

Measurement Uncertainty Methodology in METBENCH

Introduction

While many metrologists possess the necessary mathematical skills and training to perform uncertainty analysis, almost all find themselves overwhelmed by the enormity of the task, given requirements to mass produce calculations, line-by-line, test point-by-test point, across literally hundreds or even thousands of calibrations typically performed in a year's time. METBENCH/Metrology Processing System (MPS) provides the tools for automating this task and for managing the details of the calculations so that consistent and reliable results can be achieved every time.

METBENCH/MPS permits the user to develop a detailed error budget for each line item in a calibration datasheet, saving the error budget as a template for future calibrations, or to simply let the automatic features of METBENCH/MPS perform the analysis when system information is available and adequate to define the measurement uncertainty. Access to these features is controlled enabling only authorized users to make decisions about the content of error budgets. All changes are recorded for purposes of document control and audit trail. A record is retained of the settings in effect at each calibration.

When a calibration datasheet is created or opened from those available in the system library, and after calibration standards have been assigned, the Measurement Uncertainty Wizard provides a grid for developing a detailed error budget. Starting with the specifications for the unit under test embedded in the datasheet, including its resolution, and by finding the accuracy specifications for the standards used in the integrated MetSpec™ equipment specification system, the Wizard immediately has access to two key pieces of information needed to determine measurement uncertainty. If others sources of error are present and have been previously defined, these too will automatically appear in the grid. Or, authorized users may add or delete error components as necessary.

Measurement Uncertainty

The Measurement Uncertainty Wizard automatically combines specified sources of Type B uncertainty, including errors contributed by the standards used (u_s), resolution uncertainty contributed by the unit under test (u_r), and any other uncertainties (u_o) introduced as a result of performing the test, to arrive at the estimated measurement uncertainty (EMU) according to the following formula:

$$EMU = k \cdot \sqrt{\sum (c_i \cdot u_s)^2 + \sum (c_j \cdot u_o)^2 + \sum (c_k \cdot u_r)^2 + \dots n^2}$$

Type A uncertainties resulting from observation of repeated measurements where applicable, may be included at the discretion of authorized users for reporting purposes, but are typically excluded from the

analysis when considering conformance or nonconformance with specifications. Correlated uncertainties, if present, may be combined externally by an appropriate method and entered into the grid as a static value for each test point.

The coverage factor (k) is retrieved by the Measurement Uncertainty Wizard from the system configuration settings where the default setting may be set to 2 or other value established by laboratory policy. This setting may be overridden by authorized users on a case-by-case basis. The sensitivity coefficients (c) are constants used where necessary to adjust the weighting of each error component based on its relative contribution to EMU , including units of measure conversion factors. Their values are typically unity for a simple comparison calibration but where necessary, may be derived separately by an appropriate method and entered into the grid by authorized users.

Uncertainty of Standards Used

METBENCH/MPS uses a reliability model to estimate the uncertainty of standards used (u_s) from manufacturer's accuracy specifications (L_s) using the inverse normal distribution (Φ^{-1}) as a function of intolerance probability (P), as determined from user-supplied information on the effectiveness of the laboratory's internal calibration program. This information is retrieved by the Measurement Uncertainty Wizard from the system configuration settings. The following formula is applied:

$$U_s = \frac{L_s}{\Phi^{-1}\left(\frac{1+P}{2}\right)}$$

Resolution Uncertainty

METBENCH/MPS uses the presumption of a rectangular distribution to derive the resolution uncertainty of the unit under test based on one least significant digit in the display (R_x). The following formula is applied:

$$u_r = \frac{R_x \cdot 0.5}{\sqrt{3}} = \frac{R_x}{\sqrt{12}}$$

If other information on the uncertainty of standards used or resolution uncertainty of a particular instrument is available, then an appropriate substitution can be made by authorized users.

Other Uncertainties

Other user defined uncertainties (u_o) are expressed on a $k = 1$ basis and entered into the grid together with the appropriate sensitivity coefficient; for example, uncertainties resulting from changing environmental conditions. However, for many calibrations conducted in well-controlled environments with simplified test connections and minimal disturbances, the uncertainties accounted for automatically by METBENCH/MPS is sufficient and no additional analysis is required.

Test Accuracy Ratio (TAR) / Test Uncertainty Ratio (TUR)

METBENCH/MPS offers two options for calculating accuracy ratios. *TAR* is a simple ratio between the tolerance applied to the unit under test (T_x) and the accuracy specification of standard used (L_s), or by TUR using an uncertainty-based model. The option in effect is retained by the system configuration settings. The formula used by Option 1 is as follows:

$$TAR = \frac{T_x}{L_s}$$

Example: UUT specification (T_x) $\pm 1\%$ I.V Reference Standard (L_s) $\pm 0.25\%$ I.V.

$$TAR = \frac{T_x}{L_s} = \frac{1\%}{0.25\%} = 4$$

Where multiple standards are used, METBENCH/MPS applies the root-sum-square of the standards accuracy specifications.

In the uncertainty-based model, Test Uncertainty Ratio (TUR), the interval between the upper tolerance (+L) and lower tolerance (-L) is used to define the maximum permissible error (*MPE*) of the unit under test. TUR is defined as the ratio of the *MPE* to $2 \times EMU$. The formula used by Option 2 is as follows:

$$TUR = \frac{MPE}{(2 \cdot EMU)}$$

Example: UUT specification (*MPE*) ± 0.1 VDC, Test point 10 VDC

$$MPE = L + (-L) = 0.2 \text{ VDC}$$

Reference Standard Expanded Measurement Uncertainty (*EMU*) = ± 0.025 VDC

$$TUR = \frac{MPE}{(2 \cdot EMU)} = \frac{0.2}{(2 \cdot 0.025)} = \frac{0.2}{0.05} = 4$$

Selection of the uncertainty-based model is required to enable guard banding, conformance test decision rules and other advanced features of METBENCH/MPS.

References:

1. ANSI/NC SL Z540-2-1997, U.S. Guide to the Expression of Uncertainty in Measurement
2. ASME B89.7.3.1-2001, Guidelines for Decision Rules: Considering Measurement Uncertainty in Determining Conformance to Specifications