MEASUREMENT UNCERTAINTY

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IEC: International Electrotechnical Commission

IECEE: IEC system for conformity testing and certification of Electrotechnical Equipment and Components also known as CB-scheme

General Background

- ISO/IEC 17025 contains , among others, requirements for testing laboratories to apply Uncertainty of Measurement (UOM) principles in day-to-day testing
- These requirements are intended to provide assurance of validity of test results
- Understanding of UOM principles and their practical application is necessary for full understanding of critical aspects of tests
- General UOM principles are described in the ISO/IEC Guide to the Uncertainty of Measurement (GUM)

General Background

- Generally, IEC product safety standards had not considered UOM, and relied instead on a presumed built-in safety factor in all critical safety requirements
- CTL Guide 001, later published as IEC Guide 115, was endorsed by ILAC and IAF as an acceptable approach to UOM in the field of conformity assessment activities in the Electrotechnical Sector

IEC Guide 115

The main objective was to reduce the time, cost and effort required to estimate the uncertainty of measurement.

The approach taken in IEC Guide 115 is based on:

- Minimizing the significant sources of variability in testing - by controlling them
- Eliminating from the analysis those sources that have little influence on the outcome
- Using the known accuracy of the testing equipment as a representation of the measurement uncertainty of a test

IEC Guide 115

There are many test parameters that influence the results of tests; some with significant influence, some with very little effect

The IECEE approach (Guide 115) is to limit the effect of significant UOM sources by restricting the permissible limits of their variability, e.g.:

- Input power source: voltage ± 2%, frequency ± 0.5 %, total harmonic distortion (THD) 3% max.
- Equipment accuracy: according to CTL Decision 251B
- The measurement result is considered the best estimate of the measurand

IEC Guide 115

Procedure 1

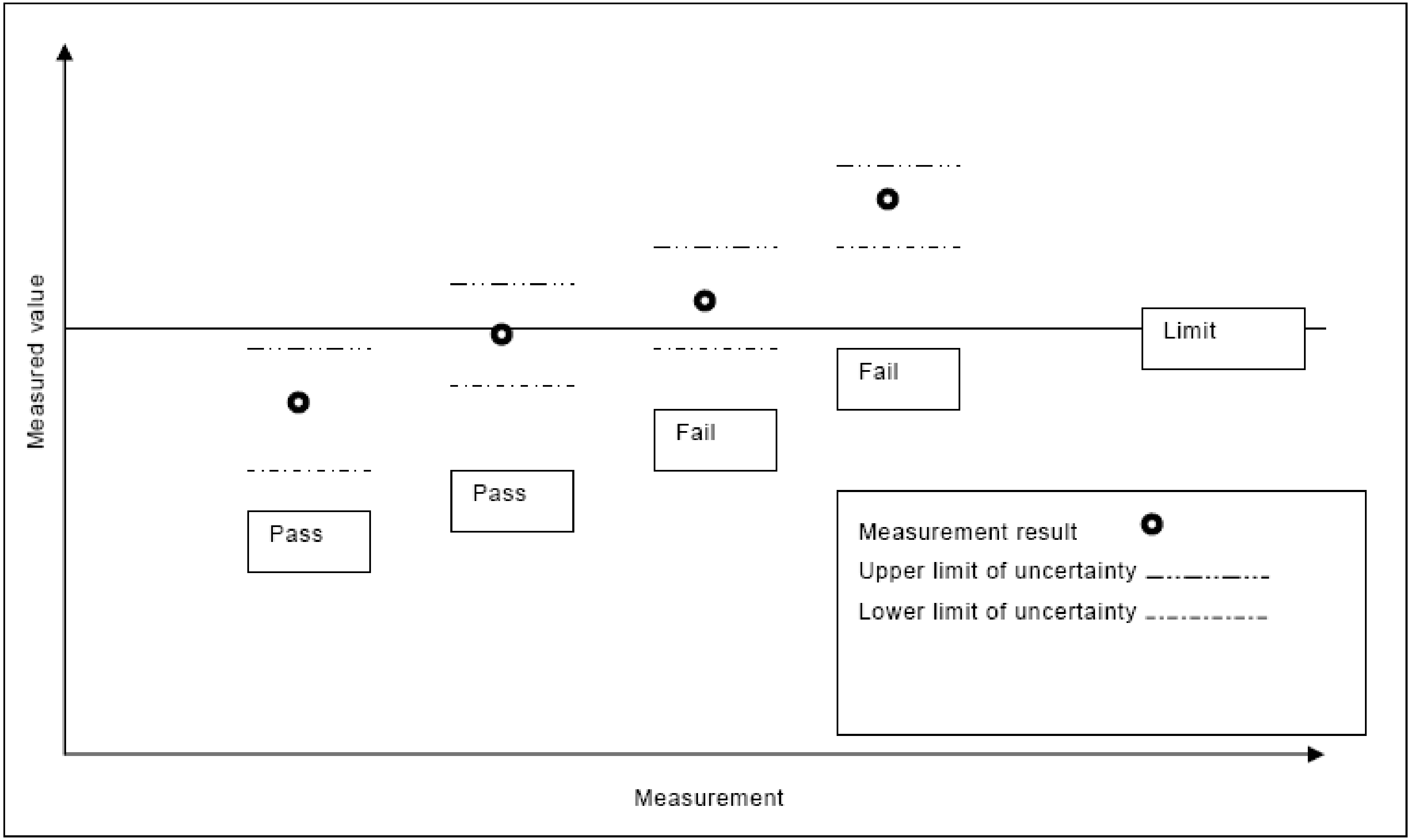

Figure 1 – Procedure 1: uncertainty of measurement calculated

IEC Guide 115

Practical Application

- Procedure 1 (Fig. 1) is used when a UOM calculation is required (17025, Cl. 5.10.3.1 c):
  - When UOM is relevant to the validity of application of the test results
  - Where client requires the UOM information
  - When the uncertainty affects compliance with specification limits
- Procedure 1 should be used where the significant uncertainty components of some measurement cannot be limited as per the Accuracy Method
- A measurement complies if its best estimate is below the specified limit

Procedure 2

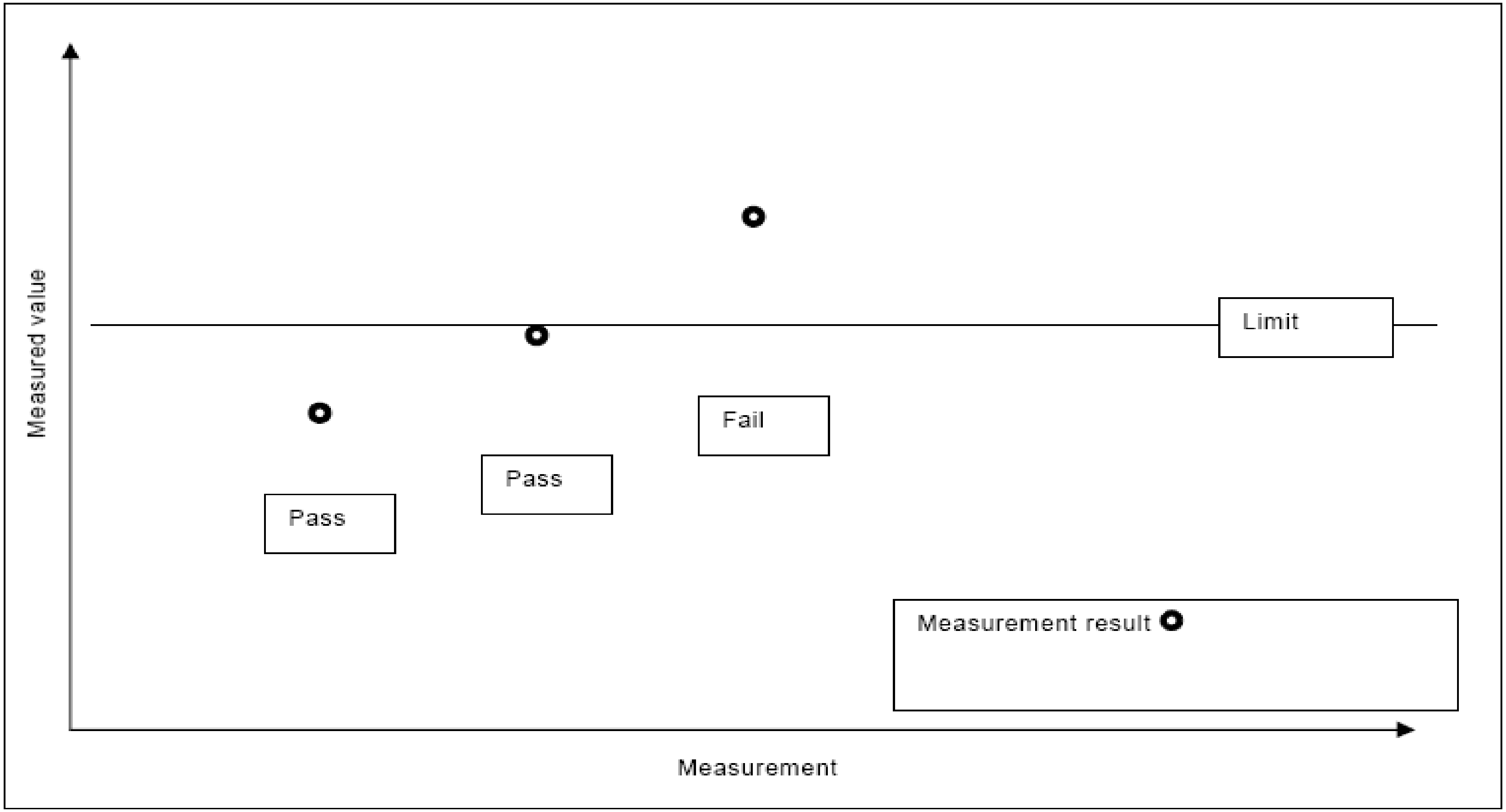

Figure 2 – Procedure 2: accuracy method

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Practical Application

- Procedure 2 (Fig. 2) – the accuracy method - is used when Cl. 5.4.6.2, Note 2 of 17025 applies:
  - Sources of uncertainty are controlled and uncertainty components are limited in value – there is no need to estimate the UOM
  - Variability of the test parameters and instrument accuracies are within the acceptable limits
- The accuracy specification for a measuring instrument is considered to be the representation of the uncertainty of measurement (UOM) of the particular measurement set-up

IEC Guide 115

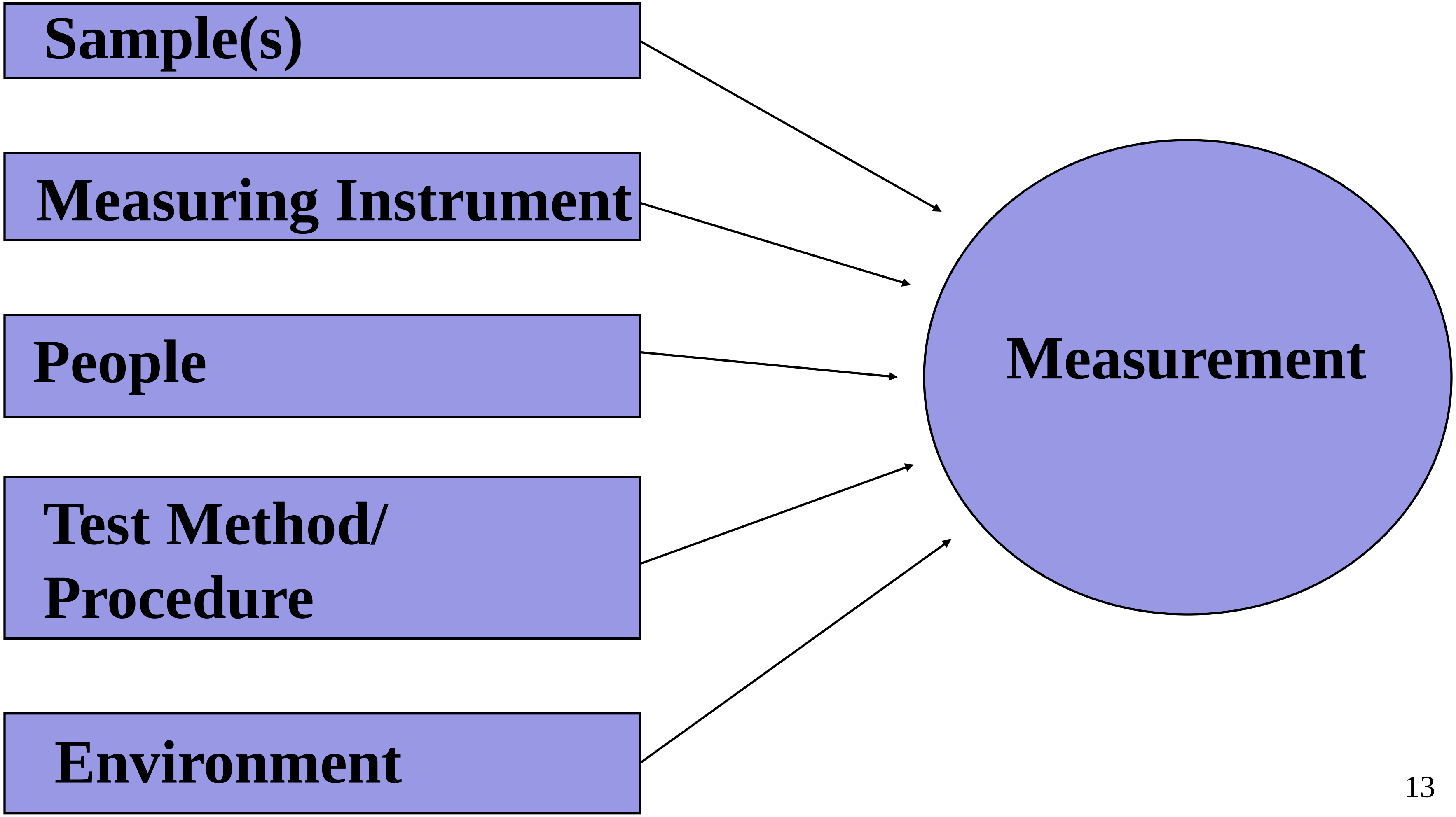
- The accuracy method is the traditional approach to UOM in the electro-technical sector
- It allows the measured result to be directly compared to the test limit to determine conformance
- It provides valid criteria for pass/fail decisions, while saving time and costs
- Where the accuracy method cannot be used, the UOM values are calculated/estimated using the methodology specified in the ISO/IEC GUM and IEC Guide 115 examples

IEC Guide 115

General Guidance

- As per the guidance provided in the GUM, the total measurement uncertainty is a combination of many component uncertainties
- Even a single instrument reading can be influenced by a number of factors
- The uncertainty of measurement requires a thorough understanding of:
  - measuring equipment
  - principles and practical aspects of the test, and
  - influence of the environment
- Step 1 - list all sources of uncertainty

Contributing Factors



IEC Guide 115

Examples of sources of measurement uncertainty:

- Instrument calibration data
- Temperature changes during test
- Humidity and pressure changes during test
- Electrical loading of the measured and measurement circuits
- Air flow over the test samples
- Instrument resolution
- Procedures used for conditioning and to prepare samples for test
- Parallax error in reading analog instruments

IEC Guide 115

Practical Steps

- Transform the influencing factors (input quantities) to the units of the measured (output) quantity
- Determine probability distributions for each component of uncertainty as per the GUM guidance
  - Type A (normal)
  - Type B (normal, rectangular, triangular,..)
- Estimate the combined variance and the combined standard deviation
  - Where input quantities are correlated, determine the covariance's
- Estimate the expanded deviation, typically with a coverage factor of 2 – to give an approx. 95% level of confidence

IEC Guide 115 – Example 1

Test name: input power test.

Result: uncertainties expressed in per cent of input power in watts.

Description: input power is measured to product operating in stabile condition while connected to regulated mains power source. Input power measured by analog or digital power meter.

Quantity X_i	Source of uncertainty	X_i	Type	Relative error quantity, $S_p(X_i)$	Probability shape	Distribution division factor, k	Relative standard uncertainty, $u(X_i)$	Sensitivity coefficient, C_i	Relative uncertainty contribution, $u_i(y)$
δ_R	Repeatability of measurement	X_R	A		Normal		0,2 %	1	0,2 %
δ_{instr}	Specification for instrument	X_{instr}	A	0,2 %	Normal	2	0,1 %	1	0,1 %
$\delta_{reading}$	Reading error	$X_{reading}$	B	0,45 %	Rectangular	$\sqrt{3}$	0,26 %	1	0,26 %
δ_{power}	Specification for power mains fluctuation	X_{power}	B	0,35 %	Rectangular	$\sqrt{3}$	0,2 %	1	0,20 %
					Relative combined standard uncertainty, u_c				0,40 %
					Coverage factor k_p = 2; confidence level: 95 %				–
					Relative expanded uncertainty, $U = u_c \times k_p$				0,80 %

IEC Guide 115

Reported Result – The measured input power is m_x (1 ± 0,008) W, $k = 2$, 95 % confidence level.

δ_R **repeating error repeatability of measurement –** uncertainty due to repeatedly making the same measurement – Type A with normal distribution

$$u_1 = \bar{\sigma}_{n-1} = \sqrt{\frac{\sum\left(x_i - \bar{x}\right)^2}{n(n-1)}} = 0{,}2\ \%$$

δ_{instr} **specification for instrument –** uncertainty due to instrument used for measurements. Determined from calibration laboratory report. Expanded uncertainty reported is ±0,2. Distribution is normal, $k = 2$.

$u_2 = 0{,}2/2 = 0{,}1\ \%$

$\delta_{reading}$ **reading of instrument –** uncertainty due to technician reading instrument – estimated.

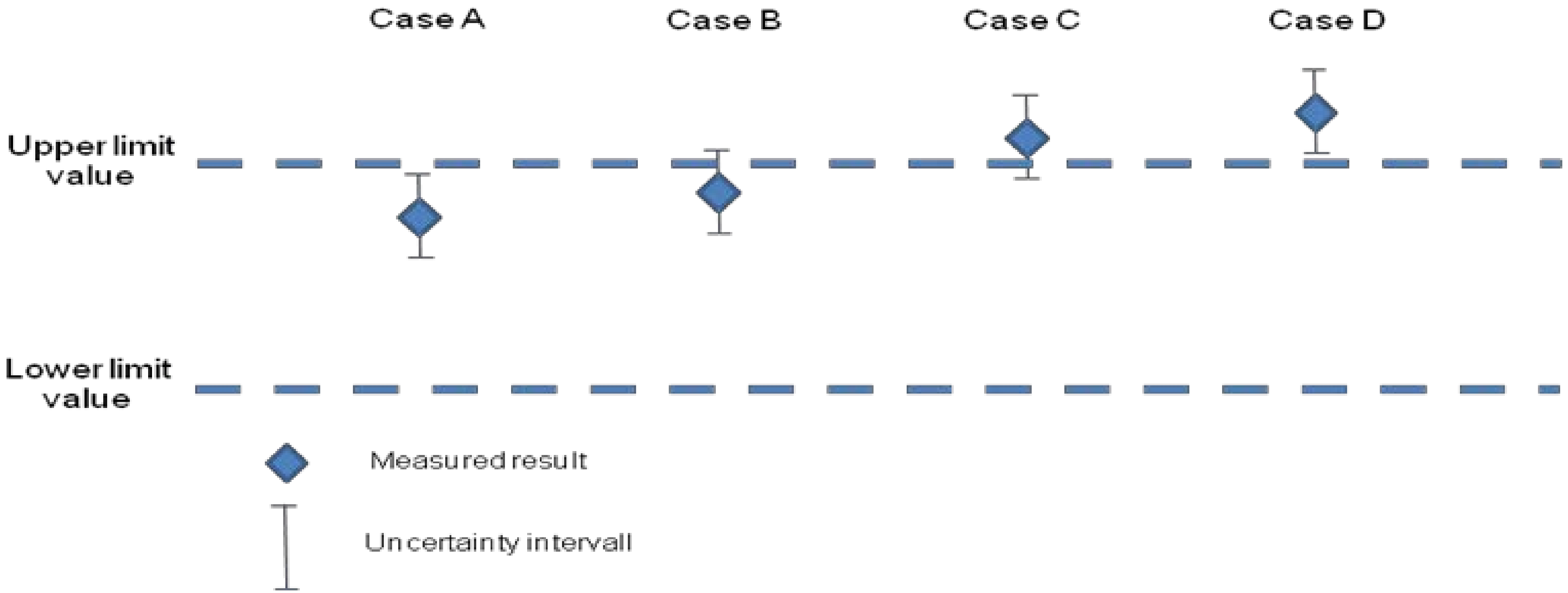
δ_{power} **specification of power mains fluctuation –** uncertainty due to fluctuations in power mains voltage.

Practical guidance

- Before the start of tests make sure, that test equipment is appropriate for the intended activity and calibrated.
- You shall be familiar with the test equipment. If required the user manual shall be consulted.
- In order to get statements about use and measurement accuracy, the user manuals are available for the operators of the devices.
- In addition to the identification about the status of calibration which is normally attached to the device itself, the calibration status and calibration certificates shall be verified.

Practical guidance

Following figures show typical cases of measurement results. In the following it is explained how to evaluate the compliance or non compliance with limit values



Practical guidance

Case A

The measured result is within the limits, even when extended by the uncertainty interval.

If the limits are not breached by the measured result, extended by the expanded uncertainty interval at a level of confidence of 95%, then the product complies with the specification.

Practical guidance

Case B

The measured result is below the upper limit, but by a margin less than half of the uncertainty interval; it is therefore not possible to state compliance based on the 95%
level of confidence

If the measured value falls sufficiently below the limit such that half of the expanded uncertainty interval overlaps the limit, it is not possible to confirm compliance or non-compliance at the 95% level of confidence.
The test result and expanded uncertainty should be reported together with a statement indicating that compliance was not demonstrated. However, the result indicates that compliance is more probable than non-compliance.

Practical guidance

Case C

The measured result is above the upper limit, but by a margin less than half of the uncertainty interval; it is therefore not possible to state non-compliance based on the 95% level of confidence.

If the measured value falls sufficiently above the limit such that half of the expanded uncertainty interval overlaps the limit, it is not possible to confirm compliance or non-compliance at the 95% level of confidence.

The test result and expanded uncertainty should be reported together with a statement indicating that compliance was not demonstrated. However, the result indicates that non-compliance is more than probable than compliance.

Practical guidance

Case D

The measured result is beyond the upper limit, even when extended downwards by half of the uncertainty interval.

Where an upper specification limit is exceeded by the result even when it is decreased by half of the expanded uncertainty interval, then the product therefore does not comply with the specification.

Practical guidance

Environmental Conditions

- The environmental conditions stated in the standards have to be setup and maintained in their limits during the test. The environmental conditions have to be documented in the test protocol.
- If a pre-conditioning is required for the equipment under test so the requirement must be fulfilled.
- Any influences which change this pre-condition status (like transportation etc.) must be avoided or the test can be performed only if the equipment under test fulfils again the requirements of pre-conditioning.

Practical guidance

Impacts on Measurement Uncertainty

- The uncertainty of the measured value depends on the measuring system and the uncertainty of the particular test equipment/test procedure

Practical guidance

Measurement results close to limit value

If a measured safety critical result is 10 % to a defined limit value, or where the measured values are close to tolerances specified in other documents (regulations, guides, etc), one or several of the following steps shall be applied:

1. Second measurement with a different (if necessary more accurate) test equipment or with a new test sample
2. Check of the environmental conditions and the test setup
3. Check of the actual existing uncertainty of the used test equipment (the measuring scale if necessary) with the help of the latest calibration documents.

If no clear statement is gained by the above steps, the errors with major impact on uncertainty in the measurement chain shall be estimated or reduced by further means (where appropriate after agreement with the costumer).

Practical guidance

Estimation of Measurement Uncertainty

If required (e.g. measurement results are close to limit value or the impact of major errors in measurement chains must be judged) measurement uncertainty of test results shall be estimated.

Therefore it is necessary to specify combined standard uncertainty $u_c(y_i)$.

Practical guidance

Combined standard uncertainty of errors shall be calculated as following:

a) Identify all errors and select the errors with the major impact

b) For single errors, e.g. resultant errors of previous measurements, correction values, errors from literature etc. adopt the variance where they are given or can be calculated. If this is not the case, estimate variance on the ground of experience.

Practical guidance

c) Estimate maximum range of errors (e.g.: error 1 = +/- 0,1 mm, error 2 = +/- 0,05 mm)

d) Calculate the sum with the square of each error (e.g. 0,01 + 0,0025 = 0,0125mm²)

e) Divide the sum by 3 (rectangle distribution) and calculate the square root of the result to get the combined standard uncertainty of error 1 and error 2.

f) Calculate the uncertainty by multiplying the combined standard deviation $u_c(y_i)$ by the factor k=2

References

- Guide to the expression of uncertainty in measurement (GUM), OIML G 1-100: 2008
- Guidance note EL 001:2002, measurement uncertainty for electrical testing field, SINGLAS

Thank you

Any questions?