Metrology in the future: two scenarios for methodology and industry

V Granovskii
General Research Fellow, Concern CSRI Elektropribor JSC,
30 Malaya Posadskaya St, 197046 St Petersburg, Russia

E-mail: vgranovsky@eprrib.ru / valgr39@mail.ru

Abstract. Main problems of metrology in connection with tendencies of engineering development are discussed. Incorporation measuring elements into most of technical systems is treated as fundamental factor having an influence on applied metrology development. Nearly the same effect is caused by introduction logic information elements into measuring instruments and systems. The problem consists in that it is impossible to determine traditional measuring channels in the system and represent through metrological characteristics of the channel comprising both measuring and logic elements. Another problems or more correct - opportunities - arise because of transfer to new definitions of units. Metrology development perspectives in connection with above-mentioned factors and context are considered. Two possible alternative ways - widening or narrowing metrology object and sphere - are discussed.

1. Introduction
Metrology is now at the crossroads because of measurement technology perspective. Measurement had arisen as a quantities comparison, and it was worked up by direct comparison of a measurand with measure. Accordingly, metrology arose as a science and practice of measure, The latter was introducing firstly as subjective-anthropomorphous one, and then it was made as objective one by creation of artifacts. Measurement unit was inseparable from measure, properly speaking the latter was as unit. Then the transition to indirect comparison with measure arose - measuring instruments (MI), measuring transducers, measuring plants and systems were appeared. Measurements, became complicated, have got as a challenge for metrology which has widened, branched, and complicated: introduction of well founded systems of units, reference standards development, traceability ensuring, measurement data processing, introduction and determination of metrological characteristics. But, measurements objects in the nature (scientific measurements) and techno-sphere (industrial measurements) were as methodologically uniform. It means that objects properties and attributes under measurements are presented with measurands which have fundamental character of principally measurable parameters of object models. In other words, not depending of measurement accuracy required, there is no doubt of model adequacy, and the measurand can be treated ambiguo usly in every measurement. The important peculiarity of that stage was that processes and elements of techno-sphere were separated from measurements and MI, and vice versa. As corollary, metrology did not include above-mentioned processes and elements as its own ones. Measurement unity was ensured by centralisation of metrological traceability systems.
Now the situation is cardinally changed. Scientific investigations are focusing more and more on fundamental processes and elements of nature. Accordingly, measurement object models lose their univocacy, and measurands range broadening in both directions – to very small and extra large values – erodes traditional concept of accuracy then traditional concept of measurement.

So, in the nano-technology sphere, sub-nanometer lengths are under measurement. But state-of-the-art lower limits of measurement and respective accuracies don’t meet these requirements in full measure. In Europe industry, micro-CMMs don’t permit to reach the contact measurement uncertainty less than 100 nm [1]. The project JRP SIB08 for high accuracy displacement measurement [2], in which six European national metrology institutes participate, hasn’t completed yet. The project is aimed at uncertainty decreasing up to 1 nm and 10 pm in the displacement measurement ranges 100 µm and 1 µm, accordingly.

Technologies engendered by science and practical demands bring to not only techno-sphere objects complication but an incorporation of measurement per se processes and elements into the above-mentioned objects as well.

Crossroads of metrology, which is mentioned above, consists of that whether metrology has to follow complicated measurements of complicated objects properties, so to widen turning into accuracy meta-science and practice or to save limits of metrological methodology, accordingly practice, ignoring relative narrowing field of application.

2. Scientific and practical components of metrology

Metrology is defined as the science of measurement which is aimed at solving practical problems, and so relationship of scientific and practical metrology aspects are under explanation.

Generally speaking, methodology of any scientific discipline develops in accordance with its intrinsic logic; at that one problem solution begets another problem, and so on. Address to practice (direct or mediate of scientific experiment) is binding but not regular, so practice sometimes outrun science producing challenges for the latter, sometimes practice becomes detached from science, and scientific results permit practice rapid development.

Scientific metrology, in spite of especially close connection with practice, has also intrinsic logic relatively independent from practice. This logic is conditioned by methodological problems of measurement theory and traceability. Relatively independence of metrology methodology is illustrated by introducing notion of uncertainty instead of error – mainly on the base of methodological (even epistemological and ontological) considerations.

Practice of metrology – it is look from outside, from the direction of creation of new technical equipments requiring control and checking, correspondingly industrial measurements.

Common field where two approaches, methodological and practical, meet each other serve, in fact, measurements, their practice and theory. Methodological core (constant part) and methodological envelope (variable part) should be distinguished in metrological assurance of measurement. The core consists of measurement unity problems, particularly, problems of reference standards development. The envelope consists of problems caused by measurement complication, firstly by measurement incorporation into new technical equipments. The envelope development looks like process of widening metrology content: complicated measurement needs complicated methods and MI that leads to new metrological objects and processes. Information technologies use plays special role in measurement complication and its consequences.

3. Metrological assurance methodology and metrology development perspective

As it was shown in [3], incorporation measurement into different technical devices or, backwards, incorporation non-measurement function into MI leads to appearance of new technical apparatus category – technical device with measurement functions (DMF) [4]. DMF contain at least two kinds of elements: measuring (instruments, transducers), and non-measuring (logic transducers). Such DMF composition begets some metrological problems. Firstly, the structure of measuring systems and information-measuring systems becomes differ as compared with traditional multichannel systems –
they can be single-channel. Secondly, traditional measuring channel cannot be picked out in single-channel system. Thirdly, logic transducer characteristics can be hardly chosen [5] which present metrological properties of the transducer. Moreover, it is not clear what could be mentioned as metrological property in that case. Fourthly, DMF can contain database which is necessary for identification of objects under observation, and representation of which as used here is a problem.

Therefore, incorporation of measurement and MIs is accompanied with "smearing" of classic notion of measurement as a process of getting estimate (in general case - probabilistic one) of the measurand. Smearing goes in two lines: of functional-aim (aim and function of quantity estimation inseparably interlaces with aims and functions of detection, identification, and control), and of functional-objective (measurement and non-measurement conversions and data transducers interlaces). The above-mentioned crossroad of metrology, in terms of metrological ensuring these devices, looks like the following. Either metrological assurance of the concrete device should cover it wholly including non-measuring components or only measuring elements of the device remain as objects of metrological assurance at that traditional metrological procedures fulfilling will be expedient only if these elements are separated physically. In the first case, principally new methods of the device work results representation and principally new categories of the device element metrological characteristics have to be involved. In the second case, sphere of metrology get narrow regarding to technical devices with measurement functions as compared with traditional MIs.

4. Methodological core of metrology and perspective its development
The development vector of reference standards as measures reproducing units which based on fundamental physical constants was preset in the middle of last century. Mentioned units differ principally from the units of past generation. The latter are, in essence, specifications of some artifacts which elements are subjected to every possible physical agent. Such unit reproduction, even using an ideal device corresponding its definition, is possible only with restricted accuracy. Figuratively speaking, unit was determined with potential error. For instance, the definition of ampere is principally uncertain if it is considered as specification for unit reproduction. Unit defined on the base of fundamental physical effects and fundamental physical constants is deprived of the mentioned defect: the effects and constants are not depended, in principle, from macro-effects. Of course, corresponding reference standard as any artifact (macro-device) is subjected to external influences. But potentially achievable accuracy is much more in that case.

The qualitative character of the above-mentioned transition has following reasons. When quantity reproducing by reference standard is conditioned directly on physical properties of material of reference construction elements then influencing factors affect immediately the quantity size. This is the case of metre as prototype of platinum-iridium alloy. When the reproducing quantity is conditioned by atomic system quantum characteristics then influencing factors affect properties of the quantity conversion into the reference standard output signal; that is the factors affect, as result, systematic and random corrections to the quantity estimate error. In other words, in the second case, influence of conditions is qualitatively decreased.

Therefore, it is possible to return, on the new physical and technological level, to the idea of distribution of uniformly precise reference standards between users just as it was made in 1889 in the framework of Metric Convention realization. So, for instance, standard Josephson measure based on frequency generator with error of order $10^{-10}$ (which generator is available for many users), ensures reproduction of voltage on the level $10^{-6}$ [6]. The latter meets main measurement accuracy requirements in industry. In other words, main industry needs of quality level of electrical voltage unit reproduced, and thereby of measurement unity assurance level, can be satisfied owing to reproduction technology of principally perfective specification (of the unit reproduction). Calibration of Josephson measure as working reference standard can be fulfilled using portable measure making function of secondary reference standard. Inter-calibration interval can be essentially increased as compared with traditional intervals for usual voltage calibrators. As consequence of all said, metrological (calibration) load on the primary national voltage reference standard is multiply reduced.
Therefore, the transfer to definition and reproduction of units on the base of fundamental physical phenomenon and fundamental physical constants leads to collapse of one of metrology conceptual pillars, that is measurement unity assurance in today’s strongly centralized variant.

Other factors of metrology development increase the aspiration for decentralization. It was shown in the course of fulfillment of the investigation project of Russian measurement unity system decentralization problem (Russian Academy of Sciences, 1992-93). Particularly, M. D. Vaysband has given a demonstration of that it is possible to construct the measurement unity assurance sub-system for measurement on alternating current basing only on analog-digital conversion of instantaneous voltages. The rest of parameters of signals and chains could be determined by indirect measurements, that is by numerical transformation of figures obtained. If take into account that NIST and PTB (jointly with The Supracon AG) produce now devices on the base of Josephson effect which reproduce sinusoidal voltage with error not worse than $2 \times 10^{-8}$ [6], then Vaysband’s idea realisation get solid technological base.

5. Conclusions
Three powerful tendencies of engineering and applied metrology –
- technical devices complication,
- measurement technology perfection,
- tendency to making measure as objective which tendency inherent in metrology
– put modern metrology before principle alternative of further development way. One way consists in that metrology will try to run down measurement practice following engineering and industry development. It means necessity of widening metrology towards all kinds of signal and data conversion, that is making absolutely new tools for theoretical understanding, modelling and presentation of non-measuring conversions, and elaboration of corresponding new methodology of metrological assurance. Other development metrology way consists in that to penetrate to a depth developing methodology and practice of calibration, namely making reference standards ensuring traceability. The latter will inevitably, as technique become more complicated and broad, require decentralisation of traceability systems on the base of ultimate objective stable measures.

Now there are no significant signs of movement along the first way. Most likely, the second variant will be realised probably in paradoxical form: scientific metrology will shrink down to the limit, and applied metrology, particularly metrological services activity in industry, should be flow (and dissolve) in mainstream – creation and exploitation of new technique.

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