

JAB NOTE4
ESTIMATION OF MEASUREMENT UNCERTAINTY
(Electrical Testing / High Power Testing)



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The Japan Accreditation Board for Conformity Assessment (JAB)

JAB NOTE 4

ESTIMATION OF MEASUREMENT UNCERTAINTY (Electrical Testing/ High Power Testing)

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Laboratory Accreditation Division

The Japan Accreditation Board for Conformity Assessment

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1. INTRODUCTION

The method of estimating "uncertainty" in laboratories for high power testing, with focus on the measurement of values relative to electric current, has been studied. The basic principles of the estimation of uncertainty and its method for high power testing are not different from the one for other test fields. However, once it comes down to their application to practical cases, it is possible to encounter several kinds of alternatives in interpretation in terms of how to apply calculation formulas, etc.

This document describes the general principles for estimating the uncertainty in a high current measuring system and is also intended for use in high power testing laboratories, for which cases of measurement instruments and tools actually used in high power testing are addressed and specific examples of the estimation of uncertainty in measurement using such instruments are given.

2. SCOPE

This document applies to the estimation of uncertainty and its evaluation in a high current measuring system and measurement results in high power testing laboratories or laboratories under application for accreditation.

3. REFERENCES

- 1 ISO/IEC 17025:1999, General requirements for the competence of testing and calibration laboratories
- 2 ISO/IEC Guide 2:1991, General terms and their definitions concerning standardization and related activities
- 3 International Vocabulary of Basic and General Terms in Metrology: 1993, issued by BIPM, IEC, ISO, IFCC, IUPAC, IUPAP and OIML (abbr. VIM)
- 4 Guide to the Expression of Uncertainty in Measurement: 1995, issued by BIPM, IEC, ISO, IFCC, IUPAC, IUPAP and OIML (abbr. GUM)
- 5 IEC 60060-1:1989, High-voltage test techniques. Part 1: General definitions and test requirements
- 6 IEC 60060-2:1994, High voltage test techniques. Part 2: Measuring systems
- 7 IEC 60060-2 Annex H: 1996
- 8 CIGRE 33-96 (WG 03):1996, Uncertainty of HV Measurements - the Situation at IEC and CENELEC
- 9 STL GUIDE TO THE INTERPRETATION OF IEC 60060-2, 1999-11

4. TERMS AND DEFINITIONS

- measurand (VIM 2.6)
particular quantity subject to measurement.
- true value (VIM 1.19)
value consistent with the definition of a given particular quantity.
- error (in measurement) (VIM 3.10)
result of a measurement minus a true value of the measurand.
- uncertainty of measurement (VIM 3.9)
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.
- test (ISO/IEC Guide 2)
technical operation that consists of the determination of one or more characteristics of a given product, process or service according to a specified procedure.
- calibration (VIM 6.11)
set of operations that establish, under specified conditions, the relationship between values of quantities

indicated by a measuring instrument or measuring system, or values represented by a material measure or a reference material, and the corresponding values realized by standards.

- resolution

minimum significant identifiable difference (e.g., a change by "1" of the last digit on a digital display)

- normal distribution, Laplace-Gauss distribution

distribution of continuous variables whose probability density functions are given by:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right], \quad -\infty < x < \infty$$

- rectangular distribution (uniform distribution)

distribution whose probability density function has a given value in a finite interval [a, b] and 0 outside the interval.

- correlation (ISO 3534)

the relationship between two or several random variables within a distribution of two or more random variables.

- standard deviation

the positive square root of the variance.

- experimental standard deviation (VIM 3.8)

for a series of n measurements of the same measurand, the quantity s characterizing the dispersion of the results and given by the formula:

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$$

x_i being the result of the i th measurement and \bar{x} being the arithmetic mean of the n results considered.

- level of confidence

value expressing the level of confidence in a result (e.g., 95%).

- standard uncertainty (GUM 2.3.1)

uncertainty of the result of a measurement expressed as a standard deviation.

- combined standard uncertainty (GUM 2.3.4)

standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities.

- coverage factor (GUM 2.3.6)

numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty.

- expanded uncertainty (GUM 2.3.5)

quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand.

(Note) A coverage factor, k , is typically in the range 2 to 3.

- national standard (VIM 6.3)

standard recognized by a national decision to serve, in a country, as the basis for assigning values to other standards of the quantity concerned.

- reference standard (VIM 6.6)

standard, generally having the highest metrological quality available at a given location or in a given organization, from which measurements made there are derived.

- traceability (VIM 6.10)

property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.

(Note) The concept is often expressed by the adjective traceable.

- measuring system (VIM 4.5)

complete set of measuring instruments and other equipment assembled to carry out specified measurements.

- rss (root sum square) method

a calculation method for obtaining a combined standard uncertainty by combining components that contribute to uncertainty of measurements, this is sometimes called as such because the calculation involves a root sum square of each component by the rule of uncertainty propagation.

Example: $\sqrt{2^2 + 3^2 + 6^2} = 7$

- output quantity

a designation of a measurand in the process of its derivation, in most cases, the measurand is not directly measured, and is determined through functional relation of other more than one quantity, and is called "output quantity" in the sense that it is the output of the process by the function.

- input quantity (-ies)

quantity measured directly to obtain an output quantity and quantity determined through reference, estimation, etc., the input usually is normally in plural and an output quantity is determined on input quantities by functional relationship.

5. PRINCIPLES FOR THE ESTIMATION OF UNCERTAINTY

5.1 Concept of uncertainty

When a measurement is repeated a number of times, even if one thinks that it has been done under the same condition, the resulting values are dispersed. If measured under alternative conditions, e.g. as for the operators, devices or methods, the results will be dispersed due to the changes in conditions. Results are dispersed in a certain range and such range is the uncertainty of measurement.

Among conditions of measurement, some are controllable and others not. While conducting a measurement, all or a part of the former (controllable conditions) is held constant. Conditions that are not held constant (usually, portions beyond the limit of control) bring about uncertainty in measured results.

There are three kinds of "measurement uncertainty", standard uncertainty "u", combined standard uncertainty "u_c", and expanded uncertainty "U". Values stated in reports of measurement results are, usually, expanded uncertainties.

By using expanded uncertainty "U", one can state that a measurement result is expected to fall between y-U and y+U in almost all cases of repeated measurement. The extent of "almost all cases" is determined arbitrarily but in many cases a level of confidence of 95% is adopted, which means if the same measurement is conducted 20 times, it is expected that the results will be within this range 19 times out of the 20.

5.2 Method for evaluating uncertainty

Procedure for obtaining uncertainty is shown in Figure 5.1.

In many cases, measurand Y is not directly measured, but determined from other n quantities: X₁, X₂, ..., X_N. This functional relationship is called a mathematical model, and can be expressed, as expressed in the GUM, by formula:

$$Y = f(X_1, X_2, \dots, X_N) \tag{1}$$

Where, Y is called output quantity and X₁, X₂, ..., X_N input quantities.

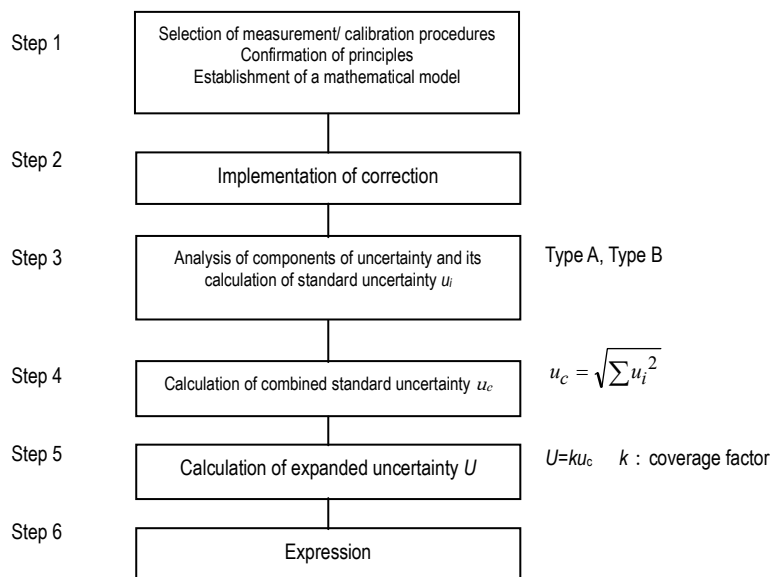


Figure 5.1 Procedure for obtaining uncertainty

There are two types of method A and B as shown below for evaluating standard uncertainties:

- Type A: Evaluations by a statistical analysis of the results of a series of repeated measurements. The standard deviation obtained from the statistical analysis is considered as standard uncertainty. Usually, normal distribution (Laplace-Gauss distribution) is presumed.
- Type B: Evaluation by methods other than statistical. Attention should be paid to the form of distribution (whether rectangular, normal, etc.).

5.3 Type A evaluation of standard uncertainty

In many instances, measurement is repeated several times under the same condition, i.e. to obtain estimated value q of measurand Q , experiments are repeated n times, observed values q_i ($i = 1, 2, \dots, n$) from each experiment are averaged, and the mean value \bar{q} is determined to be estimated value q .

$$\bar{q} = \frac{1}{n} \sum_{i=1}^n q_i \tag{2}$$

The experimental variance $s^2(q_k)$ is used as the estimate of the variance σ^2 of q .

$$s^2(q_k) = \frac{1}{n-1} \sum_{i=1}^n (q_i - \bar{q})^2 \tag{3}$$

The positive square root of the experimental variance is the experimental standard deviation $s(q_k)$. In this case, the degree of freedom of the experimental standard deviation is $n-1$.

The variance of the mean \bar{q} is given by $\sigma^2(\bar{q}) = \frac{\sigma^2}{n}$. Therefore, (4) is used as its estimated value:

$$s^2(\bar{q}) = \frac{s^2(q_k)}{n} \tag{4}$$

Where, $s^2(\bar{q})$ is called the experimental variance of the mean, and its positive square root $s(\bar{q})$ the experimental standard deviation of the mean.

Through the above experiments and statistical analyses, the estimated value q of measurand Q is obtained as the mean value \bar{q} and its standard uncertainty $u(\bar{q})$ as the experimental standard deviation of the mean $s(\bar{q})$.

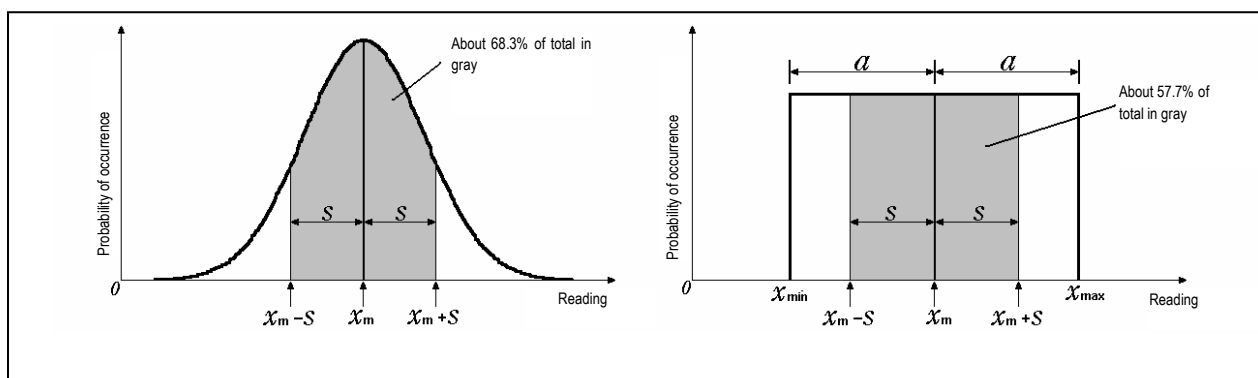
$$u(\bar{q}) = s(\bar{q}) \tag{5}$$

(REMARK 1) There is a procedure to multiply the experimental standard deviation by t -value to get a kind of expanded uncertainty corresponding to 95% level of confidence and then divide it by 2 followed by the calculation of combined standard uncertainty. This is not a procedure prescribed in the GUM and should not be used.

5.4 Type B evaluation of standard uncertainty

The standard uncertainties associated with the estimated values of input quantities that are not from repeated observation will be evaluated through scientific judgments based on all available information. Type of probability distribution, standard uncertainty and, if necessary, degree of freedom should be determined.

With regard to the probability distribution, there are normal, rectangular, triangular, trapezoidal, U-shaped, etc., of which the normal and rectangular distributions are most frequently used and illustrated in Figure 5.2.



(a) Normal distribution (standard deviation s) (b) Rectangular distribution (standard deviation s)

Figure 5.2 Standard deviation s of normal distribution (a) and rectangular distribution (b)

If the value of input quantity is estimated to be within the range of minimum x_{min} and maximum x_{max} and if any value within this range is evaluated equally adoptable, this is the case of the rectangular distribution shown in Figure 5.2 (b), and its standard uncertainty is given by formula (6):

$$u(x) = \frac{a}{\sqrt{3}} \tag{6}$$

Where,

$$a = \frac{x_{max} - x_{min}}{2} \tag{7}$$

In this document, "a" is called a half-width of (rectangular distribution).

The degree of uncertainty ν for Type B evaluation, is straightforward if it is stated in a calibration certificate, or derived from a coverage factor and level of confidence if they are stated there. In the absence of such reference, it will be determined from the level of confidence which the laboratory estimates of the uncertainty by formula:

$$\nu \approx \frac{1}{2} \cdot \frac{1}{\left(\frac{\Delta u(x)}{u(x)}\right)^2} \tag{8}$$

Where, Δu is the uncertainty of uncertainty u .

For example, if it is estimated that the estimated uncertainty has an uncertainty of about 25%, which means

$$\frac{\Delta u(x)}{u(x)} = \frac{1}{4}, \text{ then } \nu = 8 \text{ can be obtained from the formula (8)}$$

5.5 Calculation of combined standard uncertainty

The standard uncertainty of output quantity is obtained by combining standard uncertainties of each input quantity by a method based on the law of propagation of uncertainty, i.e., first, multiply each standard uncertainty of input quantity by corresponding sensitivity coefficient, second, square each of the multiplied results, third, sum them up, and finally calculate the square root of the sum (root sum square method).

$$u_c(y) = \sqrt{\sum_{i=1}^n [c_i u(x_i)]^2} \quad (9)$$

Where $u(x_i)$ is the standard uncertainty of the i th input quantity X_i ; c_i is the sensitivity coefficient of Y to X_i .

Sensitivity coefficient may be obtained from the formula (1) by its partial derivative $\frac{\partial f}{\partial X_i}$ at $X_i = x_i$. In cases where the form of mathematical function is not clear, it can be obtained experimentally, i.e., change x_i by a small amount Δx_i in the neighborhood of $X_i = x_i$ and observe the corresponding change Δy of Y , and then calculate by formula (10):

$$c_i = \frac{\Delta y}{\Delta x_i} \quad (10)$$

(NOTE 1) The formula (9) is for the case where there is no correlation among input quantities. For the case where input quantities are correlated, please refer to the GUM etc.

(NOTE 2) The formula (9) is for an uncertainty in absolute value (not a relative value). When the function of the mathematical model is the product (including quotient) of input quantities, the direct use of formula (9) makes the calculation complicated. In such case, modification of the formula (9) paying attention to factors contained in sensitivity coefficients leads to a formula of a simple root sum square method for relative uncertainty.

(NOTE 3) Calculation of combined standard uncertainty may be divided in several steps. Especially, when there exist more than one component contributing to the uncertainty of a certain input quantity, it is desirable to obtain the standard uncertainty of the input quantity by combining the standard uncertainties of its components. Such process will make the whole procedure of uncertainty evaluation easy to grasp.

5.6 Calculation of expanded uncertainty and rounding

Expanded uncertainty U is calculated by multiplying the combined standard uncertainty $u_c(y)$ by a coverage factor k .

$$U = k u_c(y) \quad (11)$$

Coverage factor k is determined in relation to the degree of freedom ν and level of confidence p . The coverage factor should be obtained in general from the Student's distribution (t-distribution), but, in many instances, $k=2$ is adopted with the level of confidence of $p = 95\%$. $p = 95\%$ with $k=2$ may be claimed only where the degree of freedom is larger than about 20.

The degree of freedom for a combined standard uncertainty is derived from the degrees of freedom ν_i 's of standard uncertainties by formula (12):

$$\nu_{eff} = \frac{u_c^4(y)}{\sum_{i=1}^n \frac{u_i^4(y)}{\nu_i}} \quad (12)$$

Where, $u_i(y) = c_i u(x_i)$ (13)

ν_{eff} is called effective degree of freedom.

Table 5.1 Student's *t* distribution
(Value of *t* for a specific level of confidence *p*% as a function of the number of observations *n*)

<i>n</i> \ <i>p</i> %	68.3	95.0	99.7
5	1.14	2.78	6.62
6	1.11	2.57	5.51
7	1.09	2.45	4.90
8	1.08	2.36	4.53
9	1.07	2.31	4.28
10	1.06	2.26	4.09
20	1.03	2.09	3.45
Infinite	1.00	1.96	3.00

Determined value of measurement uncertainty has its own uncertainty. The evaluation of uncertainty is usually performed so as to make the uncertainty of uncertainty less than about 5%. The rationale for considering *k*=2 is acceptable is that $\nu \geq 20$ is achieved in many measurements and therefore *p*=95% may be claimed with *k*=2.

The expression of the value of calculated expanded uncertainty *U* shall be consistent with the uncertainty of the expanded uncertainty. Usually, as it is considered that the uncertainty of uncertainty is about 5%, the number of significant digits should be up to two.

(NOTE 4) For rounding to two significant digits, it suffices to count fractions over 0.5 as 1 and disregard the rest at the third digit. This is because that even in the case of 1.04..., where the maximum underestimation of uncertainty occurs, the underestimation by rounding off the third digit is less than 5%. However, in case where a number is rounded to one significant digit and the underestimation by the rounding-off becomes 5% or more, the number should be rounded up (Ex.: 8.4.....9).

5.7 Expression of results

A measurement result with its associated uncertainty may be expressed in the form of:

$$y \pm U \quad (A) \tag{14}$$

where, *y* is the measurement result and *U* is its expanded uncertainty.

For the cases of high power measurement, uncertainty is often expressed by percentage $\frac{U}{y} \times 100$ (%), in that case,

the measurement result with its associated uncertainty is expressed by the formula of:

$$y (1 \pm \Delta \times 10^{-2}) \quad (A) \tag{15}$$

(REMARK 2) An expression such as $y (A) \pm \Delta(\%)$ must be avoided.

(NOTE 5) The least significant digit of expanded uncertainty *U* should be put to the same order as the least significant digit of the value *y* of the measurement result.

(NOTE 6) The coverage factor *k*=2 is applied in this document for the reason that it is generally accepted. But in the GUM no specific number is given and it says that it should be selected based on the required level of confidence, saying also that, in general, the number is between 2 and 3. Anyway the value given to *k* needs to be stated together

with the value of uncertainty. Furthermore, if possible, the degree of freedom and level of confidence should also be stated.

(Example: $XX \pm YY$ (A), where the number following symbol \pm is the number value of an expanded uncertainty, determined from a coverage factor $k=2$ based on the t -distribution for $\nu=50$ degrees of freedom, and defines an interval estimated to have a level of confidence of 95%.)

6. GUIDELINES FOR THE ESTIMATION OF UNCERTAINTY IN HIGH POWER TESTING

6.1 Structures of high current measuring systems

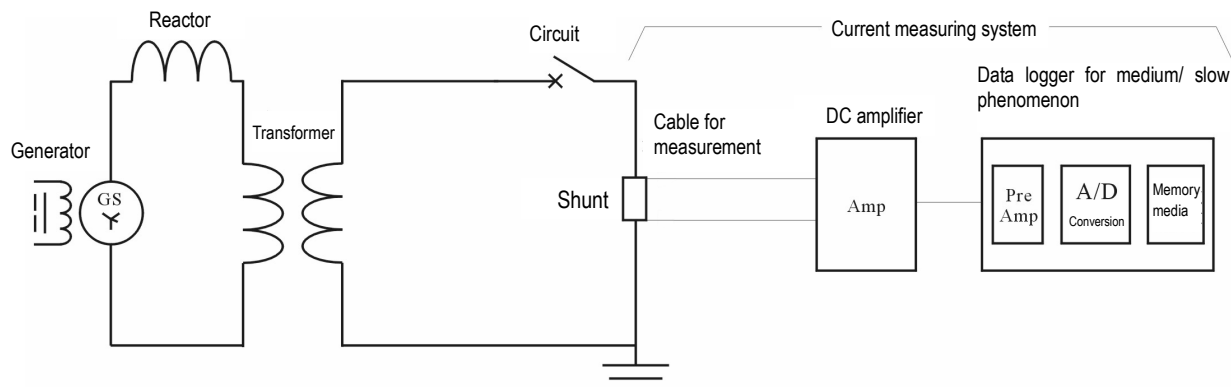


Figure 6.1 Representative case of a current measuring system

A high current measuring system consists of detector, transmission system, amplifier, and converter. The structures of measuring systems used generally in high power testing laboratories are largely grouped into the following four cases (see Table 6.1). Other methods than given here are the ones that use Rogowsky coils or optical current transformers (CTs) for the detector, but they are not covered here since their records of application as well as their data are scarce.

- Case 1: Measuring system composed of a shunt and digital optical link.
- Case 2: Measuring system composed of a shunt and analogue optical link.
- Case 3: Measuring system composed of a shunt and coaxial cable.
- Case 4: Measuring system where a current transformer (CT) output is converted into a voltage signal and transmitted by coaxial cable.

Table 6.1 Representative structures of high current measuring systems

Case	Case 1	Case 2	Case 3	Case 4
Component				
1 Detector (shunt / CT)	1-1 Shunt			1-2 CT / secondary shunt
2 Transmission system	2-1 Optical fiber link (Digital E/O-O/E)	2-2 Optical cable (Analogue E/O-O/E)	2-3 Coaxial cable	
3 Amplifier		3 DC amplifier		
4 Converter		4 A/D converter		
5 Data processing	5 Software			

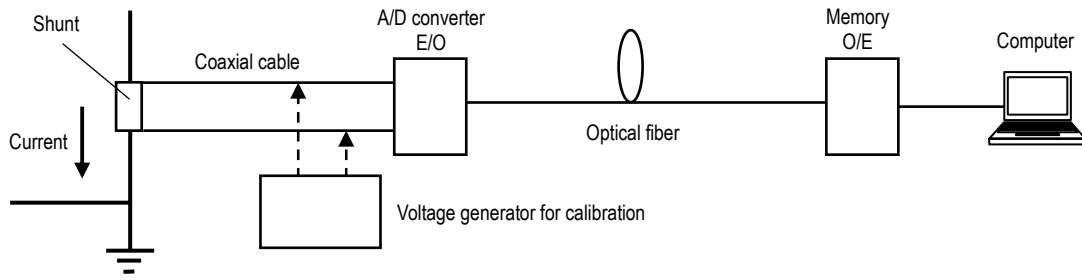


Figure 6.2 Measuring system of high current (Case 1)

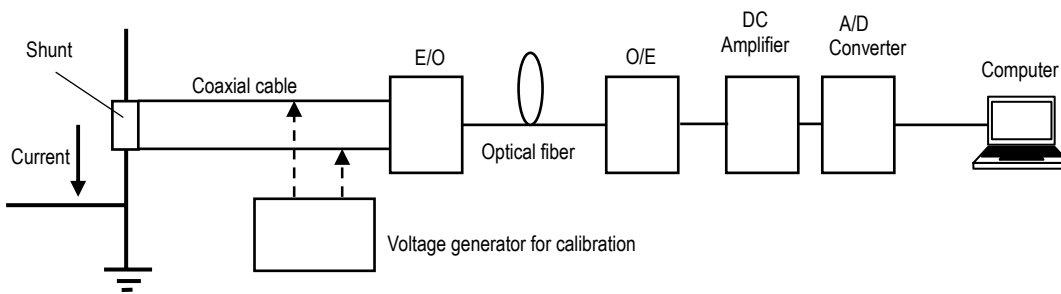


Figure 6.3 Measuring system of high current (Case 2)

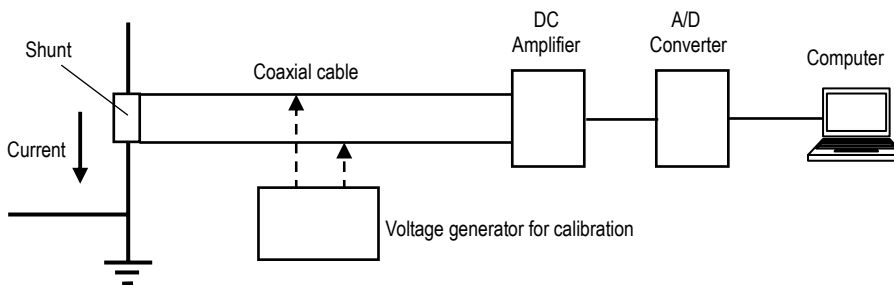


Figure 6.4 Measuring system of high current (Case 3)

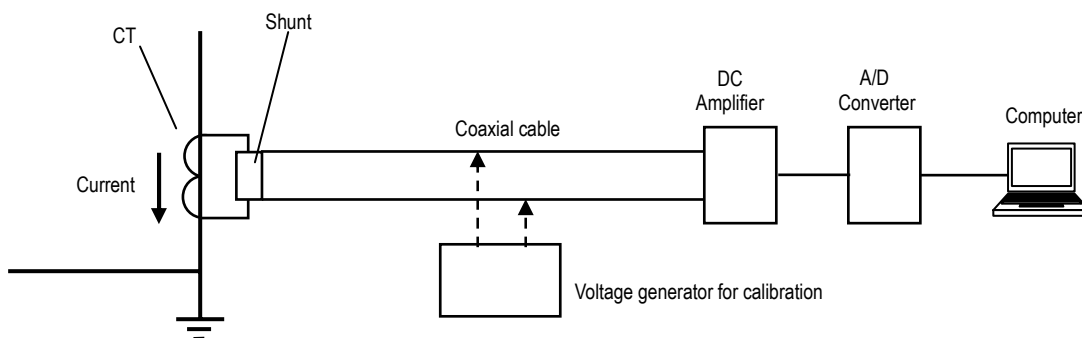


Figure 6.5 Measuring system of high current (Case 4)

6.2 Factors contributing to uncertainty in a high current measuring system

In order to estimate uncertainty in this measuring system, it is necessary to estimate first, normally, standard uncertainty (or standard deviation) in every possible component contributing to expanded uncertainty during high current measurement. However, the method of calculating uncertainty through a comparison calibration against a standard shunt shall be defined separately.

First of all, major sources that contribute to uncertainty in every component of measuring system are shown in the table below:

Table 6.2 Sources contributing to uncertainty in a high current measuring system and their classification

Component	Type of Component	Source of uncertainty	Importance	Type	Probability Distribution	Formula to calculate standard uncertainty
1 Detector (shunt / CT)	1-1 Shunt	U ₁ repeatability	1	A	Normal	(5)
		U ₂ uncertainty of a double bridge calibration value	1	B	Normal / Rectangular (*1)	(5) / (6)
		U ₃ temperature effect by ambient temperature	2	B	Rectangular	(6)
		U ₄ temperature effect by Joule heat	2	B	Rectangular	(6)
	1-2 CT / secondary shunt	U ₅ repeatability	1	A	Normal	(5)
		U ₆ uncertainty in calibration value of secondary shunt	1	B	Normal / Rectangular (*1)	(5) / (6)
		U ₇ temperature effect by secondary shunt	2	B	Rectangular	(6)
		U ₈ non-linearity of CT	2	B	Rectangular	(6)
2 Transmission system	2-1 Optical fiber link (Digital E/O-O/E)	U ₉ temperature drift	2	B	Rectangular	(6)
		U ₁₀ non-linearity	2	B	Rectangular	(6)
	2-2 Optical cable (Analogue E/O-O/E)	U ₁₁ temperature drift	1	B	Rectangular	(6)
		U ₁₂ non-linearity	2	B	Rectangular	(6)
2-3 Coaxial cable	This item can be neglected at power frequencies					
3 Amplifier	3 DC amplifier	U ₁₃ gain (including gain adjustment)	1	B	Rectangular	(6)
		U ₁₄ non-linearity	1	B	Rectangular	(6)
		U ₁₅ temperature drift	1	B	Rectangular	(6)
4 Converter	4 A/D converter	U ₁₆ resolution of digital detector system	1	B	Rectangular	(6)
		U ₁₇ temperature drift	2	B	Rectangular	(6)
5 Data processing	5 Software	U ₁₈ least-square method	1	B	Rectangular	(6)
		U ₁₉ three(3) crest method	1	B	Rectangular	(6)

This table presumes a case where a double bridge calibration is carried out in a testing laboratory using a reference standard with measurement traceability.

For the column of "Importance": "1" = contributing component required to be taken into consideration for the calculation of uncertainty.

"2" = contributing component that may be omitted from the calculation of uncertainty, when justifiable.

(*1): Applicable evaluation method depends on the existence of a statement of uncertainty on the calibration certificate, to choose either one of "normal distribution" or "rectangular distribution".

Using the identification numbers shown in Table 6.2, factors of uncertainty for each component and examples of the calculation of standard uncertainty are shown below:

6.2.1 u_1 through u_8 - Detector(shunt / CT)

6.2.1.1 u_1 through u_4 - Shunt

Shunt is a resistive element that converts current into voltage, and in order to exclude reactance component as much for accurate measurement, coaxial type shunts with least inductance are generally applied in high current measuring. The uncertainty of a shunt relates to its resistance, where uncertainties by its resistance measurement, surrounding temperature, temperature rise by Joule heat, etc, introduce effects. In designing shunt, usually, material with minimum temperature coefficient is applied, so as to satisfy the thermal capacity specification regarding the temperature rise.

(a) Factors contributing to uncertainties in measured values of shunt resistance

[u_1 repeatability]

Table 6.3

Times of measurements	Measured resistance value (mΩ)
1	0.3971
2	0.3968
3	0.3969
4	0.3970
5	0.3970
6	0.3970
7	0.3971
8	0.3971
9	0.3972
10	0.3972
Mean value	0.39704
Standard deviation	0.000126
Percentage of deviation to mean value	0.0317(%)

Applying measuring instrument which is traceable to National Standard, the resistance is measured, e.g. ten times. Assuming the measured values distribute along normal distribution, the percentage standard deviation to the mean value, i.e. the standard uncertainty is obtained as follows:

Table 6.3 is an example.

$$\frac{0.000126}{0.39704} \times 100 = 0.0317(\%)$$

[u_2 uncertainty of a double bridge (resistance measuring instrument) calibration value]

The uncertainty stated on the calibration certificate is used. Otherwise, uncertainty is derived from the half-width of a rectangular distribution that is corresponding to the accuracy stated in that calibration certificate.

(b) Factors relating to the condition of use (temperature change)

[u_3 temperature effect by ambient temperature]

In general, the resistance materials used for the shunts are Manganin wire or sheets with small temperature coefficients. In this case, if assumed:

- (1) the temperature coefficient is about 25×10^{-6} ,
- (2) the ambient temperature is 0~40°C, and
- (3) the temperature of the shunt at the time of the calibration is 20°C,
i.e. the maximum temperature difference is 20K,
then the resistance change becomes: $25 \times 10^{-6} \times 20 = 0.0005 (=0.05\%)$,

which is considered as rectangular distribution and the standard uncertainty is 0.029% as the result of division by $\sqrt{3}$.

[u_4 temperature effect by Joule heat]

Assuming that the temperature rise due to Joule heating is 60K, the resistance change becomes as above:

$$25 \times 10^{-6} \times 60 = 0.0015 (=0.15\%),$$

and the standard uncertainty is 0.087% as the result of division by $\sqrt{3}$.

Summary of u_1 through u_4 .

[u_1 repeatability]

By formula (5): $u_1 = \frac{0.0317}{\sqrt{10}} = 0.01(\%)$

[u_2 uncertainty of a double bridge (resistance measuring instrument) calibration value]

Assuming that the expanded uncertainty ($k=2$) stated on the calibration certificate is 0.05 (%),

$$u_2 = \frac{0.05}{2} = 0.025(\%)$$

[u_3 temperature effect by ambient temperature]

$25 \times 10^{-6} \times 20 = 0.0005$ (=0.05%), therefore, by formula (6): $u_3 = \frac{0.05}{\sqrt{3}} = 0.029(\%)$

[u_4 temperature effect by Joule heat]

$25 \times 10^{-6} \times 60 = 0.0015$ (=0.15%), therefore, by formula (6): $u_4 = \frac{0.15}{\sqrt{3}} = 0.087(\%)$

6.2.1.2 u_4 through u_8 - CT / secondary shunt

As a method to estimate the uncertainty of a CT for high current measuring, the comparison measuring by the relevant CT and an already calibrated shunt connected in series seems to be most appropriate.

Since performance of a CT depends on magnitude of the current as for both AC and DC components, the estimated uncertainty is valid within the highest current which has been applied in the evaluation.

Conditions to be applied in the current carrying test and its evaluation method shall be as follows:

- Set up around CT:

Connections are to be the same as in actual current flowing tests regarding the main current path, the secondary circuit load impedance and the power factor.

- Test current:

Current with the maximum DC component (the first crest value of the current is equal or higher than 2.5 times of the specified r.m.s. value.).

- Evaluation:

Comparison between what are measured by the CT and by the calibrated shunt regarding the crest values of the currents with DC component.

[u_5 repeatability]

Using a traceable AC shunt connected in series to a CT, the same electric current is loaded n times. From the mean value and the standard deviation of those n measurements the percentile deviation of CT ratio is obtained to derive a standard uncertainty assuming they are in normal distribution. Estimation is made by the comparison of the first peak of the loaded current.

Table 6.4 shows an example of measurements and evaluation results.

Table 6.4 Example of measurements by a CT and a shunt for comparison connected in a series. (repeatability)

Alternate current shunt measured values I _m [kA]	CT measured value I _i [kA]	Ratio (= I _i / I _m)
53.05	52.63	0.9921
57.30	56.90	0.9930
53.17	52.74	0.9919
57.39	56.97	0.9927
53.13	52.73	0.9925
57.24	56.82	0.9927
53.32	52.90	0.9921
57.49	57.06	0.9925
52.97	52.58	0.9926
57.40	56.95	0.9922

Average of ratios: 0.9924
 Standard deviation: 0.000345
 Uncertainty of CT ratio:
 $\frac{0.000345}{0.9924} \times 100 = 0.0348(\%)$

[u₆ uncertainty in calibration value of secondary shunt]

Same as u₂.

[u₇ temperature effect by secondary shunt]

Same as u₃.

[u₈ non-linearity of CT]

Using a traceable alternate current shunt connected in a series to a CT, electric current divided approximately in 5 steps within a measurement range is loaded, and the ratio of maximum change breadth from its average value is obtained, which is assumed as in rectangular distribution, thus deriving standard uncertainty. Estimation is made by the comparison of the first wave height values of loaded current. Table 6.5 shows an example of measurement results.

Table 6.5 Example of measurement results of a CT and an alternate shunt for comparison connected in a series. (non-linearity)

Alternate current shunt measured values I _m [kA]	CT measured value I _i [kA]	Ratio (= I _i / I _m)
21.61	21.44	0.9921
29.53	29.34	0.9936
36.11	35.91	0.9945
44.96	44.77	0.9958
55.88	55.45	0.9923

Average of ratios: 0.9937

Maximum change breadth:
 0.9937-0.9958=0.0021

Uncertainty of CT Ratio:
 $\frac{0.0021}{0.9937} \times 100 = 0.211(\%)$

Summary of u₅ through u₈.

[u₅ repeatability]

Assuming that the change of CT ratio (standard deviation/ mean value) is 0.0348%, and n=10,

$$u_5 = \frac{0.0348}{\sqrt{10}} = 0.011(\%)$$

[u₆ uncertainty in calibration value of secondary shunt]

Assuming that the degree of accuracy of calibration certificate is 0.01%, $u_6 = \frac{0.01}{\sqrt{3}} = 0.006(\%)$

[u_7 temperature effect by secondary shunt]

$$25 \times 10^{-6} \times 20 = 0.0005 (=0.05\%),$$

consider only the effect by ambient temperature $u_7 = \frac{0.05}{\sqrt{3}} = 0.029(\%)$

[u_8 non-linearity of CT]

The change of CT ratio (max. change breadth/ mean value) being 0.211%, assuming that it is an rectangular distribution with $a=0.211$,

$$u_8 = \frac{0.211}{\sqrt{3}} = 0.122(\%)$$

6.2.2 u_9 through u_{12} - Transmission system

6.2.2.1 u_9 through u_{10} - Optical fiber link (digital E/O-O/E) and

6.2.2.2 u_{11} through u_{12} - Optical cable (analogue E/O-O/E)

This is a transmission system that measures phenomena by converting electric signals into optical signals, which are sent by optical fiber cable to be re-converted into electric signals from optical. By transmitting in optical signals, this method makes it possible to measure currents at a high potential portion, and because this method is less vulnerable to noises and less likely to receive interference from other measurement signals, it is often used in measurements where high current is involved. There are two types of this optical cable transmission system, depending on the mode of transmission signals by optical fiber, i.e., digital optical signal system.

The analogue optical signal system consists mainly of transmitter (E/O), optical fiber cable, and receiver (O/E). While, the digital optical signal system consists mainly of A/D converter, digital transmitter (E/O), optical fiber cable, receiver (O/E) and data memory. With the digital system, A/D converter is housed in the digital transmitter (E/O) and the data memory is housed in the receiver (O/E).

As principal factors contributing to uncertainty, in the case of optical cable transmission system, there are:

- Gain;
- Linearity; and
- Temperature drift.

For the evaluation of these uncertainties, values stated in the calibration certificate of the optical cable transmission system provided by the manufacturer (if unavailable, its specification will do) of the degree of accuracy, etc. are used to derive uncertainty of Type B.

Some of the optical cable transmission systems have auto-calibration function that adjusts automatically gains and temperature drift, in which case, it is possible to evaluate uncertainty taking into consideration the automatic adjustment function. The analogue optical signal system is comparatively less reliable in its accuracy and mandates measurements using this function.

Summary of u_9 through u_{12} .

[u_9 temperature drift]

Assuming the temperature of use is 0~40°C (outdoor use), an rectangular distribution having as its half-width the temperature drift (0.4%) from the zero level drift of (0.02% / K) written on the inspection certificate issued by the manufacturer, to the reference temperature of 20°C:

$$u_9 = \frac{0.4}{\sqrt{3}} = 0.231(\%)$$

[u_{10} non-linearity]

A rectangular distribution having as its half-width the linearity error of (0.075%) stated on the inspection certificate issued by the manufacturer:

$$u_{10} = \frac{0.075}{\sqrt{3}} = 0.043(\%)$$

[u_{11} temperature drift]

Assuming that the temperature difference of use is ± 5 K (indoor use), a rectangular distribution having as its half-width the temperature drift of (0.8%) from the zero level drift of (0.16% / K) written on the inspection certificate issued by the manufacturer:

$$u_{11} = \frac{0.8}{\sqrt{3}} = 0.462(\%)$$

[u_{12} non-linearity]

A rectangular distribution having as its half-width the linearity error (2%) stated on the inspection certificate of

manufacturer: $u_{12} = \frac{2.0}{\sqrt{3}} = 1.155(\%)$

6.2.3 u_{13} through u_{15} - Amplifier

6.2.3.1 u_{13} through u_{15} - DC amplifier

If electric signals are measured by a DC amplifier, the measuring instrument can be protected from high frequency noises and excessive surge voltage that arise during high power testing. Items that contribute to uncertainty when using a DC amplifier are:

- Uncertainty of gain;
- Linearity;
- Frequency characteristics; and
- Temperature drift; of which,

The temperature drift should receive the heaviest attention. It is recommended to make drift adjustments not only just before commencing tests but also during tests, as appropriate, if the test lasts for a long period of time.

Summary of u_{13} through u_{15} .

[u_{13} gain (including adjustment of gains)]

A rectangular distribution with a half-width of 0.2 from the specification $u_{13} = \frac{0.2}{\sqrt{3}} = 0.115(\%)$

[u_{14} non-linearity]

A rectangular distribution with a half-width of 0.05 from dispersion of linearity stated on the test report

$$u_{14} = \frac{0.05}{\sqrt{3}} = 0.029(\%)$$

[u_{15} temperature drift]

Assuming 0.03 (% / K) from the specification, and the room temperature change $\pm 5\text{K}$:

$$u_{15} = \frac{0.15}{\sqrt{3}} = 0.087(\%)$$

6.2.4 u_{16} and u_{17} - Converter6.2.4.1 u_{16} and u_{17} - A/D converter

In order to process data by computer using electric signals, an A/D converter is used to change analogue signals to digital signals. While using an A/D converter, the principal factors of uncertainty are:

- Digital resolution; and
- Temperature drift.

For evaluating these uncertainties, uncertainty of Type B is evaluated using information on the resolution of the converter used, the ratio of minimum range of signal deflection against the full scale, and the degree of accuracy stated in the specification provided by the manufacturer.

When using an A/D converter, depending on the wave-form to be measured, attention should be paid to the following to make appropriate selection and application:

(a) Reduction of quantization error in vertical axis (voltage axis)

In order to exploit the bit resolution of an A/D converter, it is important to set the maximum level of signals as close as possible to the full scale range of the A/D converter. It is desirable that the minimum deflection of signals is larger than 30% and as to the bit resolution, 12 bit resolution or more is used.

(b) Reduction of quantization error in horizontal axis (time axis)

It is important that the sampled frequency of the A/D converter is larger than the maximum frequency by more than two times. If smaller than two times, sometimes an alias phenomenon that converts signals at the frequency lower than the actual occurs. When the maximum frequency of signals is not known, there is a method to prevent the aliasing by putting in a low-pass filter (anti-aliasing filter). For frequency for commercial use, the sampling frequencies used are higher than 10 kHz.

Summary of u_{16} and u_{17} .**[u_{16} resolution of digital detector system]**

Set the minimum deflection to 30% of the full scale using 12 bit converter:

$$\frac{1}{2048 \times 0.3} \times \frac{1}{2} \times 100 = 0.08(\%) , \text{ therefore, } u_{16} = \frac{0.08}{\sqrt{3}} = 0.046(\%)$$

[u_{17} temperature drift]

A rectangular distribution with a half-width of 0.005 from the degree of accuracy stated in the specification

$$u_{17} = \frac{0.005}{\sqrt{3}} = 0.003(\%)$$

6.2.5 u_{18} and u_{19} - Data processing6.2.5.1 u_{18} and u_{19} - Software

The data of various tests carried out by high power testing laboratories are usually automatically measured and analyzed by a measuring system that takes into consideration uncertainty. Data are generally recorded as digital data via by detector, transmission system, amplifier and converter, to be data processed. But for this digital data

processing, it is the responsibility of each laboratory to decide what method to use, which is maintained as know-how of each laboratory. As to the hardware, software including data processing algorithm and others, it is up to each laboratory to choose which to install, and each laboratory perform the automatic processing of test data using those of their choice, which, in this sense, may be said the things are in a "black box". Thus, compared with detector, transmission system, amplifier and converter, for which there is sufficient amount of common information for calculating uncertainty, the information on data processing system is insufficient. The very importance of data processing system is proved by the fact that activities to prepare a report to provide guidelines on common data processing methods are being carried out at STL (Short-circuit Testing Liaison), for making automatic evaluation of test data in high power testing laboratories. STL is an international organization to study short-circuit testing standards and technology and is conducting the activities because of the general prevalence of sophisticated and high performance measuring system and others.

The draft of this report contains examples of evaluation for applicable algorithm and recommended data processing system specification. Furthermore, there is manufacturing work going on of a generator of a series of representative basic wave forms (calibration wave forms) to be used for the verification of software for computers as described in this report, and in the near future, it will become easier to make interlaboratory comparisons of test data including data processing.

Summary of u_{18} and u_{19} .

[u_{18} least-square method]

[u_{19} three(3) crest method]

In order to evaluate test results, it is necessary to obtain "test quantities" defined in the applicable standard, from measurement values saved in a computer in digital quantity. The calculation algorithm that is used for this process contains uncertainty, which is described here using an example of uncertainty in the evaluation of rms values of short-circuit current.

As one of the method to obtain the rms values of short-circuit current, the three(3) crest method shown in Figure 6.6 is used, i.e., a sequential set of three values of wave crest, A, B and C are used, to determine two parallel straight line $f(t)$ and $g(t)$, to obtain rms value by dividing the distance between them, $D-D'$ by $\sqrt{8}$, in which case there are following two types of uncertainty:

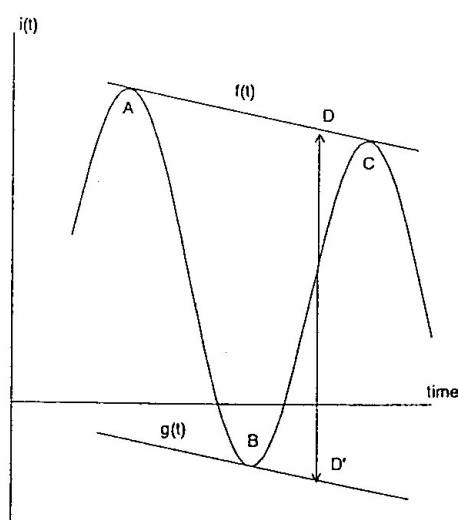


Fig. 6.6 three(3) crest method

< Uncertainty existing in least-square method >

Uncertainty existing in the least-square method used for obtaining the crests.

By picking out 20 data within the timeframe in which peak points are contained, and to approximate them with least-square method in parabola, a standard uncertainty as a rectangular distribution with its half-width considered as 0.5 % of the crest can be obtained:

$$u_{18} = \frac{0.5}{\sqrt{3}} = 0.289(\%)$$

<Uncertainty of three(3) crest method>

Uncertainty of three(3) crest method against true current wave-forms.

Assuming that the original current wave-form is expressed by the following formula, the uncertainty that the three(3) crest method will have for the value of this formula can be evaluated.

$$I(t) = I_m \left\{ \sin(\omega \cdot t + \phi) - \sin(\phi) \exp\left(\frac{-t}{\tau}\right) \right\}$$

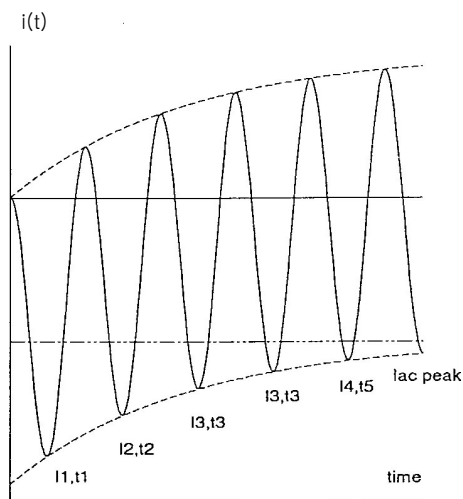


Fig. 6.7 Calculation of rms values

When the maximum DC component is included, $\phi = \frac{\pi}{2}$, the uncertainty is affected by the time constant of attenuation for DC component decrement, “ τ ”, and by the period to be chosen for calculation after short-circuit (see Fig. 6.7), whose result of calculation is shown in Fig. 6.8. With typical short-circuit testing laboratories, $\tau = 100$ ms is no difficult task to accomplish, and therefore, the standard uncertainty can be obtained from a rectangular distribution with its half-width of 0.2 % as indicated in Fig. 6.8.

$$u_{19} = \frac{0.2}{\sqrt{3}} = 0.115(\%)$$

In standards generally used, the value of short-circuit current is calculated based on three(3) crest method and there is no reason to consider "Uncertainty of three(3) crest method" itself.

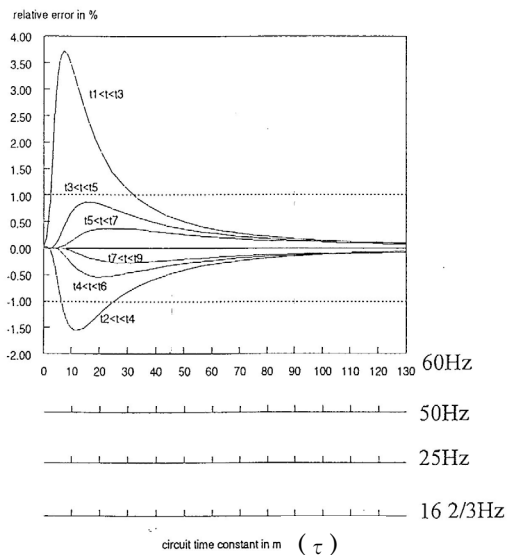


Fig. 6.8 Relative error in three(3) crest method

Based on u_1 through u_{19} , specific examples of the estimation of uncertainties are shown in Tables 6.6 through 6.9.

6.3 Uncertainty budget (Case 1)

Table 6.6 Uncertainty budget (Case 1)

Component	Component type	Source of uncertainty	Estimation reasoning	Value of calibration certificate, actual measurement, etc.	Probability distribution	Divisor	C_i	Standard uncertainty u_i (%)	Degree of freedom (n-1)
1 Detector (shunt / CT)	1-1 Shunt	U_1 repeatability	Actual measurement	0.01 %	Normal	1.0	1.0	0.01	9
		U_2 uncertainty of a double bridge calibration value	Expanded uncertainty stated on calibration certificate	0.05 %	Normal	2.0	1.0	0.03	infinite
		U_3 temperature effect by ambient temperature	Specification	20 K	Rectangular	$\sqrt{3}$	25×10^{-4} (% / K)	0.03	infinite
		U_4 temperature effect by Joule heat	Specification	60 K	Rectangular	$\sqrt{3}$	25×10^{-4} (% / K)	0.09	infinite
2 Transmission system	2-1 Optical fiber link (digital E/O-O/E)	U_9 temperature drift	Specification	20 K	Rectangular	$\sqrt{3}$	2×10^{-2} (% / K)	0.23	infinite
		U_{10} non-linearity	Specification	0.075 %	Rectangular	$\sqrt{3}$	1.0	0.04	infinite
3 Amplifier									
4 Converter									
5 Data processing	5 Software	U_{18} least-square method	Calculation formula	0.5 %	Rectangular	$\sqrt{3}$	1.0	0.29	infinite
		U_{19} Three(3) crest method (*1)	Calculation formula	0.2 %	Rectangular	$\sqrt{3}$	1.0	0.12	infinite
Combined standard uncertainty (%) u_c					Normal			0.40	>10 ⁷
Expanded uncertainty (%) U (k=2)					Normal			0.80	>10 ⁷

(*1) See 6.2.5 for the description regarding "three(3)-crest method".

6.4 Uncertainty budget (Case 2)

Table 6.7 Uncertainty budget (Case 2)

Component	Component type	Source of uncertainty	Estimation reasoning	Value of calibration certificate, actual measurement, etc.	Probability distribution	Divisor	C_i	Standard uncertainty u_i (%)	Degree of freedom (n-1)
1 Detector (shunt / CT)	1-1 Shunt	U_1 repeatability	See Case 1						
		U_2 uncertainty of a double bridge calibration value							
		U_3 temperature effect by ambient temperature							
		U_4 temperature effect by Joule heat							
2 Transmission system	2-2 Optical cable (analogue E/O-O/E)	U_{11} temperature drift	Specification	5 K	Rectangular	$\sqrt{3}$	1.6×10^{-1} (% / K)	0.46	infinite
		U_{12} non-linearity	Specification	2.0 %	Rectangular	$\sqrt{3}$	1.0	1.15	infinite
3 Amplifier	3 D/C amplifier	U_{13} gain (including gain adjustment)	Specification	0.2 %	Rectangular	$\sqrt{3}$	1.0	0.12	infinite
		U_{14} non-linearity	Specification	0.05 %	Rectangular	$\sqrt{3}$	1.0	0.03	infinite
		U_{15} temperature drift	Specification	5 K	Rectangular	$\sqrt{3}$	3×10^{-2} (% / K)	0.09	infinite
4 Converter	4 A/D converter	U_{16} resolution of digital detector system	Specification	0.08 %	Rectangular	$\sqrt{3}$	1.0	0.05	infinite
		U_{17} temperature drift	Specification	0.005 %	Rectangular	$\sqrt{3}$	1.0	0.003	infinite
5 Data processing	5 Software	U_{18} least-square method	See Case 1						
		U_{19} Three(3) crest method (*1)							
Combined standard uncertainty (%) u_c					Normal			1.29	>10 ⁹
Expanded uncertainty (%) U ($k=2$)					Normal			2.6	>10 ⁹

(*1) See 6.2.5 for the description regarding "three(3)-crest method".

6.5 Uncertainty budget (Case 3)

Table 6.8 Uncertainty budget (Case 3)

Component	Component type	Source of uncertainty	Estimation reasoning	Value of calibration certificate, actual measurement, etc.	Probability distribution	Divisor	C_i	Standard uncertainty u_i (%)	Degree of freedom (n-1)
1 Detector (shunt / CT)	1-1 Shunt	U_1 repeatability							
		U_2 uncertainty of a double bridge calibration value							
		U_3 temperature effect by ambient temperature							
		U_4 temperature effect by Joule heat							
See Case 1									
2 Transmission system	2-3 Coaxial cable	This item can be neglected for commercial frequencies.							
3 Amplifier	3 D/C amplifier	U_{13} gain (including gain adjustment)							
		U_{14} non-linearity							
		U_{15} temperature drift							
See Case 2									
4 Converter	4 A/D converter	U_{16} resolution of digital detector system							
		U_{17} temperature drift							
See Case 2									
5 Data processing	5 Software	U_{18} least-square method							
		U_{19} Three(3) crest method (*1)							
See Case 1									
Combined standard uncertainty (%) u_c					Normal			0.37	>10 ⁷
Expanded uncertainty (%) U (k=2)					Normal			0.74	>10 ⁷

(*1) See 6.2.5 for the description regarding "three(3)-crest method".

6.6 Uncertainty budget (Case 4)

Table 6.9 Uncertainty budget (Case 4)

Component	Component type	Source of uncertainty	Estimation reasoning	Value of calibration certificate, actual measurement, etc.	Probability distribution	Divisor	C_i	Standard uncertainty u_i (%)	Degree of freedom (n-1)
1 Detector (shunt / CT)	1-2 CT / secondary shunt	U_5 repeatability	actual measurement value	0.01 %	Normal	1.0	1.0	0.01	9
		U_6 uncertainty in calibration value of secondary shunt (*2)	Accuracy data on calibration certificate	0.01 %	Rectangular	$\sqrt{3}$	1.0	0.006	infinite
		U_7 temperature effect by secondary shunt	Specification	20 K	Rectangular	$\sqrt{3}$	25×10^{-4} (% / K)	0.03	infinite
		U_8 non-linearity of current transformer	Actual measurement	0.211 %	Rectangular	$\sqrt{3}$	1.0	0.12	infinite
2 Transmission system	2-3 Coaxial cable	This item can be neglected for power frequencies							
3 Amplifier	3 D/C amplifier	U_{13} gain (including gain adjustment)	See Case 2						
		U_{14} non-linearity							
		U_{15} temperature drift							
4 Converter	4 A/D converter	U_{16} resolution of digital detector system	See Case 2						
		U_{17} temperature drift							
5 Data processing	5 Software	U_{18} least-square method	See Case 1						
		U_{19} Three(3) crest method (*1)							
Combined standard uncertainty (%) u_c					Normal			0.37	>10 ⁷
Expanded uncertainty (%) U (k=2)					Normal			0.74	>10 ⁷

(*1) See 6.2.5 for the description regarding "three(3)-crest method".

(*2) Here, different from u_2 , a standard uncertainty, u_6 is calculated as a rectangular distribution having the degree of accuracy obtained from the data from the calibration certificate, as its half-width, assuming that there is no statement of uncertainty in the calibration certificate.

7. CLOSURE

This is the summary of the results of studies made by the High Power Technical Sub-committee on specific examples of the estimation of uncertainty necessary for a high power testing laboratory aiming to meet the requirements of ISO/IEC 17025.

JAB NOTE4 is wished to be improved by receiving valuable advice from relevant industries and specialists as well as the accumulation of assessment experiences.

**- Members of the Preparation of JAB NOTE4 -
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Addendum 1 REQUIREMENTS FOR MEASUREMENT UNCERTAINTY IN ISO/IEC 17025

4 **Management requirements**4.12 **Control of records**4.12.2 **Technical records**

4.12.2.1 The laboratory shall retain records of original observations, derived data and sufficient information to establish an audit trail, calibration records, staff records and a copy of each test report or calibration certificate issued, for a defined period. The records for each test or calibration shall contain sufficient information to facilitate, if possible, identification of factors affecting the uncertainty and to enable the test or calibration to be repeated under conditions as close as possible to the original. The records shall include the identity of personnel responsible for the sampling, performance of each test and/or calibration and checking of results.

5 **Technical requirements**5.1 **General**

5.1.2 The extent to which the factors contribute to the total uncertainty of measurement differs considerably between (types of) tests and between (types of) calibrations. The laboratory shall take account of these factors in developing test and calibration methods and procedures, in the training and qualification of personnel, and in the selection and calibration of the equipment it uses.

5.4 **Test and calibration methods and method validation**5.4.1 **General**

The laboratory shall use appropriate methods and procedures for all tests and/or calibrations within its scope. These include sampling, handling, transport, storage and preparation of items to be tested and/or calibrated, and, where appropriate, an estimation of the measurement uncertainty as well as statistical techniques for analysis of test and/or calibration data. (The rest omitted.)

5.4.5 **Validation of methods**

5.4.5.3 The range and accuracy of the values obtainable from validated methods (e.g. the uncertainty of the results, detection limit, selectivity of the method, linearity, limit of repeatability and/or reproducibility, robustness against external influences and/or cross-sensitivity against interference from the matrix of the sample/test object), as assessed for the intended use, shall be relevant to the clients' needs. (The rest omitted.)

NOTE 3 Validation is always a balance between costs, risks and technical possibilities. There are many cases in which the range and uncertainty of the values (e.g. accuracy, detection limit, selectivity, linearity, repeatability, reproducibility, robustness and cross-sensitivity) can only be given in a simplified way due to lack of information.

5.4.6 **Estimation of uncertainty of measurement**

5.4.6.1 A calibration laboratory, or a testing laboratory performing its own calibrations, shall have and shall apply a procedure to estimate the uncertainty of measurement for all calibrations and types of calibrations.

5.4.6.2 Testing laboratories shall have and shall apply procedures for estimating uncertainty of measurement. In certain cases the nature of the test method may preclude rigorous, metrologically and statistically valid, calculation of uncertainty of measurement. In these cases the laboratory shall at least attempt to identify all the components of uncertainty and make a reasonable estimation, and shall ensure that the form of reporting of the result does not give a wrong impression of the uncertainty. (The rest omitted.)

NOTE 1 The degree of rigor needed in an estimation of uncertainty of measurement depends on factors such as:

- the requirements of the test method;
- the requirements of the client;
- the existence of narrow limits on which decisions on conformance to a specification are based.

NOTE 2 In those cases where a well-recognized test method specifies limits to the values of the major sources of uncertainty of measurement and specifies the form of presentation of calculated results, the laboratory is considered to have satisfied this clause by following the test method and reporting instructions (see 5.10).

5.4.6.3 When estimating the uncertainty of measurement, all uncertainty components which are of importance in the given situation shall be taken into account using appropriate methods of analysis.

NOTE 1 Sources contributing to the uncertainty include, but are not necessarily limited to, the reference standards and reference materials used, methods and equipment used, environmental conditions, properties and condition of the item being tested or calibrated, and the operator.

NOTE 2 The predicted long-term behavior of the tested and/or calibrated item is not normally taken into account when estimating the measurement uncertainty.

NOTE 3 For further information, see ISO 5725 and the Guide to the Expression of Uncertainty in Measurement (see bibliography).

5.6 **Measurement traceability**

5.6.2 Specific requirements

5.6.2.1 Calibration

5.6.2.1.1 (Omitted) A calibration laboratory establishes traceability of its own measurement standards and measuring instruments to the SI by means of an unbroken chain of calibrations or comparisons linking them to relevant primary standards of the SI units of measurement. The link to SI units may be achieved by reference to national measurement standards. National measurement standards may be primary standards, which are primary realizations of the SI units or agreed representations of SI units based on fundamental physical constants, or they may be secondary standards which are standards calibrated by another national metrology institute. When using external calibration services, traceability of measurement shall be assured by the use of calibration services from laboratories that can demonstrate competence, measurement capability and traceability. The calibration certificates issued by these laboratories shall contain the measurement results, including the measurement uncertainty and/or a statement of compliance with an identified metrological specification (see also 5.10.4.2).

5.6.2.2 Testing

5.6.2.2.1 For testing laboratories, the requirements given in 5.6.2.1 apply for measuring and test equipment with measuring functions used, unless it has been established that the associated contribution from the calibration contributes little to the total uncertainty of the test result. When this situation arises, the laboratory shall ensure that the equipment used can provide the uncertainty of measurement needed.

NOTE The extent to which the requirements in 5.6.2.1 should be followed depends on the relative contribution of the calibration uncertainty to the total uncertainty. If calibration is the dominant factor, the requirements should be strictly followed.

5.10 Reporting the results

5.10.3 Test reports

5.10.3.1 c) where applicable, a statement on the estimated uncertainty of measurement; information on uncertainty is needed in test reports when it is relevant to the validity or application of the test results, when a client's instruction so requires, or when the uncertainty affects compliance to a specification limit;

5.10.4 Calibration certificate

5.10.4.1b) the uncertainty of measurement and/or a statement of compliance with an identified metrological specification or clauses thereof;

5.10.4.2 The calibration certificate shall relate only to quantities and the results of functional tests. If a statement of compliance with a specification is made, this shall identify which clauses of the specification are met or not met. When a statement of compliance with a specification, is made omitting the measurement results and associated uncertainties, the laboratory shall record those results and maintain them for possible future reference. When statements of compliance are made, the uncertainty of measurement shall be taken into account.

Addendum 2 STANDARD DEVIATION OF RECTANGULAR DISTRIBUTION

One assumes a case where the probability densities of a quantity X taking a value x are distributed uniformly between the lower limit of $\mu - a$ and the upper limit of $\mu + a$. If the function of probability densities of this distribution is $f(x)$, it can be expressed by the following formula:

$$f(x) = \frac{1}{2a} \quad (\mu - a \leq x \leq \mu + a)$$

$$= 0 \quad (x < \mu - a, x > \mu + a)$$

The average of this distribution is μ and the dispersion σ^2 is calculated as follows:

$$\sigma^2 = \int_{-\infty}^{\infty} f(x) \cdot (x - \mu)^2 dx$$

$$= \frac{1}{2a} \int_{-a}^a x^2 dx$$

$$= \frac{a^2}{3}$$

Therefore, the standard deviation σ is:

$$\sigma = \frac{a}{\sqrt{3}}$$

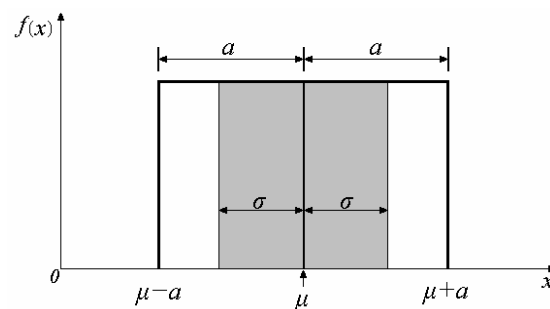


Figure A.1 Rectangular distribution