IMPORTANT FEATURES OF ESTIMATION & INTERPRETATION OF MEASUREMENT UNCERTAINTY

By

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1. INTRODUCTION

In the last few years a lot of awareness has been created regarding uncertainty of measurement, due mainly to 2 reasons. Laboratory accreditation, which has steadily been on the rise, requires estimation of uncertainty of measurement particularly in the field of calibration. In fact, calibration uncertainty determines the calibration capability of a laboratory. Second, increased maturity level of the ISO 9000 quality system certification has the manufacturing companies looking at the reliability of measurement through correct calibration of Inspection, Measuring and Test equipment. Proper calibration requires not only the estimation of uncertainty of measurement, it also requires the estimate to be small compared to the stated accuracy/tolerance (uncertainty) of the measuring instrument.

With the issue of the ISO/IEC 17025, which supersedes ISO/IEC Guide 25 as the basis of laboratory accreditation, estimation of measurement uncertainty is going to be pursued with more vigour since this Standard requires estimation of measurement uncertainty even in testing activity.

National Measurement Institutes (NMI) and higher level laboratories have qualified and competent persons to deal with this subject exclusively. However, laboratories directly servicing the industry and in-house laboratories may not possess the same expertise. It is hoped that some of the important and practical aspects of estimation of measurement uncertainty discussed here would provide useful guidance not only to these laboratories but would also prove to be an aid to auditors and assessors when they are assessing the extent of compliance of measurement uncertainty in calibration and test situations.

2. ESTIMATION

2.1 Measurement Equation

Almost all industrial and in-house laboratories perform calibrations by direct comparison against Standard. Such laboratories also perform measurements of parameters by using direct reading instruments. In all such cases the measurement equation simply is

$Y = X \pm \Delta X$

where

Y = The conventional true value
X = Measured value
ΔX = Uncertainties due to various factors providing boundaries around 'X' within which 'Y' is expected to lie

2.2 Sources of Uncertainty

Whenever a calibration is performed by comparison with a higher standard, two sources of uncertainty come into the picture. ***First*** is the stated tolerance or the accuracy of the standard. This would be a type 'B' evaluation and follow a rectangular probability distribution. ***Second*** is the uncertainty of calibration of the standard as reported on the calibration certificate by the higher level laboratory. As per Central Limit theorem, this would be normally distributed though type 'B' evaluation would be applicable.

Third source of uncertainty is the non-repeatability of the measurement at identical points. This would be type 'A' evaluation.

Other sources of uncertainty would be the effect of environment (e.g. effect of temperature variation etc.), instrument resolution, secondary instrumentation if used, knowledge of previous calibration or known behaviour of the unit under calibration (UUC) etc.

2.3 Degree of Freedom

Degree of Freedom is an indication of reliability of the uncertainty component. Higher the Degree of Freedom, better is the confidence on the estimated uncertainty. For Type-A evaluation, Degree of Freedom, $\upsilon = n - 1$, where n = No. of observations

For Type-B evaluation, different uncertainties of the measurement system are assumed to follow a rectangular probability distribution within the boundaries of semi-ranges. The degree of Freedom, υ in all such cases is considered infinity (∞).

Though the coverage factor for different Confidence Level depends on the effective degree of freedom, which is calculated from the Welch-Satterthwaite equation, for all practical purpose using k=2 for 95 % and k=3 for 99% for industrial laboratories is quite adequate.

2.4 Calculations

Estimation of measurement uncertainty is done based on the law of propagation of errors, by "root sum squares" formula, i.e. $U_C = \sqrt{(U_1^2 + U_2^2 + U_3^2 + \ldots + U_N^2)}$, where U_C is the Combined Standard Uncertainty and U_1, U_2, U_3 etc are the individual uncertainties. U_C is then multiplied by the coverage factor 'k' to obtain the Expanded Uncertainty, U_E, which is reported as the Measurement Uncertainty for all calibration and test results.

Normally, for a stable measurement process, type 'A' evaluation, which is associated with Random causes, would be small compared to type 'B' evaluations, which are associated with the variation in system aspects of the measurement process. In fact, in situations where a very high TUR is employed, the type 'A' evaluation may be negligible and may not be measurable. In such cases, U_C is the combination of only type 'B' evaluations. However, in certain situations e.g. analogue meter calibration, type 'A' evaluation could be appreciable and therefore, should be considered in the estimation.

The laboratories should, however, maintain records of all such calculation as objective evidence of the above fact.

3. INTERPRETATION

3.1 Calibration

ISO 10012 Part 1 : 1992 states that "The error attributable to calibration should be as small as possible. In most areas of measurement, it should be no more than one third and preferably one tenth of the permissible error of the confirmed equipment when in use".

According to ANSI/NCSL Z540-1-1994, "…the collective uncertainty of the measurement standards shall not exceed 25% of the acceptable tolerance for each characteristic of the measuring and test equipment being calibrated or verified"

ISO/IEC 17025 : 1999, the basis of laboratory accreditation world-wide, states under cl. 5.4.6 that "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."

It is thus necessary to estimate the calibration uncertainty or the measurement uncertainty for all calibrations, and this value should preferably be limited to 1/3rd of the specification of the UUC. The instrument specification expands negligibly when test uncertainty ratio (TUR) is 3:1 for calibrations. However, in case a lower TUR is used, the expansion of the specification could be substantial and should be known to the user. Compliance should be given only when the indicated values of the UUC, expanded by the uncertainty, are within the specified accuracy (tolerance/uncertainty) limits of the UUC.

3.2 Test Result

Where it is required to state compliance of test result to specification, the algebraic addition of measurement uncertainty and the test result should lie within the specification limits. If the added value exceeds the specification limits, either of the upper or lower boundaries, compliance to specification should not be stated. However in such cases, either the measurement uncertainty should be reported along with the test result or it should be estimated & maintained by the test laboratory to know the extent of confidence that can be reposed on the reported result.

Asia Pacific Laboratory Accreditation Co-operation (APLAC) suggests that when a specification describes an interval with an upper and lower limit, the ratio of the uncertainty of measurement to the specified interval should be reasonably small (i.e. 1:3).

If the tolerance limits are large and the test result is well within the limits, then rigors of measurement uncertainty need not be followed. However, where tolerance limits are small, the treatment suggested above should be followed.

4. CONCLUSION

While estimation of measurement uncertainty is very important for reliability of measurement data, the process of estimation and the interpretation should be easy to follow and practice. Attempting to develop complicated measurement equation and quantify effects of all applicable sources may prove to be detrimental to the dissemination of this important aspect of measurement. In fact, it is quite possible that some of the finer sources may be missed while estimating, but as long as the major ones are taken into consideration, the omissions would not have any tangible bearing on the final result. Similarly, there may be type ‘B’ evaluations where triangular probability distribution is technically more applicable. However, even in such cases, assumption of rectangular distribution for simplicity would result in acceptable value of uncertainty.

Efforts should, therefore, be made by all concerned to propagate the concept and method of measurement uncertainty in a simple manner so that the test & calibration laboratories across the country can comprehend and practice the same for better reliability of measurement data. This would go a long way in enhancing the much-needed quality of manufactured products in the country.

About the authors

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