

Comparison of the Measurement of Current Transformers EUROMET Project 473

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1. Abstract

EUROMET grew from an informal collaboration of National Measurement Institutes (NMI) which started in 1975 and which is now based on a Memorandum of Understanding signed in 1987. Comparisons are performed to establish equivalence of measuring standards between all NMIs.

The EUROMET project 473 “Comparison of the measurement of current transformers” was started during April 1999, with the National Physical Laboratory (NPL) as pilot laboratory and ten other participating European NMIs. Project 473 was completed in June 2001, and a supplementary comparison was started in December 2000 with a further four NMIs. Detailed in this report is the protocol for the comparison, the influencing factors associated with assigning the comparison reference values and a brief description of the methods used by the participants.

2. Introduction

Current transformer calibrations carried out by the participating national laboratories support a large number of measurements made in the electrical generation, supply and distribution industries in their own countries, as well as supporting many transformer manufacturers who rely on national standards as a source of traceability. In one case, a participant also provides traceability to NMIs of other countries.

The transfer standard was an uncompensated Class 0.01 current transformer with nine ratios. The current ratio error and phase displacement (phase angle error) of each ratio of the transfer standard were determined at a defined frequency, burden and power factor, using each participant’s own measuring methods standards and equipment.

3. Participants

Project 473 participants in order of transfer standard circulation:

NPL, National Physical Laboratory, Teddington, United Kingdom. (Pilot Laboratory)

SP, Swedish National Testing and Research Institute, Borås, Sweden

SMD, Service de la Métrologie/Metrologische Dienst, Brussels, Belgium

PTB, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

GUM, Central Office of Measures, Warsaw, Poland

OMH, National Office of Measures, Budapest, Hungary

IEN, Istituto Elettrotecnico Nazionale “Galileo Ferraris”, Turin, Italy

METAS, Swiss Federal Office of Metrology and Accreditation, Bern-Wabern, Switzerland

BEV, Bundesamt für Eich-und Vermessungswesen, Vienna, Austria

HUT, Helsinki University of Technology, Helsinki, Finland

MIKES, Centre for Metrology and Accreditation, Helsinki, Finland

4. Measurement protocol

Each participant made measurements under their normal laboratory conditions using the following guidelines:

Transformation ratios: 1000, 500, 200, 100, 50, 20, 10, 5, 1 / 5 A

Burden:	5 VA, at unity power factor
Test frequency:	50 or 60 Hz
Ambient temperature:	20 to 23 °C ±1 °C
Rated current:	120, 100, 50, 20, 10, 5 & 2% (1% optional)

The participants were asked to report the measured current error and phase displacement values, with an uncertainty for each measurement calculated in accordance with the Guide to the Expression of Uncertainty in Measurement [2]. Additional information such as the method and a statement of traceability were also to be reported.

5. Measured quantities

The symbols and definitions used are in accordance with IEC 60044-1:1996 [1].

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 ppm is given by the formula:

$$\text{Current error (ppm)} = 10^6 \cdot (K_n I_s - I_p) / I_p$$

Phase displacement: The difference in phase, expressed in μrad , 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.

6. Methods of measurement

The majority of the participants used compensated current comparators in conjunction with homemade or commercial test sets to determine the transfer devices errors. The other method employed uses Rogowski coils and/or current shunts with outputs measured using digital multimeters.

Figure 1 shows the basic calibration circuit for the passive compensated current comparator designed by Kusters and Moore [4], 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, 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. 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. The error β is then given by $i r (G + j\omega C)$.

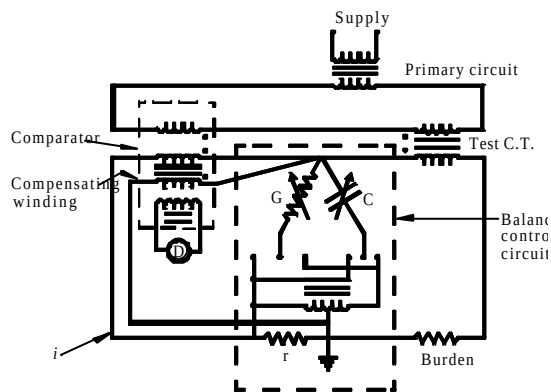


Figure 1. Basic calibration circuit

7. Transfer standard behaviour

NPL measured the transfer standard four times during the project, at the start, the end and twice during circulation, so that any change of the transfer standard would be detected. The standard deviation of these measurements showed that there was no significant change throughout the period of the comparison.

Figure 2 shows the current error deviation from a reference value for a measurement made by NPL. Typically the standard deviation of the mean of the measurements is less than 1 ppm.

Figure 3 shows the phase displacement as a deviation from a reference value for a measurement made by NPL. In all cases the standard deviation of the mean for phase displacement is less than 5 μrad .

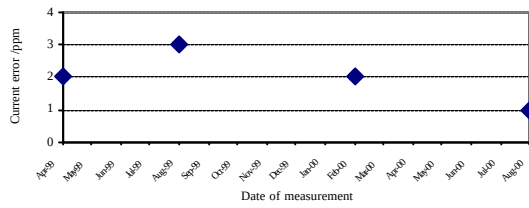


Figure 2. Current error behaviour

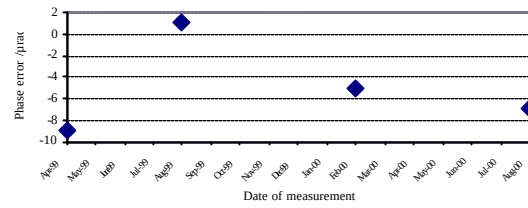


Figure 3. Phase displacement behaviour

8. Uncertainty calculations

Table 3 shows a typical uncertainty budget used in the calculation of the NPL uncertainty values. The uncertainty budgets supplied by each of the participants contained all or most of the principle contributions listed below.

Current error uncertainty							
Source of uncertainty	Value ($\pm$) ppm	Type	Prob.Dist.	Divisor	C_i	u_i ($\pm$) ppm	V_i or V_{eff}
Calibration of bridge and comparator	2	B	normal	2	1	1.000	8
Error in the bridge	1	B	rectangular	1.7321	1	0.577	8
Error due to frequency setting	1	B	rectangular	1.7321	1	0.577	8
Resolution of test set	0.5	B	rectangular	1.7321	1	0.289	8
Error due to burden setting	1.76	B	rectangular	1.7321	1	1.016	8
Circuit configuration	2	B	normal	2	1	1.000	8
Error due to current setting	1	B	rectangular	1.7321	1	0.577	8
Repeatability	0.85	A	normal	1	1	0.850	3
Combined uncertainty						2.199	134
Expanded uncertainty	k=2					4.398	

Table 1 Sample uncertainty budget

The degrees of freedom (ν_i) for all type B contributions are assumed to be infinite [2]. The effective degrees of freedom (ν_{eff}) for all type A contributions are estimated using the Welch-Satterwaite formula [2] based on the degrees of freedom of the individual uncertainty contributions $u_i(y)$ to obtain a coverage factor k .

For all measurements made by NPL, 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 %.

9. Comparison reference value

The comparison reference values have been calculated using the median of each set of measurement results rather than the mean or weighted mean. The use of the median, described in NPL report CISE 42/99 [3], was used as it is less influenced by the presence of extreme values. Using this method, the individual laboratory uncertainties are not used in the calculation of the reference value. This is an approach, which is free of subjective decisions, therefore removing discussion regarding credible and non-credible uncertainties.

From [3], the probability that a reference value lies within a certain interval can be obtained and the intervals containing the endpoints of the 95 % confidence intervals for that reference value can also be found.

The most likely interval for the reference value, once a binomial distribution has been calculated from binomial probabilities, is the interval associated with the centre of the binomial distribution. If N is the number of participating laboratories and the results for each set of measurements are arranged in order of magnitude, for even values of N the median is the midpoint of interval $N/2$. If N is odd, interval $(N-1)/2$ and interval $(N+1)/2$

are equally likely to contain the median value, therefore the median can be chosen using $(N+1)/2$ since it is an endpoint of both intervals.

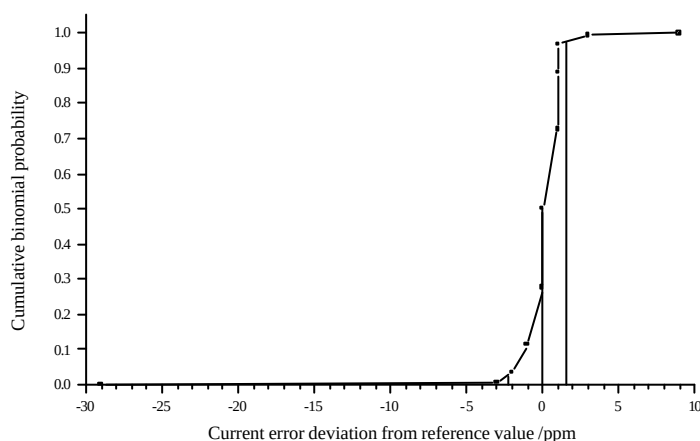
10. 95% Confidence intervals

The confidence interval $[\tau_L, \tau_H]$, which contain the endpoints of the 95% confidence interval for the reference value are obtained by calculating their cumulative probabilities. The natural choices are for τ_L to lie in an interval having endpoints corresponding to cumulative probabilities that bracket the value 0.025, and for τ_H to lie in an interval having endpoints corresponding to cumulative probabilities that bracket the value 0.975. The intervals τ_L and τ_H can be located by inverse linear interpolation in the graph in figure 4, of the corresponding binomial probabilities against each result. For $N=10$, τ_L lies between τ_2 and τ_3 , and τ_H between τ_8 and τ_9 . Different results will apply for other values of N . The extreme values τ_1 and τ_N do not influence the determination of the confidence interval for $N=9$.

The following steps summarise the procedure for calculating the 95% confidence intervals.

Use ${}^N C_k = N! / \{k!(N-k)!\}$, which is the number of ways of choosing k items from N .

Associated with each interval is a binomial probability, which is calculated using $p_{N,j} = {}^N C_k / 2^N$, $j = 0, \dots, N$.



These are combined to form a cumulative binomial probability. By linear inverse interpolation the corresponding value associated with each binomial probability can be obtained. In particular the reference value, $\tau_{ref} = 0.5$ (the median), and $\tau_{0.025}$ and $\tau_{0.975}$ the endpoints of a 95% confidence interval for τ_{ref} .

Figure 4 shows the cumulative binomial probability for $N=11$ (i.e. 11 laboratories), with the location of the reference value (central vertical line) and the endpoints of the 95% confidence intervals τ_L and τ_H (outer vertical lines).

Figure 4. Cumulative binomial probabilities

11. Results

Results will be displayed at the conference.

12. References

- [1] IEC 60044-1:1996, Instrument Transformers, Part 1: Current Transformers
- [2] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, Guide to the Expression of Uncertainty in Measurement, International Organisation for Standardization, Geneva, First Edition 1993.
- [3] Cox MG, A discussion of approaches for determining a reference value in the analysis of key-comparison data, NPL Report CISE 42/99, 1999, 17 p.
- [4] Moore WJM and Miljanic PN, The Current Comparator, IEE Electrical Measurement Series 4, Peter Peregrins Ltd, London, 1988, 120 p.

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