2003-2, Instrument Transformers, Part 1: Current Transformers

[2] Moore W.J.M. and Miljanic P.N., The Current Comparator, IEE Electrical Measurement series 4, Peter Peregrinus Ltd, London, 1988.

[3] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, Guide to the Expression of Uncertainty in Measurement, International Organisation for Standardization, Geneva, First Edition 1993.

[4] Stuart Harmon and Lesley Henderson, "Final Report EUROMET.EM-S11 on EUROMET projects 473 and 612: Comparison of measurement of current transformers (CTs)", Metrologia, vol. 46, Technical Supplement, 2009.

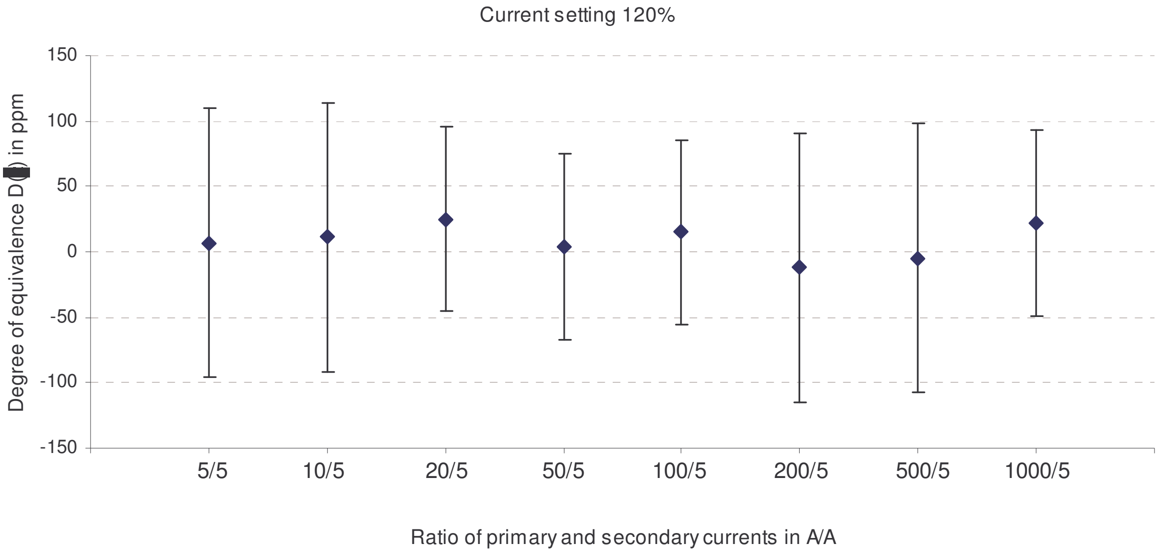

Figure 11. The degrees of equivalence *D(ε)* and expanded uncertainties *U[D(ε)]* (k = 2) for all ratios, at I/I_n=120%.

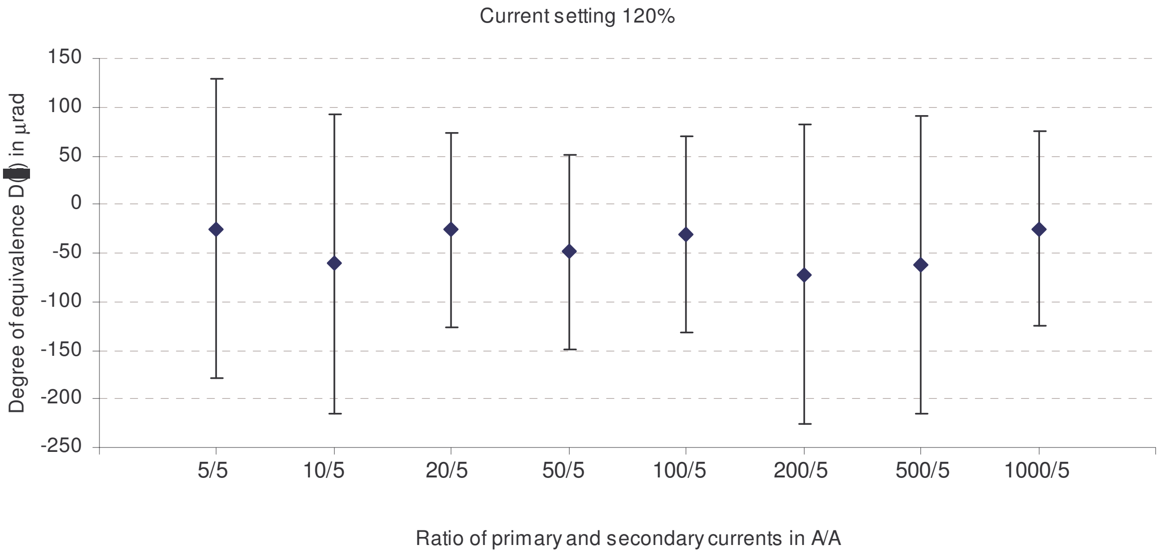

Figure 12. The degrees of equivalence *D(δ)* and expanded uncertainties *U[D(δ)]* (k = 2) for all ratios, at I/I_n=120%.

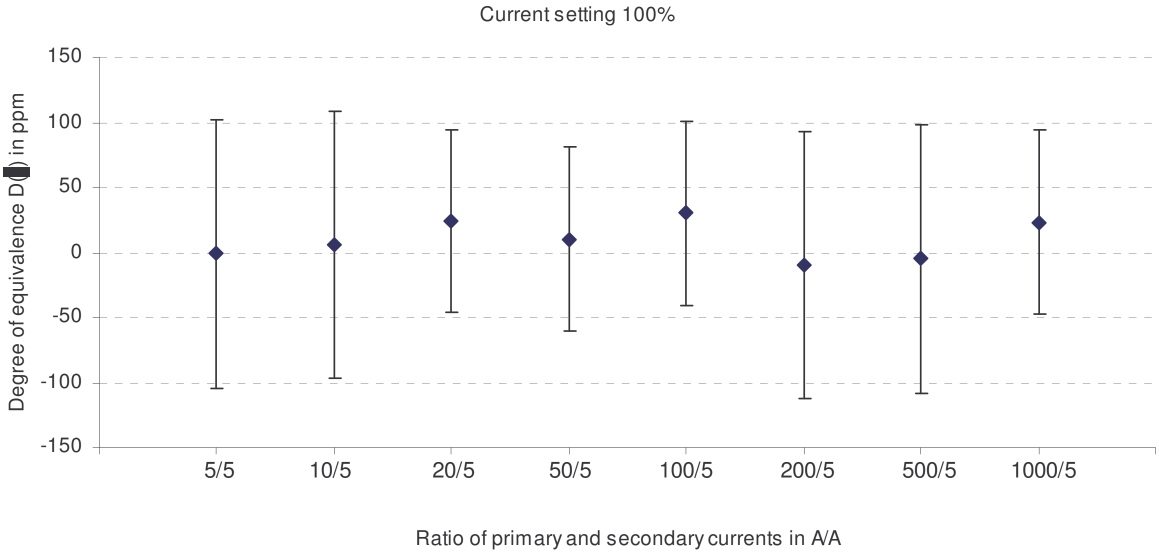

Figure 13. The degrees of equivalence *D(ε)* and expanded uncertainties *U[D(ε)]* (*k* = 2) for all ratios, at I/I_n=100%.

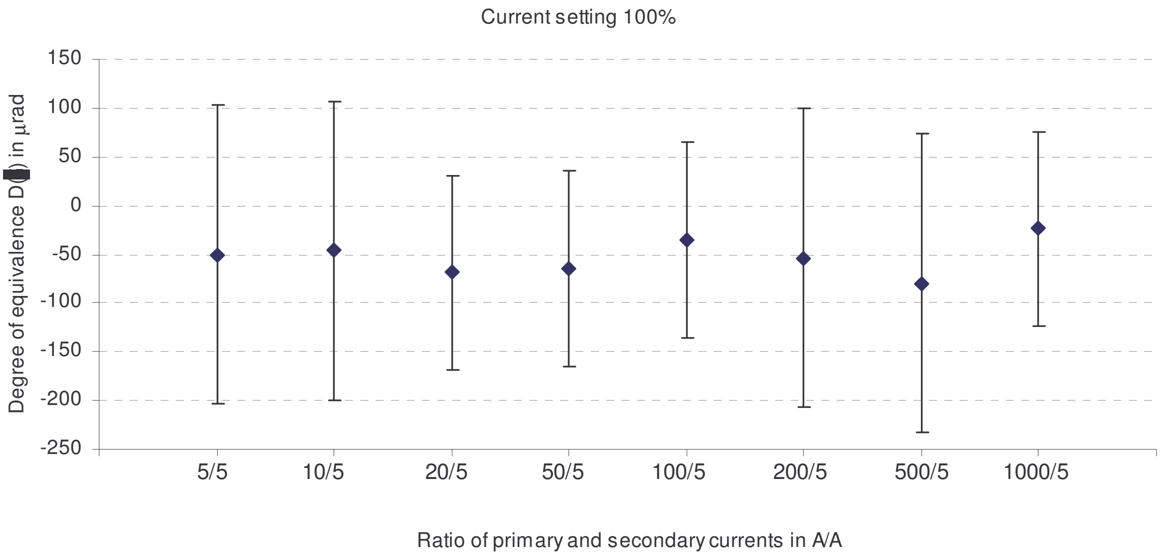

Figure 14. The degrees of equivalence *D(δ)* and expanded uncertainties *U[D(δ)]* (*k* = 2) for all ratios, at I/I_n=100%.

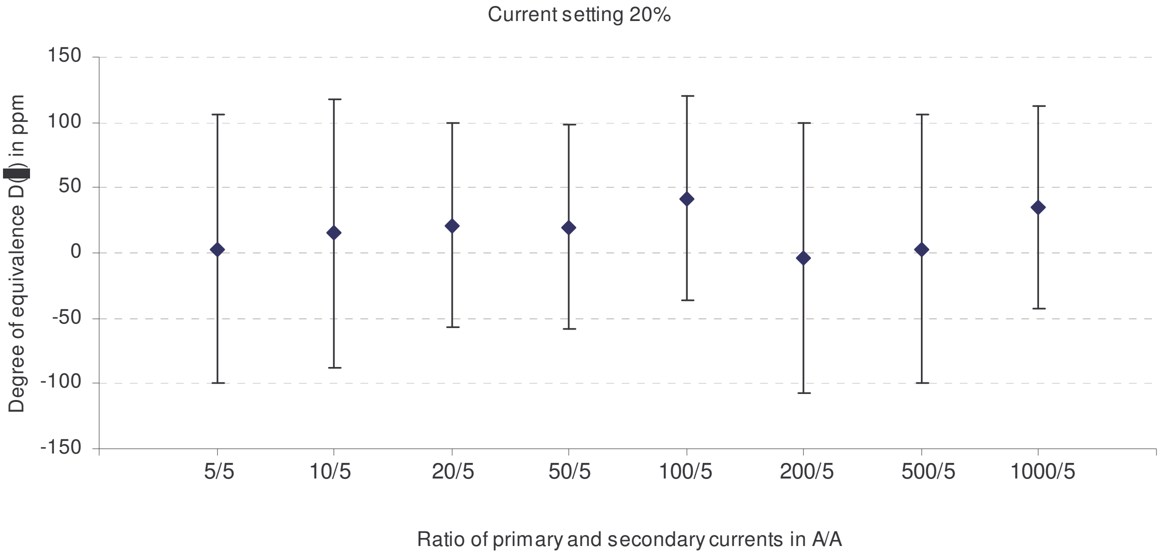

Figure 15. The degrees of equivalence *D(ε)* and expanded uncertainties *U[D(ε)]* (k = 2) for all ratios, at I/I_n=20%.

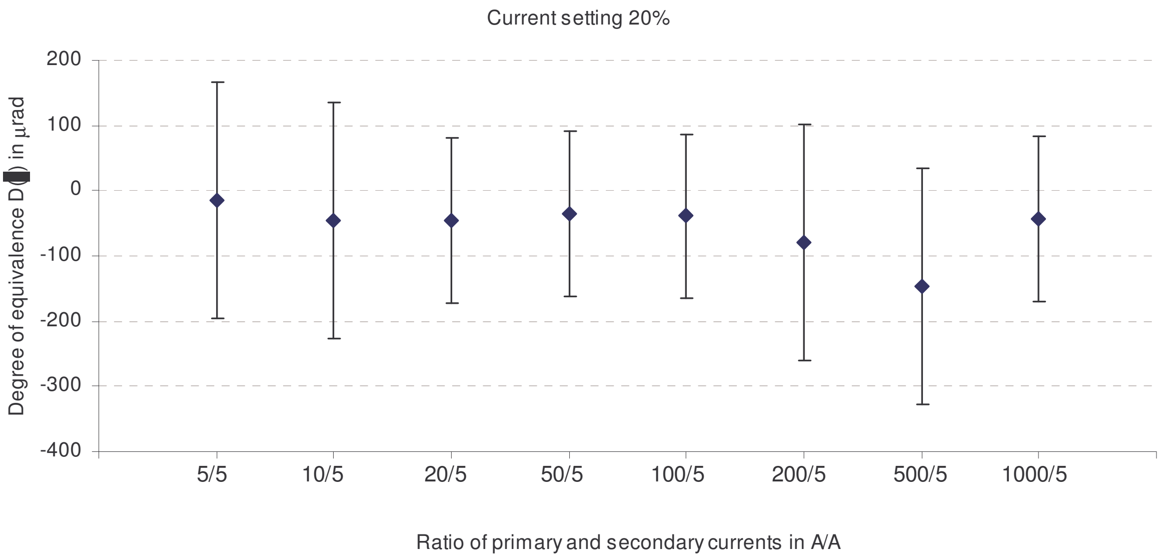

Figure 16. The degrees of equivalence *D(δ)* and expanded uncertainties *U[D(δ)]* (k = 2) for all ratios, at I/I_n=20%.

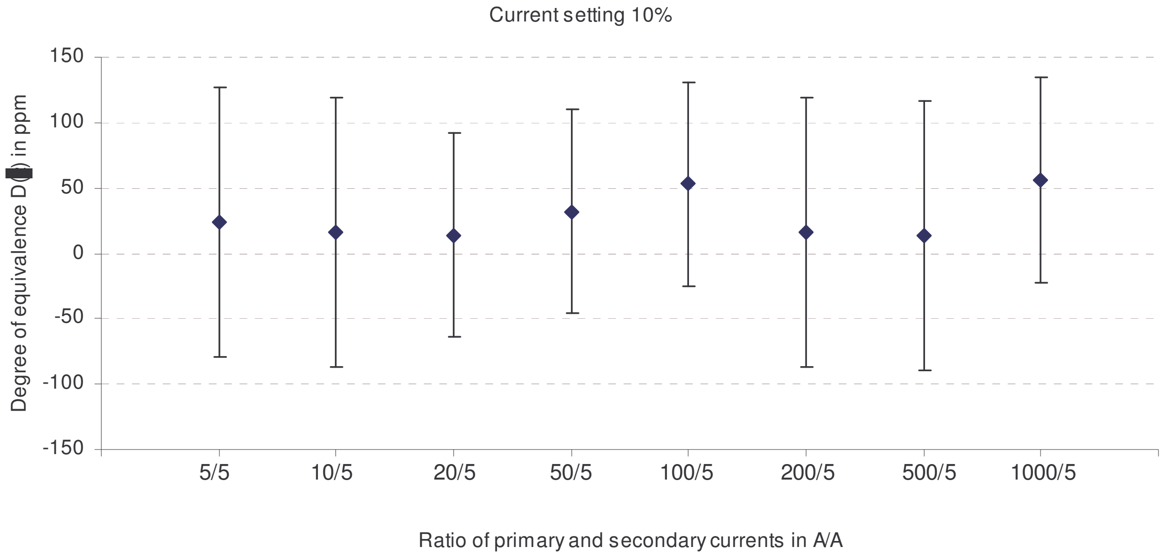

Figure 17. The degrees of equivalence *D(ε)* and expanded uncertainties *U[D(ε)]* (*k* = 2) for all ratios, at I/I_n=10%.

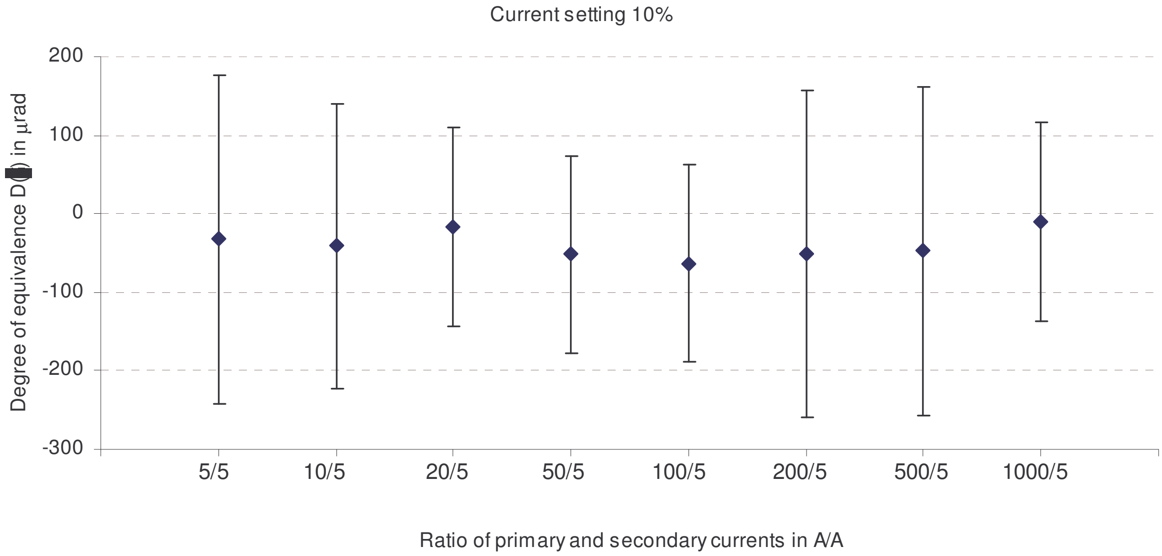

Figure 18. The degrees of equivalence *D(δ)* and expanded uncertainties *U[D(δ)]* (*k* = 2) for all ratios, at I/I_n=10%.

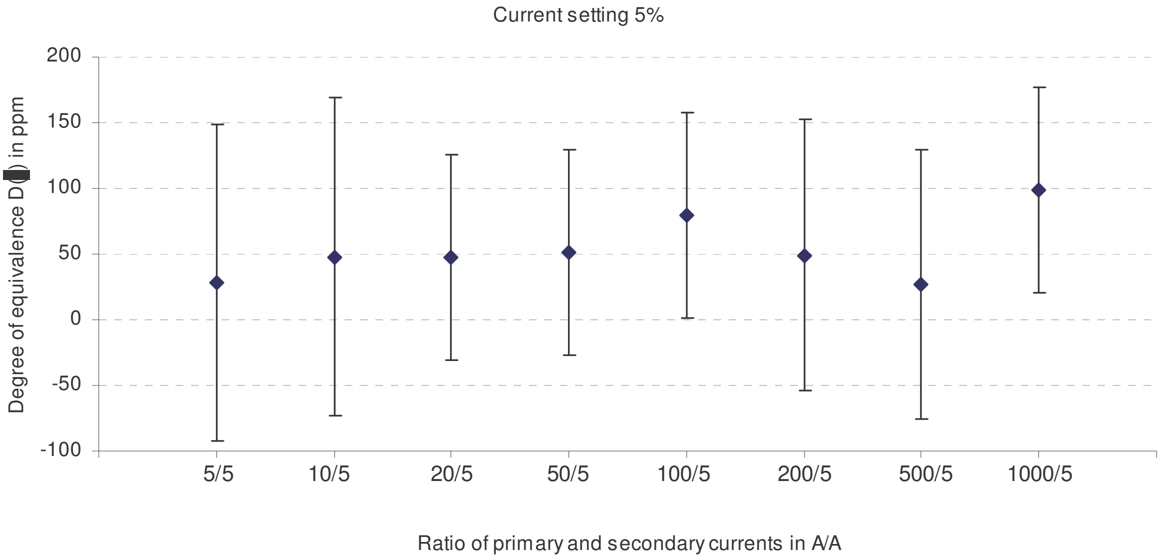

Figure 19. The degrees of equivalence *D(ε)* and expanded uncertainties *U[D(ε)]* (*k* = 2) for all ratios, at I/I_n=5%.

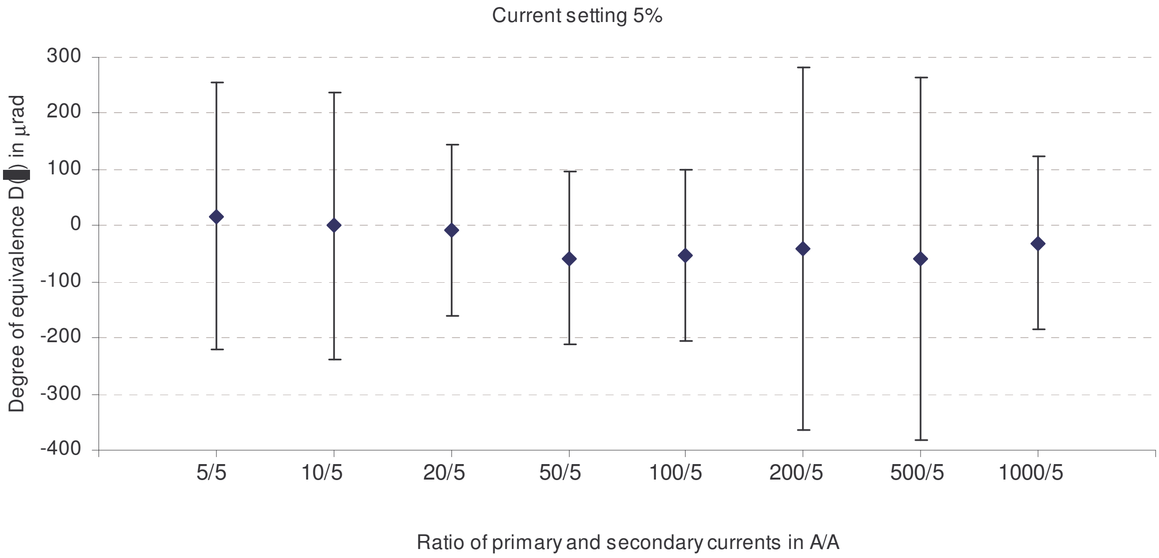

Figure 20. The degrees of equivalence *D(δ)* and expanded uncertainties *U[D(δ)]* (*k* = 2) for all ratios, at I/I_n=5%.

I/I_n	5A/5A		10A/5A		20A/5A		50A/5A		100A/5A		200A/5A		500A/5A		1000A/5A	
%	$D(\varepsilon)$	$U[D(\varepsilon)]$	$D(\varepsilon)$	$U[D(\varepsilon)]$	$D(\varepsilon)$	$U[D(\varepsilon)]$	$D(\varepsilon)$	$U[D(\varepsilon)]$	$D(\varepsilon)$	$U[D(\varepsilon)]$	$D(\varepsilon)$	$U[D(\varepsilon)]$	$D(\varepsilon)$	$U[D(\varepsilon)]$	$D(\varepsilon)$	$U[D(\varepsilon)]$
120	7	103	11	103	25	71	4	71	15	71	-12	103	-5	103	22	71
100	-1	103	6	103	24	71	10	71	30	71	-10	103	-5	103	23	71
20	3	103	15	103	21	78	20	78	42	78	-4	103	3	103	35	78
10	24	103	16	103	14	78	32	78	53	78	16	103	14	103	56	78
5	28	121	48	121	47	78	51	78	80	78	49	103	27	103	99	78

Table 8. Degrees of equivalence for ratio, and their expanded uncertainties

I/I_n	5A/5A		10A/5A		20A/5A		50A/5A		100A/5A		200A/5A		500A/5A		1000A/5A	
%	$D(\delta)$	$U[D(\delta)]$	$D(\delta)$	$U[D(\delta)]$	$D(\delta)$	$U[D(\delta)]$	$D(\delta)$	$U[D(\delta)]$	$D(\delta)$	$U[D(\delta)]$	$D(\delta)$	$U[D(\delta)]$	$D(\delta)$	$U[D(\delta)]$	$D(\delta)$	$U[D(\delta)]$
120	-25	153	-61	153	-26	100	-49	100	-31	100	-72	153	-62	153	-25	100
100	-50	153	-46	153	-69	100	-65	100	-36	100	-54	153	-80	153	-24	100
20	-15	181	-45	181	-46	126	-36	126	-39	126	-79	181	-146	181	-43	126
10	-32	209	-41	181	-17	126	-52	126	-63	126	-51	209	-47	209	-11	126
5	17	237	0	237	-8	153	-58	153	-53	153	-40	323	-59	323	-31	153

Table 9. Degrees of equivalence for phase, and their expanded uncertainties

$D(\varepsilon)$ and $D(\delta)$ are the degrees of equivalence for ratio and phase in ppm and µrad, respectively.

$U[D(\varepsilon)]$ and *$U[D(\delta)]$* are the expanded uncertainties in ppm and µrad, respectively.

APPENDIX A1. Methods of Measurement

A1.1. Detailed description of the BIM measurement setup and method

The measurements were performed using a manually balanced measurement system (Bridge: type K 507, manufacturer: Russia). The transformer test set measures the transfer standard (marked as DUT) errors by dividing the differential current into two components. These values are evaluated manually as current error (CE) and phase displacement (PE) by the bridge. The display "In %" on the test set indicates the percentage of the nominal ratio.

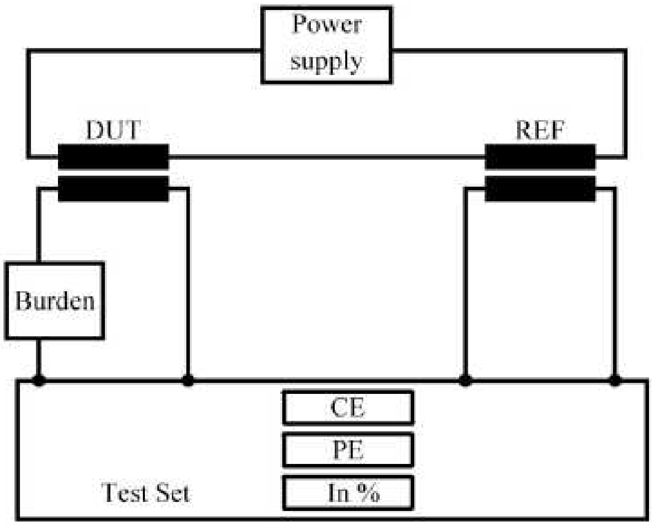

Figure 21. Schematic diagram of the BIM measurement setup

A1.2. Detailed description of the UME measurement setup and method

<u>Passive Compensated Current Comparator Method:</u>

Figure 22 shows the basic calibration circuit for the passive compensated current comparator designed by Kusters and Moore, with a test current transformer connected in series.

The compensation winding, which has the same number of turns as the secondary winding, will have a current which is the difference between the comparator secondary winding current and the test transformer secondary current.

If i is the nominal secondary current and α and β are respectively the errors of the comparator and the test transformer secondary currents, then the compensation winding current is $(i + \alpha) - (i + \beta)$ which is equal to $(\alpha - \beta)$. In linking the detector core, the compensation winding ampere-turns due to α will subtract from those of $(i + \alpha)$ due to the secondary winding, giving a resultant due to i, which exactly cancels the primary ampere-turns.

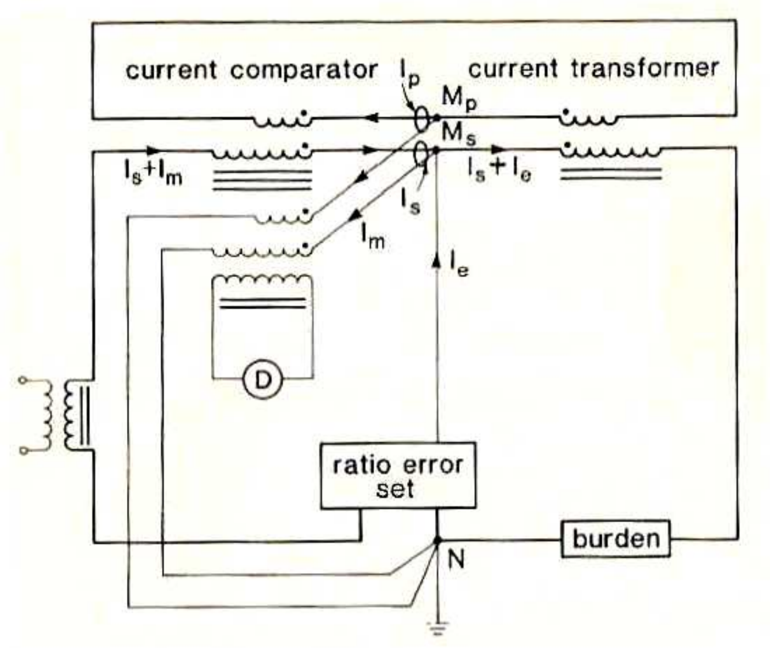

Figure 22. Basic calibration circuit

The detector core is therefore magnetized only by a current β, the error of the test current transformer. An equal and opposite current from the balance control circuit is injected into the compensation winding to give null deflection of the detector.

Electronically Compensated Comparator and Test Set:

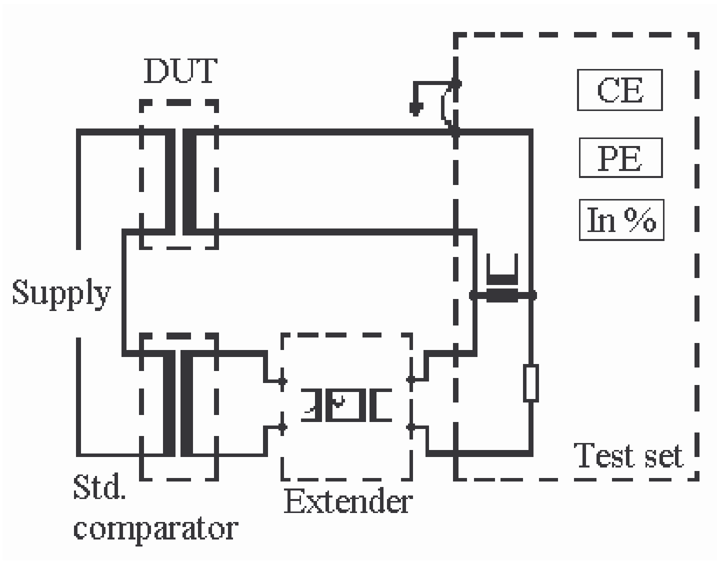

Figure 23. Electronic measurement system

Figure 23 shows the calibration circuit for the electronically compensated comparator and test set. The transformer test set measures the transfer standard (marked DUT in circuit) errors by dividing the differential current into two components. These values are evaluated automatically as current error and phase displacement by the test set electronics.

APPENDIX A2. Uncertainty Budgets

A2.1. Detailed uncertainty budget of BIM

Uncertainty budget for ratio error measurement (%): 5A/5A, 100%

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	repeatedly measured error	Normal	-0,0029	1,49E-05	9	1	1,49E-05	0,003579
2	error of the reference std.	Normal	-0,002	0,004	50	1	0,004	0,960763
3	error of the test set	Rectangular	0	0,001155	infinity	1	0,001155	0,277348
y		Normal	-0,0049	0,004163	58,68206			
		Conf. level =	95,45%	k =	2,0435			
		Result =	-0,0049	U =	0,0085			

Uncertainty budget for ratio error measurement (%): 10A/5A, 100%

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	repeatedly measured error	Normal	-0,00434	4,47E-05	9	1	4,47E-05	0,010736
2	error of the reference std.	Normal	-0,001	0,004	50	1	0,004	0,960714
3	error of the test set	Rectangular	0	0,001155	infinity	1	0,001155	0,277334
y		Normal	-0,00534	0,004164	58,69408			
		Conf. level =	95,45%	k =	2,0435			
		Result =	-0,0053	U =	0,0085			

Uncertainty budget for ratio error measurement (%): 20A/5A, 100%

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	repeatedly measured error	Normal	-0,00306	2,79E-05	9	1	2,79E-05	0,01208
2	error of the reference std.	Normal	-0,001	0,002	50	1	0,002	0,865962
3	error of the test set	Rectangular	0	0,001155	infinity	1	0,001155	0,499964
y		Normal	-0,00406	0,00231	88,91482			
		Conf. level =	95,45%	k =	2,0285			
		Result =	-0,0041	U =	0,0047			

Uncertainty budget for ratio error measurement (%): 50A/5A, 100%

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	repeatedly measured error	Normal	-0,00312	1,56E-05	9	1	1,56E-05	0,006755
2	error of the reference std.	Normal	-0,001	0,002	50	1	0,002	0,866006
3	error of the test set	Rectangular	0	0,001155	infinity	1	0,001155	0,499989
y		Normal	-0,00412	0,002309	88,897			
		Conf. level =	95,45%	k =	2,0285			
		Result =	-0,0041	U =	0,0047			

Uncertainty budget for ratio error measurement (%): 100A/5A, 100%

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	repeatedly measured error	Normal	-0,00194	1,05E-05	9	1	1,05E-05	0,004547
2	error of the reference std.	Normal	0	0,002	50	1	0,002	0,866016
3	error of the test set	Rectangular	0	0,001155	infinity	1	0,001155	0,499995
y		Normal	-0,00194	0,002309	88,89256			
		Conf. level =	95,45%	k =	2,0285			
		Result =	-0,0019	U =	0,0047			

Uncertainty budget for ratio error measurement (%): 200A/5A, 100%

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	repeatedly measured error	Normal	-0,00571	3,95E-05	9	1	3,95E-05	0,009487
2	error of the reference std.	Normal	-0,003	0,004	50	1	0,004	0,960726
3	error of the test set	Rectangular	0	0,001155	infinity	1	0,001155	0,277338
y		Normal	-0,00871	0,004164	58,69112			
		Conf. level =	95,45%	k =	2,0435			
		Result =	-0,0087	U =	0,0085			

Uncertainty budget for ratio error measurement (%): 500A/5A, 100%

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	repeatedly measured error	Normal	-0,00307	2,12E-05	9	1	2,12E-05	0,005092
2	error of the reference std.	Normal	-0,001	0,004	50	1	0,004	0,960756
3	error of the test set	Rectangular	0	0,001155	infinity	1	0,001155	0,277347
y		Normal	-0,00407	0,004163	58,6836			
		Conf. level =	95,45%	k =	2,0435			
		Result =	-0,0041	U =	0,0085			

Uncertainty budget for ratio error measurement (%): 1000A/5A, 100%

i	Quantity (unit)	Distribution	x_i	$u(x_i)$	ν_i	c_i	$u_i(y)$	$r(x_i,y)$
1	repeatedly measured error	Normal	-0,00472	3,13E-05	9	1	3,13E-05	0,013552
2	error of the reference std.	Normal	0	0,002	50	1	0,002	0,865946
3	error of the test set	Rectangular	0	0,001155	infinity	1	0,001155	0,499954
y		Normal	-0,00472	0,00231	88,92152			
		Conf. level =	95,45%	k =	2,0285			
		Result =	-0,0047	U =	0,0047			

A2.2. Detailed uncertainty budget of UME

The following sample table shows a typical uncertainty budget used by UME in the calculation of its uncertainty values. The uncertainty budget given shows the contributions associated with the measurements made on ratio 5A/5A at I/I_n=100%, at a burden of 5VA, unity power factor, at a frequency of 50Hz and an ambient temperature of 23˚C.

Quantity	Standard Uncertainty (ppm)	Type	Probability Distribution	Sensitivity Coefficient	Uncertainty Contribution (ppm)
Calibration of bridge and comparator	16.0	B	normal	1	16.0
Error in the bridge	5.8	B	rectangular	1	5.8
Error due to frequency setting	1.2	B	rectangular	1	1.2
Resolution of test set	0.3	B	rectangular	1	0.3
Error due to burden setting	0.6	B	rectangular	1	0.6
Error due to temperature	1.2	B	rectangular	1	1.2
Circuit configuration	1.0	B	normal	1	1.0
Error due to current setting	0.6	B	rectangular	1	0.6
Repeatability	10	A	normal	1	10
Combined uncertainty					19.8
Expanded uncertainty (U) (k=2)					**39.7**

The contributions for the “Calibration of the bridge and comparator” and “Error in the bridge” take into account any error of the test set and standard comparator used in calibration of the transfer standard.

The contribution for the error due to the burden setting takes into account the fact that the actual burden was either too high or too low. The change in ε_X and δ_X for a change in VA was calculated and then the error included in the budget. The contribution for the error due to the current setting covers any inaccuracy in the setting of the applied current, I/I_n. The value for repeatability is the standard deviation of the mean for each individual set of measurements.

The overall uncertainty of UME: The rounded off figure of 50ppm (or µrad) is preferred to use for both error components.

APPENDIX A3. Comparison Protocol

Guidelines for Bilateral Comparison between UME and BIM
Comparison of the measurement of current transformers (CTs)
EUROMET project 688

Pilot laboratory

TÜBİTAK-UME
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TURKEY

Coordinator

Hüseyin Çaycı
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fax: +90 262 679 5001
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Traveling standard

Traveling Standard	3 kA transformer (BIM-owned)
Type	uncompensated, multi-ratio, class 0.05, 1A and 5A secondary
Manufacturer	I-512 (Russia)
Serial number	21/1980
Weight	106 kg

Transportation information

UME and BIM will be responsible for arranging transportation to each other. UME and BIM should inform each other by e-mail or fax when the transformer is sent.

Custom information

The ATA Carnet document ***must always*** travel with the equipment, so UME and BIM should ensure that the correct paperwork accompanies the CT. Endorsements by customs will be required at departure from BG, entry to and departure from TR.

Circulation scheme and timetable

The following dates have been allowed for the participants and include transportation time to the next participant.

Laboratory	Period of measurements
BIM, BG	April-May, 2003
UME, TR (pilot)	June-August, 2003
BIM, BG	September-October, 2003

Measurements

Measurements should be made at the laboratory’s normal power frequency. The pilot laboratory will make measurements at 50 Hz.

The 3 kA transformer has several ratios, however the following ratios will be used: 1000, 500, 200, 100, 50, 20, 10, 5:5A. All ratios should be measured with a burden of 5 VA at unity power factor and with the following % of rated current: 120, 100, 50, 20, 10, 5 & 2 %. Measurements at 1 % rated current are optional.

Measurements should be made at the laboratory’s normal laboratory temperature. BIM should inform UME if the normal temperature is not 20°C or 23°C. The pilot laboratory will make measurements normally at 23 ± 1°C. However, pilot laboratory will make measurements both at 20 ± 1°C and 23 ± 1°C, if needed.

Report

The report should be sent to the pilot laboratory within 6 weeks of completing measurements. In addition to the results, the report should contain a brief description of the measurement technique and all relevant defining conditions such as actual burden achieved and temperature.

The report should contain an uncertainty budget and statement. The uncertainty calculations should comply with the requirements of the GUM for the calculation of the uncertainty of measurement. On the uncertainty the report should include the degrees of freedom and the complete budget of uncertainty.

Uncertainty Budget

The following table shows a typical uncertainty budget for current transformer calibrations. The uncertainty budgets supplied by BIM and UME should contain most of the principle contributions listed below. Values would be ppm for ratio errors and µrad or min. for phase errors.

Source of Uncertainty	Standard Uncertainty (ppm)	Probability Distribution	Sensitivity Coefficient	Contribution to the Standard Uncertainty (ppm)
Calibration of references	X_1	normal	1	X_1
Error in the bridge/test set	X_2	rectangular	1	X_2
Resolution of test set	X_3	rectangular	1	X_3
Errors due to • frequency setting • burden setting • temperature • current setting	X_4	rectangular	1	X_4
Circuit configuration	X_5	normal	1	X_5
Repeatability	X_6	normal	1	X_6
Standard uncertainty (k=1)				$\sqrt{X_1^2 + ... + X_6^2}$

Laboratory contact details

Laboratory address	Contact name, e-mail
UME TÜBİTAK Ulusal Metroloji Enstitüsü (NMI of Turkey) PO Box 54 Gebze, 41470 Kocaeli TURKEY Tel. : +90 262 6795000	Hüseyin ÇAYCI huseyin.cayci@ume.tubitak.gov.tr
BIM Bulgarian Institute of Metrology General Directorate “National Centre of Metrology” Section “Electric Energy Measurements” 52-B G.M. Dimitrov Blvd. 1040 Sofia BULGARIA Tel. : +359 29702792	Emil DIMITROV e.dimitrov@bim.government.bg