TRACEABILITY OF MEASUREMENT RESULTS IN INDUSTRIAL METROLOGY

Michael Kühne, Michael Krystek, Andreas Odin
Physikalisch-Technische Bundesanstalt
Bundesallee 100, 38116 Braunschweig, Germany
phone: +49/531/592-3000, fax: +49/531/592-3002, e-mail: michael.kuehne@ptb.de

Abstract : Traceability of Measurement results to the international system of units (SI) is playing an important role for global production and international trade. The development of a modern concept of traceability is described and the requirements for internationally accepted traceability for industrial metrology is discussed with relation to international standards.

1. INTRODUCTION

Metrology has always been of crucial importance for industrial production reflecting the old wisdom "what cannot be measured cannot be manufactured". In recent years the growing globalisation of trade and the distributed production of highly complex technical systems have significantly increased the demand for reliable and accurate measurements.

This is reflected in quality management systems (QMS) fulfilling ISO 9001:2000 [1] or ISO/IEC 17025: 2000 [2] which require that all measurements are performed with calibrated measuring instruments being traceable to the international system of units (SI).

2. THE REALIZATION AND DISSEMINATION CONCEPT FOR THE SI

Metrology is not an invention of modern times. Weights and measures have always been important for governments and societies to facilitate trade and to levy taxes. Units of measurements have mostly been defined locally, like the foot length of the country's king. While in pre-industrial time such a system was sufficient considering the limited frontier-crossing trade, with the dawning of the industrial age the inefficiency of such systems became more and more obvious.

Industrial production became profitable only when significant quantities of goods could be produced requiring the export of the products into other countries.

In recognition of this need in 1875 the leading industrial nations signed a diplomatic treaty, the "Meter Convention". In this treaty they agreed to promote in their countries a metric measuring system which later on developed into today's "International System of Units (SI)". To assure the consistency of the national measuring systems the "International Bureau of Weights and Measures" (BIPM) was established in Sévres in France which disseminated prototypes of the base length and mass units meter (m) and kilogram (kg), respectively, to the participating countries and conducted intercomparisons with the master prototype maintained at the BIPM. For supervision of the BIPM the International Committee of Weights and Measures (CIPM) was established. In the participating countries the national offices of weights and measures were responsible for the dissemination of the metric system. These offices, however, were in general not engaged in research in metrology in those days.

In the decade after signing the Meter Convention it became apparent, that the growing needs in industry for more accurate measuring instruments and for new instruments in the emerging field of electricity required institutions dedicated to fundamental and applied research in metrology.

In 1887 the "Physikalisch-Technische Reichsanstalt" was founded in Germany, given the mission to conduct research and development in the field of metrology to support government and industry.
Today in practically all industrialized nations national metrology institutes (NMIs) are trusted given a double mission:

- Realization and dissemination of the SI to industry and society
- Research and development in the field of metrology for government, industry and society

A recent survey in EUROMET has shown that on average the budgets are about evenly spent on SI dissemination and metrological research.

For the dissemination of the SI a NMI is maintaining national standards which are either primary realizations of the SI (primary standards) or they are secondary standards calibrated against a primary standard of an other NMI. In order to assure the equivalence of the SI throughout the world the NMIs compare their national standards with those of other countries and the BIPM.

Since 1999 the Mutual Recognition Arrangement (MRA) of the CIPM [3] provides a framework for establishing the equivalence of national standards and the recognition of calibration and measurement capabilities of the NMIs. This way the MRA provides a solid base for the national dissemination of the metric system on a national level.

A typical structure for a national measurement system, taken from the EUROMET Guide 1 [4] is shown in Fig 1.

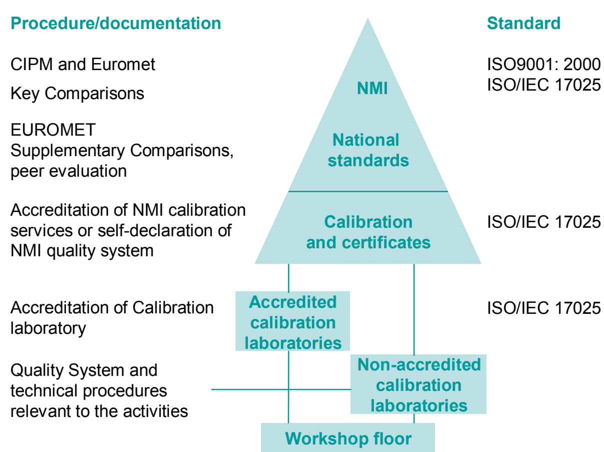

Fig. 1 *Traceability in a National Measurement System*

3. THE CONCEPT OF TRACEABILITY OF MEASUREMENT RESULTS

The modern concept of industrial traceability was first outlined in a guideline by the US department of defence in 1962. The MIL STD 45662A required:

Measuring and test equipment shall be calibrated utilizing reference standards whose calibration is certified traceable to the U.S. National Bureau of Standards (NBS), has been derived from acceptable values of the natural physical constants, or has been derived by the ratio type of self-calibration techniques. Reference standards used in the calibration shall be supported by certificates, reports, or data sheets attesting to the date, accuracy and conditions under which the results furnished were obtained.

This guideline describes the most important concept for establishing traceability of industrial measurement: The shop floor measuring and testing instruments shall be calibrated utilizing reference standards which by themselves have a calibration being traceable to a national standard. In addition it points to the possibility to use accepted values of natural constants.

The discussion in the years between 1962 and 1977 showed however that that MIL STD 45662A was insufficient in one essential aspect: It contained no requirement to state a measurement uncertainty. In 1977 with the help of the NBS (today the NIST) a new definition regarding traceability was formulated by the ASTM working group E46:

Traceability to designated standards (national, international, or well-characterized reference standards based upon fundamental constants of nature) is an attribute of some measurements. Measurements have traceability to the designated standards if and only if scientifically rigorous evidence is produced on a continuing basis to show that the measurement process is producing measurement results (data) for which the total measurement uncertainty relative to national or other designated standards is quantified.

For the first time traceability of a measurement result required a statement of the assigned measurement uncertainty and an essential gap in the definition of traceability was removed but on this occasion not all deficiencies had been eliminated.

Another gap was cured in the year 1980 when the US Ministry of Defence published a revision of the directive MIL STD 45662A in which the following regulation was found:

Traceability is to relate individual measurement results to national standards or nationally accepted measurement systems through an unbroken chain of comparisons.

This definition required an unbroken chain of comparison measurements. The restriction to national standards was loosened in the revision of MIL STD 45662A in 1988:

3.5 <u>Traceability</u>. The ability to relate individual measurement results through an unbroken chain of calibrations to one or more of the following:
3.5.1 U.S. national standards maintained by the U.S. National Bureau of Standards (NBS) and the Naval Observatory;
3.5.2 Fundamental or natural physical constants with value assigned or accepted by the U.S. NBS;
3.5.3 National standards of other countries which are correlated with U.S. national standards;
3.5.4 Ratio type of calibrations;
3.5.5 Comparison to consensus standards.

But not only the USA thought about a binding definition of the term traceability of measurement results. The first international definition can be found in the first edition of the international dictionary for metrology (International Vocabulary of Metrology (VIM) of the year 1984, section 6.12, as follows:

Traceability: the property of the result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons.

This definition includes the unbroken chain of comparisons however it lacks the requirement for a stated uncertainty. It is also very vague in its requirements concerning the standard the measurement must be traceable to.

This shortcomings were eliminated in the second edition of the VIM in 1993 [5] where the definition for traceability reads:

Property of the result of a measurement or 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.

With that the metrological community had finally come to a definition which includes three essential components:

- Stated references (usually national or international standards)
- Unbroken chain of comparisons
- Stated uncertainties

In addition to the metrologist's quality insurance experts began to recognize the importance of traceability.

Quality standards like e.g. the ISO-9000 series were published and with these standards traceability of measurement results became an essential component of the quality assurance system. In the latest version of ISO 9000:2000 [6] in section 3.5.4 traceability is defined as

ability to trace the history, application or location of that which is under consideration

.

This definition clearly does not contain the three essential requirements of the VIM definition (see above), it relates to a “paper trail” of documents instead. The authors of ISO 9000 were well aware of this shortcoming and added a note:

Note 2: In the field of metrology in the definition in VIM:1993 6.10, is the accepted definition

About at the same time as ISO 9001:2000 was drafted the ISO/IEC standard 17025 was written. This standard provides the general requirements for the competence of testing and calibration laboratories. In section 5.6 under the heading "Measurement traceability" the requirements for traceable measurements are listed. Specific requirements are

5.6.2.1.1 For calibration laboratories, the programme for calibration of equipment shall be designed and operated so as to ensure that calibrations and measurements made by the laboratory are traceable to the International System of Units (SI).

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 unit 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.

This is the clearest concept of traceability in metrology of today. It was written with support of the BIPM and can be considered as state of the art.

Compared with the VIM definition of 1993 it contains several important improvements.

It clarifies that traceability is ultimately to the primary realization of the SI. In most cases this will be achieved by comparisons to national standards, however other alternatives to establish traceability are outlined in Note 2:

NOTE 2: Traceability to SI units of measurement may be achieved by reference to an appropriate primary standard (see VIM:1993, 6.4) or by reference to a natural constant, the value of which in terms of the relevant SI unit is known and recommended by the General Conference of Weights and Measures (CGPM) and the International Committee for Weights and Measures (CIPM).

The concept of ISO/IEC 17025 “Measurement Traceability” is a very specific definition compared to the more general traceability term in ISO 9000:2000. As ISO/IEC 17025 is by now a well recognized and widely applied international standard its definition regarding "Measurement Traceability" should be integrated also in other international standards and should find its way also into the revision of the VIM. It should be noted that in recent years the expression “Metrological Traceability” has become the accepted phraseology and also the latest draft of the third edition of the VIM talks about "Metrological Traceability" instead of "Measurement Traceability". A decision should be made which expression shall be used in the future to avoid that users of international standards will become confused by different definitions relating to the same subjects. In this respect it should be also pointed out that all measurement uncertainties have to be based on the *Guide to the Expression of Uncertainty in Measurement (GUM*).[7]

4. TRACEABILITY OF INDUSTRIAL MEASUREMENT RESULTS

It is the aim of industrial metrology to carry out correct and reliable measurements in order to control the production process. This is a prerequisite for global production. Apart from this simple fact it is essential in today’s competitive environment to gain and to keep customers' trust into one’s own products.

Nowadays, only QMS compliant with international standards and based on traceability to the SI will find acceptance in global trade. This also includes a GUM compliant expression of the measurement uncertainties. Operating with a suitable modern QMS is a prerequisite for obtaining internationally accepted traceability of measurement results.

As a consequence the technical competence of industrial measurement laboratories and their employees becomes more and more important in industrial metrology. The number of accredited calibration laboratories in industry is continuously increasing. Traceability to the SI is most often established by an unbroken chain of comparisons to a national standard maintained by a national metrology institute. Due to the increased demands for traceability in most industrialized countries this chain passes through a calibration laboratory which itself maintains standards calibrated against these national standards (see Fig. 1). In order to achieve international recognition of traceability use of calibration laboratories should be made, that are accredited by accreditation bodies which in turn are members of ILAC.

The above mentioned unbroken chain of comparisons to a national standard either directly via an NMI or indirectly by using the services of an calibration laboratory is the classical way to obtain traceability. However it is not the only possible way:

The VIM definition on traceability is rather vague in that respect. It requires a “stated reference, usually national or international standards”. More specific is note 2 of clause 5.6.1.1. (see chapter 3 of this article).

It must be pointed out that application of the procedures described in this note requires other additional activities defined in note 3 of clause 5.6.1.1:

NOTE 3: Calibration laboratories that maintain their own primary standard or representation of SI units based on fundamental physical constants can claim traceability to the SI system only after these standards have been compared, directly or indirectly, with other similar standards of a national metrology institute.

Note 3 clarifies that also in such particular cases a traceability link to an NMI needs to be established. In the case of a direct comparison with an NMI, the participating NMI will have to evaluate the technical competence of the participating industrial laboratories. A joint intercomparison report must be produced. It is obvious that the possibilities of NMIs to participate in such comparisons is rather limited.

This procedure will therefore certainly remain the exception rather then the rule.

In the case that the comparison of the industrial company's standards against similar standards of an NMI is done only indirectly it is essential that the partners of the comparison have established their technical competence in order to achieve recognition of the traceability.

Today this can be guarantied on the basis of an ISO/IEC 17025 based accreditation. The technical competence needed for such a solution and the efforts involved will limit this particular approach to companies having a high level of competence which might be on a similar or even higher level as the NMI.

We shall not close our eyes to the fact that nowadays large companies or companies producing high technology based measuring instruments operate calibration laboratories that rival or even surpass the metrological capabilities of some, even large, NMIs. In such cases the question arises how these laboratories can demonstrate traceability to the SI. One possibility is that they establish direct traceability to one of the worlds leading NMIs that operate primary realizations of the SI with sufficient small uncertainties.

In the case that no NMI should be available with equivalent or better capabilities a new approach needs to be developed. One solution could be to integrate the metrological capability of the industrial laboratory into the national measurement infrastructure. The MRA knows the status of a "Designated Institute" that is a keeper of national standards with all the rights and obligation of an NMI. The responsible national authorities have to decide if an industrial laboratory can comply with all requirements in order to be part of the national measurement system having the responsibility as a keeper of national standards regarding e.g. impartiality, and sustainability. If either the national authority or the industrial laboratory come to the conclusion that this is not a preferable way then a different solution has to be found.

This solution could lead to the status of an accredited calibration laboratory, however the question arises how to determine its technical competence, the measurement range and the corresponding measurement uncertainties. To follow this suggestion and thus to achieve international acceptance might be difficult for a national accreditation body. A solution could lie in establishing an internationally accepted review team appointed by the responsible Consultative Committee of the CIPM. This review team would then make a recommendation to the national accreditation body on the scope of accreditation and the necessary procedure for later re-accreditation. Following such a procedure should assure the international acceptance of traceability through this industrial laboratory.

5. CONCLUSION

Traceability of measurement results to the SI has become essential for global production and trade. This is reflected by corresponding requirements contained in todays QMS standards. Operation of a suitable QMS is essential for establishing international recognized traceability of measurement results.

The most up-to-date requirements for compliance with the VIM definition of measurement traceability can be found in ISO/IEC 17025. Accordingly traceability will be achieved through an unbroken chain of comparison to a national standard maintained by a NMI with a calibration laboratory being part of this chain. For international acceptance of the traceability accreditation of the involved calibration laboratory will in general be important.

However also alternatives are Calibration laboratories can maintain their own primary standards or representations of SI units based on fundamental physical constants, but only after these standards have been compared, directly or indirectly, with other similar standards or realizations of a NMI. In general this requires a sufficient high level of metrological expertise usually demonstrated by an accreditation according to ISO/IEC 17025.

REFERENCES

[1] ISO 9001:2000 Quality management systems – Requirements
[2] ISO/IEC 17025:1999 General requirements for the competence of testing and calibration laboratories
[3] Mutual recognition arrangement of the CIPM, 1999
[4] EUROMET Guide 1: EUROMET´s policy on the Application of Quality System in National Metrology Institutes, V2.1, May 2001

[5] International vocabulary of basic and general terms in metrology, second edition, ISO 1993
[6] ISO 9000:2000 Quality management systems – Fundamentals and vocabulary
[7] Guide to the expression of uncertainty in measurement, ISO 1993