Uncertainty of Measurement – A Concept

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Abstract: *Measurement uncertainty is a general concept associated with any measurement and can be used in professional decision processes as well as judging attributes in many domains, both theoretical and experimental. As the tolerances applied in industrial production become more demanding, the role of measurement uncertainty becomes more important when assessing conformity to these tolerances. Measurement uncertainty plays a central role in quality assessment and quality standards. Recent awareness has been created regarding uncertainty of measurement, due to mainly two reasons. Laboratory accreditation, which has steadily been on the rise, which requires an estimation of uncertainty of measurement particularly in the field of calibration. Second, increased maturity level of the quality system certification as the manufacturing companies looking at the reliability of measurement through correct calibration of inspection, measuring and test equipment. This paper explains the basic information about uncertainty of measurement and its types, sources and estimation of uncertainties.*

Keywords: *measurement, quality, uncertainty of measurement, accuracy.*

I .INTRODUCTION

Measurement is present in almost every human activity, including but not limited to industrial, commercial, scientific, healthcare, safety and environmental. Measurement helps the decision process in all these activities. Measurement uncertainty enables users of a measured quantity value to make comparisons, in the context of conformity assessment, to obtain the probability of making an incorrect decision based on the measurement, and to manage the consequential risks accompanied by a statement of the associated uncertainty [11].The purpose of measurement is to provide information about a quantity of interest -a measurand[JCGM 200:2008 (VIM) 2.3 .Measurement results are never exact, nor absolutely free of doubts. Therefore the "measurement uncertainty" is part of the result of a measurement. It is a measure for the accuracy of the result. Measurement uncertainty is derived from standard deviations. Definition: Measurement uncertainty is "A parameter associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand" (VIM1 and GUM [1]).

A measurement system is a tool used for quantifying the measured variable. Measurement is a process or act of comparison between known standard and unknown quantities known as measurand. No measurement is perfect as different factors causing variation in the measurement results are present in the system. These factors commonly are faulty instruments, faulty or complicated procedures of measurements, lack of maintenance of instruments, unskilled operators and environmental conditions. Some terminologies associated with measurement process are true value and measured value (actual value), accuracy, precision and error etc. **Accuracy** is defined as the closeness of measured value to the true or standard value, Precision is an indication of the agreement among a number of measurements made in the same way. The figures below show the relation between accuracy and precision [9].

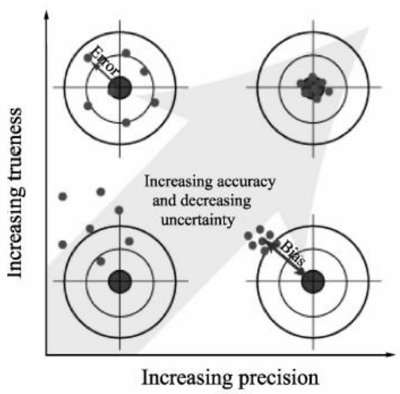

Fig-1 Relation between Accuracy and Precision

Error is the difference between the measured value and true or standard value. When the Standard input or Standard Instrument is not available, the error needs to be estimated and that estimated error is known as uncertainty. Errors can be corrected but uncertainty is always there with the system.

Every measurement has an uncertainty associated with it, unless it is an exact, counted integer, such as the number of trials performed.

Every calculated result also has an uncertainty, related to the uncertainty in the measured data used to calculate it. This uncertainty should be reported either as an explicit ± value or as an implicit uncertainty, by using the appropriate number of significant figures. The numerical value of a ± uncertainty value tells you the range of the result.

II. WHAT IS MEASUREMENT UNCERTAINTY?

Uncertainty of Measurement has been interpreted by various researcher .A measurement tells us about a property of something. It might tell us how heavy an object is, or how hot, or how long it is. A measurement gives a number to that property. Measurements are always made using an instrument of some kind. Rulers, stopwatches, Weighing scales and thermometers are all measuring instruments. The result of a measurement is normally in two parts: a number and a unit of measurement, e.g. 'How long is it? ... 2 meters.' *Uncertainty of measurement* is the doubt that exists about the result of any measurement. But for every measurement - even the most careful - there is always a margin of doubt. The definition of the term uncertainty (of measurement) used in this protocol and taken from the current version adopted for the International Vocabulary of Basic and General Terms in metrology is: "A parameter associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand**"** (BIPM/IECIIFCC/ISO/OIML/IUPAC, n.d.).

Measurement errors are never known exactly. In some instances they may be estimated and tolerated or corrected for; or they may be simply acknowledged as being present. Whether an error is estimated or acknowledged, its existence introduces certain amount of measurement uncertainty (Castrup 2001).

This brings us to an operational definition of measurement uncertainty. Since measurement error is the discrepancy between the value of a parameter and a perceived or measured parameter value, we can think of measurement uncertainty as either a lack of knowledge concerning the value of a measured parameter or as a lack of knowledge concerning the *error* in the parameter's measurement. The latter view provides a workable framework for analyzing measurement uncertainty (Kracker, 2007).

III. SOURCES OF UNCERTAINTY

There are many sources of uncertainty of measurement few sources are mentioned below.

1. Inaccurately defined measurand
2. Improper sampling that fails to represent the measurand
3. Effects of environmental conditions on the measurement
4. Imprecise values of measurement standards and reference materials
5. Imprecise values of other parameters obtained from external sources and constants
6. Approximations and assumptions united in the measurement method and Procedure
7. Variations in repeated observations of the measurand under apparently identical conditions.

Various factors responsible for uncertainty are shown with the help of cause and effect diagram below [8],[9].

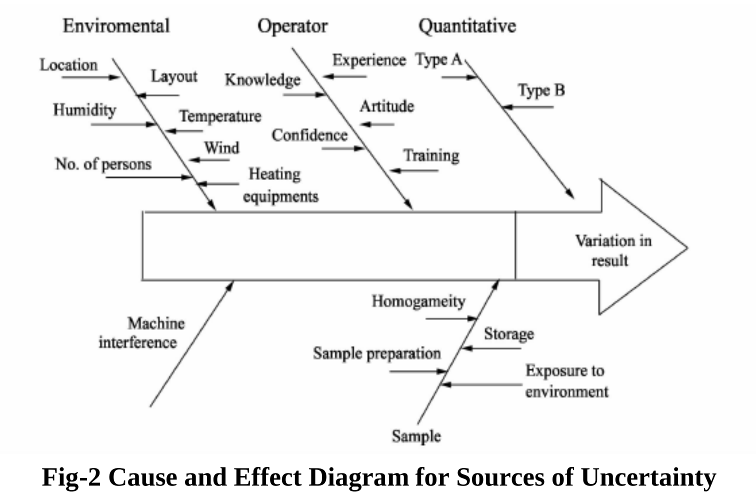

Fig-2 Cause and Effect Diagram for Sources of Uncertainty

IV. NEED OF EVALUATION OF UNCERTAINTY OF MEASUREMENT

An increasing proportion of standards users realize the great benefits of utilizing measurement uncertainty to optimize design codes, improve process control and the quality and performance of their products. Meaningful uncertainty statements can reduce costs. It is a requirement for all accredited calibration laboratories that results reported in a calibration certificate are accompanied by a statement describing the uncertainty associated with these results. It is also a requirement for test laboratories under the following circumstances:

(a) Where it is required by the client,
(b) Where it is required by the specification calling up the test, and
(c) Where the uncertainty affects compliance to a specification or limit.

In science and technology uncertainty has a narrower meaning, created by the need for accurate measurement. Accurate measurement, which implies the existence of standards of measurement, and the evaluation of uncertainties in a measurement process are essential to all areas of science and technology. The branch of science concerned with maintaining and increasing the accuracy of measurement, in any field, is known as metrology. It includes the identification, analysis and minimization of errors, and the calculation and expression of the resulting uncertainties. An increasing proportion of standards users realize the great benefits of utilizing measurement uncertainty to optimize design codes, improve process control and the quality and performance of their products. Meaningful uncertainty statements can reduce costs.

It is a requirement for all accredited calibration laboratories that results reported in a calibration certificate are accompanied by a statement describing the uncertainty associated with these results. Uncertainty evaluation is also recommended for the test laboratory to understand which aspects of the test procedure have the greatest effects on the results so that such aspects may be closely controlled or monitored.

National Accreditation Board for Testing and Calibration Laboratories (NABL) is an autonomous body under the aegis of Department of Science & Technology, Government of India, and is registered under the Societies Act. NABL has been established with the objective to provide Government, Industry Associations and Industry in general with a scheme for third-party assessment of the quality and technical competence of testing and calibration laboratories. Government of India has authorized NABL as the sole accreditation body for Testing and Calibration laboratories. In order to achieve this objective, NABL provides laboratory accreditation services to laboratories that are performing tests / calibrations in accordance with ISO/IEC 17025:2005 and ISO 15189:2007 for medical laboratories. NABL has already published the revised guideline on Estimation of Uncertainty in Measurement for Calibration Laboratories.

V. EVALUATION OF UNCERTAINTY

First of all a laboratory that has a good quality management system should have little effort to state the uncertainty of a result. The principles for correct application of measurement uncertainties are given in the GUM. Two types of uncertainties are associated with each measuring parameters [6].

To calculate uncertainty following steps are to be followed:

Step 1) Specify measurand, express mathematically the equation relating measurand and input quantities. Identify all uncertainty sources
Step 2) Determine the input quantities
Step 3) Quantify the standard uncertainties of all single components
Step 4) Identify the covariance (of correlated input quantities)
Step 5) Calculate the result of the measurement from the input quantities
Step 6) Calculate the combined uncertainty
Step 7) Calculate the expanded uncertainty
Step 8) Give the result together with the uncertainty as estimated

$$U_C = \sqrt{U_A^2 + U_{B1}^2 + U_{B2}^2 + \ldots U_r^2}$$

Where, U_A - Type A standard uncertainty, U_B - Type B standard uncertainties

VI. GUM APPROACH

Guide to the Expression of Uncertainty (GUM) establishes general rules for evaluating and expressing uncertainty in measurement that can be followed at various levels of accuracy and in many fields – from the shop floor to fundamental research. Therefore, the principles of this Guide are intended to be applicable to a broad spectrum of measurements, including those required for

- maintaining quality control and quality assurance in production;
- complying with and enforcing laws and regulations;
- conducting basic research, and applied research and development, in science and engineering;
- calibrating standards and instruments and performing tests throughout a national measurement system in order to achieve traceability to national standards;

-developing, maintaining and comparing international and national physical reference standards including reference materials

This Guide provides general rules for evaluating and expressing uncertainty in measurement. It is necessary to develop particular standards based on this Guide that deal with the problems peculiar to specific fields of measurement or with the various uses of quantitative expressions of uncertainty. These standards may be simplified versions of this Guide but should include the detail that is appropriate to the level of accuracy and complexity of the measurements and uses addressed [2][3][4].

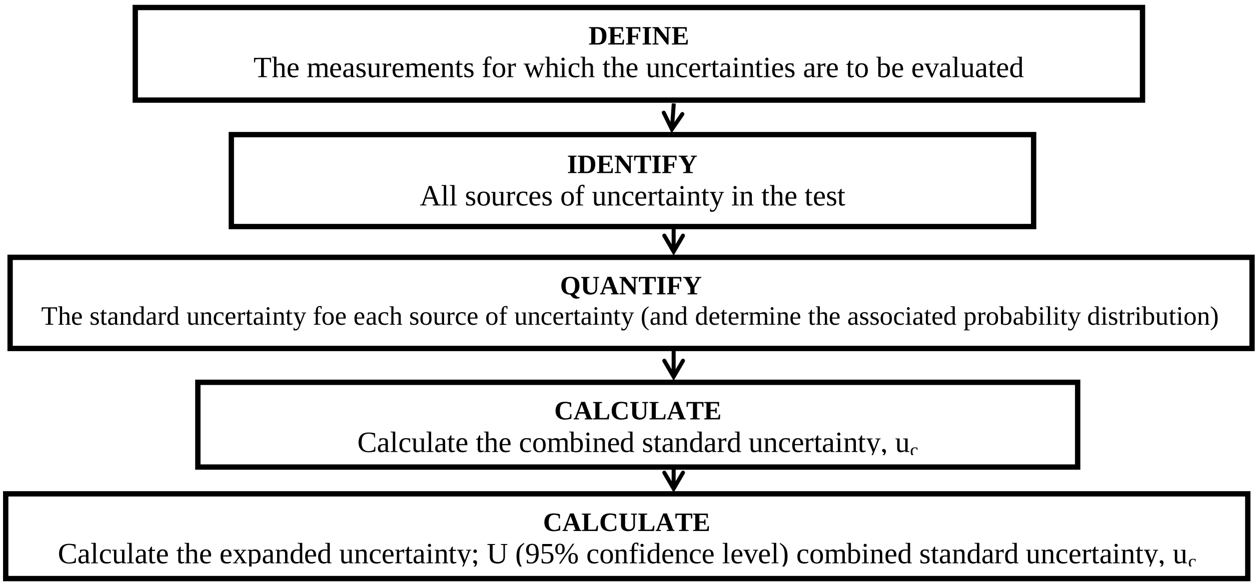

Fig-3 GUM Methodology

Difficulties in UM Research

- To decide the number of readings for calculating the repeatability effect.
- How many minimum and maximum factors to be considered for UOM?
- How to identify the affecting factors?
- How to calculate the effects of qualitative factors such as working stress of the operators, tests performed by unskilled operators etc.
- In case of type B, the effects of some factors are very less, so these factors should be taken into account or not?[11]

VII. CONCLUDING REMARKS

Uncertainty is an integral part of any measurement. Uncertainty study and estimation is very important to improve the quality of measurement results. This paper explained concept of uncertainty with definitions given by different researchers. The difference between error and uncertainty and between precision and accuracy. Paper also explained the types of uncertainties, need of uncertainty study , methods of estimations of uncertainties .It can be concluded that there is huge scope for research of uncertainty of measurement as far as accreditation of laboratories is concerned .

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