Measurement as cognitive and applied problem

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Abstract. Measurement is analyzed as a process of task-oriented actions with material and model objects. It is emphasized that model elements of measurement are of crucial importance in the formulation of measurement tasks and implementation of measurement experiments. It is shown that there is a methodological gap between the rows of material and model elements of measurement, which belong to fundamentally incompatible systems. This gap determines an adaptive nature of measurement, during which the attribute of an object being measured is specified more accurately. The need for constructing equivalence systems aimed at overcoming the gap is substantiated. The measurement traceability system fulfils the role of an internal equivalence system for measurement as a cognitive procedure. The application system in the interests of which the measurements are made fulfils the role of an external equivalence system.

1. Introduction
Metrology is an ancient scientific and practical discipline. It originates from Sumerian culture, in which measurements were a significant instrument of social life [1]. It is surprising that despite the conservatism, which is inherent in it by definition, metrology continues developing for six thousand years. This progress can only be stimulated by the presence of a permanent problem. The latter is obvious and it has two sides: the need to meet the required accuracy in measuring known quantities and the need to estimate previously unknown properties of objects, or attributes of previously unknown objects. In turn, the source of the above-mentioned never-ending renewable problem lies in an inherent contradiction: we mean a fundamental contradiction which is the basis for the development of measurements and metrology.

2. Measurement structure
Bearing in mind both sides of the problem, we can consider the establishment of relationship between a set of objects and a set of numbers to be in fact the source for the development of measurements [2]. Indeed, this problem does not have a general unambiguous solution and it resumes again and again. However, for measurement practice, it is preferential to formulate the problem more specifically, in terms of reality and its simulation.

It is argued that the basic contradiction of measurement (and metrology) consists in the fact that the purpose of measurement is formulated and attained in two fundamentally incompatible systems. The purpose of measurement is formulated as quantitative estimation of an actual manifestative

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property of a material object. In other words, we need to obtain a result in a system of real objects: material objects, processes, attributes, and properties. The term ‘quantitative’ does not change this representation in principle because the nature of measurement is to compare similar objects (attributes, properties) and express one of them through another. Therefore, it is assumed that procedure of measurement, i.e., a series of practical actions, is carried out in the above-mentioned real system.

Of course, the notion “number” is necessary for evaluation of two objects (of abioceon) relation. There is no problem because mathematics gives us this notion. But the problem exits and it turns out to be the deeper one. The reason is that not only number but notion “model”, i.e., mathematical category of more general system level, should be used. In other words, starting point that measurement as procedure (set of practical actions) is carried out in reality system (RS) referred above seems to be at least incomplete.

As regards measurement as a process of motion towards a goal, the process includes, besides practical actions, a number of manipulations in the system of models, i.e., a system of conventional and abstract elements. Moreover, it is impossible to start practical measuring procedures, first of all, formulate a practical measurement task without using a ‘model (reflection)’ system (MS). The fact is that the concept of a measurand — the key notion in the formulation of the measurement problem — is introduced on the model of the attribute (property) being measured, which, in turn, serves as an element of a more general model for the measurement object. On top of everything, it is necessary for measurement realization that second and first models are sufficiently detailed. Many practical examples confirm that exceedingly general object model and, as consequence, property model, lead to the result which does not meet the practical aim or even has no physical sense.

Thus, the property to be measured is expressed for the purpose of measurement by a model, i.e., an immaterial (information) object representing the relationship between a specified property and other known, with higher or less certainty, properties of objects, including the object of measurement. In other words, we intend to measure an attribute of a material object, but, instead, we measure an attribute of a model. This being so, we need to interpret (verify) the measurement result (MR). Interpretation is carried out in two stages (see Fig. 1): internal (MR correspondence to the measurement models) and external (correspondence of the result of interaction between the object of measurements and its environment—other objects to our expectations).

3. Measurement structure
Based on the foregoing reasoning, we define an object of measurement as an element of RS with an attribute (property) which is of interest to us. Here, we should draw your attention to the paradox of actions (interaction) with RS: as soon as we name an object, we move to MS, especially it is true for the attribute. Indeed, the name of an object follows from its classification, i.e., the assignment of an object to a group of homogeneous, in a sense, objects. Objects are classified based on a type, or group, model. Hence, denomination is establishing a correspondence between an object and a certain group model. This note is valid for an attribute too. Besides, there is no possibility to pick out the attribute from a set of all attributes of an object without modelling. To do our reasoning simpler, we ignore below this inevitable stage of modelling by name. So, an object and an attribute can be accepted as elements of RS but it not relevant to measurand.

Really, as regards the attribute, it requires a model of the subsequent (more complicated, specific, and detailed) level. The measurand in this series of representations appears as a model possessing certain features (characteristics, parameters) of a model of an attribute, or ‘a model of a model’ (except for object model).
Fig. 1. Measurement and verification of its result.
Thus, object has to be represented in measurement not only as reality object with detailed property (attribute) but as totality of models (for attribute and measurand). Measurand as “second model derivative”, on the one hand, and the input physical impact on the MI, on the other hand, are separated by a gap. It is inevitable because the RS and MS belong to different planes in the model of cognition (learning, investigation) of the universe. To overcome the gap it is necessary, after obtaining the output physical effect as a result of physical transformation of an input action, we may return, using this basis, from the RS to the MS, where the measurement result must be compared with the measurand.

The gap is overcome by constructing an equivalence system (ES). It is only within this system that the reflection of ‘attribute – number’ makes sense. We can speak about general and specific ES’s. The general ES applies to all measurements of a specific type, whereas a specific model applies to measurements made within a specific measurement task.

Obviously, the ES should rely on some reference points; it remains to find out which ones exactly.

For a specific ES, the reference points are certification of measurement procedure and MI calibration. More precisely, a reference point is obtained from both of these procedures, which ensures traceability of measurements, or MR. The reason is that going up to the reference standard and, further, to the unit, makes it possible to rely on the well-known model-reality relationship. The primary reference standard is the highest point, in the traceability chain, of model adequacy.

To put it otherwise, to search models which are adequate to reality objects, artificial reality objects are constructed, namely reference standards. They are constructed specially in order to ensure their required adequacy to initial model, i.e., measurement unit (if there is an initial etalon) or more high level etalon model.

For a general ES, the reference point is a measurement unit. It is in the unit that the maximum model adequacy, namely, identity, is attained. Indeed, the unit is a specification of a material object (artifact, physical process), an attribute of which is, by definition, identical to itself.

Therefore in this case too, the model is constructed specially which is adequate completely to the model, namely, to itself. Above-mentioned means that the problem of RS and MS connection, or ES construction, represents essentially the problem of reality objects adequacy to models, in relations object – model, and object – object, and model - model. The problem decision is in creation of real objects and construction of models with assured range of adequacy; examples are measurement unit and reference standard.

Hence, it makes sense to fix the fact that measurement as an object of introspection is related to two incompatible systems (RS and MS), which are interrelated by an ES. The ES itself is constructed by modelling specially selected objects.

Considering measurement as a process, we find that it evolves by cyclic handling with RS and MS. The structure of measurement based on two parallel rows of material and model elements has been introduced by us earlier [3] and we have used it in previous publications. This static structure ‘revives’ when measurement is considered as a process, i.e., it becomes dynamic [see fig. 2]. As a measurement process evolves, real and model elements are used alternately, which provides a confirmation and validation of the proposition that model and real elements of measurement go hand in hand inseparably. Indeed, it is impossible to proceed with the next actions towards real elements without introducing another model (object, attribute, MI, etc.).
Fig. 2. Logically-temporal measurement structure

1. Aim
2. Object
3. Measurement method
4. Measured characteristics
5. Measurement conditions (MC)
6. Measurement result
7. Interpretation

- Measuring instrument (MI)
- Measurement conditions (MC)
- Characteristic
- Property
Basically, the dynamics of the measurement structure stems from the desire to overcome the gap. Moreover, trying to overcome the gap, we actually try to find out during the measurement process what exactly we are measuring. It is important because a clear a priori separation of measurement into steps of measurand identification and its estimation is an illusion. The latter representation appears when a static structure is automatically assigned a meaning of a process structure.

From the above standpoint, the UNCERTAINTY concept is preferential to the ERROR concept. On the other hand, the ERROR concept traditionally involves analysis (structurisation of the gap) and rests on a break point. There was a further advance to be made, but the UNCERTAINTY concept makes the problem irrelevant without resolving it.

4. Practical aspect of measurement
In the foregoing, we considered measurement as a cognitive process, which it is on the merits. However, a measurement task is always an applied problem, which has to meet certain requirements of a specific application. Therefore, for the purposes of analysis, we should immerse the above-mentioned systems, in which the measurement is to be performed, in the application system (AS). The immersion in an AS should be carried out step by step: from the local system (e.g., a laboratory or enterprise) to a group system (belonging to the same group, e.g., instrument-making enterprises) and a general system (e.g., national industry), and further, up to the world economy. It is needless to say that in this case the AS levels can be configured in different ways.

An AS should be treated as a supersystem for the MS. The word ‘application’ should not be understood in a narrow sense as opposed to the words ‘scientific’ or ‘cognitive’, especially as the measurement system itself is cognitive.

The AS is an ES, which can be called external, unlike the above-mentioned internal ES (a system of standardization, traceability). Entering the AS, the measurement result agrees (or disagrees) with the RS through the measurement object, which must be in agreement with the set of RS objects.

5. Conclusions
A measurement result as a model system element represents an object (a reality system element) only within a totality of \{RS, MS, ES\}, dynamically evolving in a process called measurement. Metrology as a discipline aimed at ensuring uniformity of measurements (traceability) dictates the need and allows comparing the results of measurements of the same object property (or a property of similar objects) only in the conditions when totalities \{RS_1, MS_1, ES_1\} and \{RS_2, MS_2, ES_2\} related to the measurements being compared can be considered equivalent. In other words, we should compare the tuples \{MR_1; RS_1, MS_1, ES_1\} and \{MR_2; RS_2, MS_2, ES_2\}.

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6. References
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