A Concept of Measurement Process-Result Duality in the Context of Measurement Uncertainty

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***Abstract*—This paper introduces the concept of duality when it comes to the measurement process and measurement result. This concept simplifies the existing framework significantly by clearly specifying the existing elements of the measurement process, and how they affect the uncertainty of the measurement result. Since the measurement result and its corresponding uncertainty are a product of the non-excluded errors in the measurement process, it reasonably follows that the measurement result cannot be an element of the process. This notion is useful for retrieving and analyzing the sources of uncertainty as components of combined uncertainty (and respectively expanded uncertainty) in the presentation of the final result.**

Keywords—Measurement, Process, Result, Uncertainty, Metrology

I. INTRODUCTION

Many books and documents [1, 3, 8, 9, 14] dedicated to the metrology and measurements affect the issue of the measurement process and its elements. More or less, the base documents [1, 2, 7, 8, 9, 10, 11, 14] expressing the uncertainty of the measurement result and talking about the sources of uncertainty, direct or indirect touch the questions about the elements of the measurement process. A quick review here confirms this.

Refer to GUM [1] "3.3.2 *In practice, there are many possible sources of uncertainty in a measurement, including:*

a) incomplete definition of the measurand;

b) imperfect reaIization of the definition of the measurand;

c) nonrepresentative sampling — the sample measured may not represent the defined measurand;

d) inadequate knowledge of the effects of environmental conditions on the measurement or imperfect measurement of environmental conditions;

e) personal bias in reading analogue instruments;

f) finite instrument resolution or discrimination threshold;

g) inexact values of measurement standards and reference materials;

h) inexact values of constants and other parameters obtained from external sources and used in the data-reduction algorithm;

i) approximations and assumptions incorporated in the measurement method and procedure;

j) variations in repeated observations of the measurand under apparently identical conditions.

These sources are not necessarily independent…."

Same list of potential sources of uncertainty here is copied to other popular sources as [2, 3]. The incomplete and unsystematic list of potential sources of uncertainty here, in concrete cases of laboratory work often leave the question about the exhaustive definition of the uncertainty components.

The present paper aims to simplify the way of asking the sources of uncertainty, deciding about the model of uncertainty, logically based on the elements of the measurement process.

A little bit closer to the idea of the present work can be found in the well spread [4]: "*4. Where do errors and uncertainties come from? Many things can undermine a measurement. …. Because real measurements are never made under perfect conditions, errors and uncertainties can come from:*

- *The measuring instrument …*
- *The item being measured …*
- *The measurement process …*
- *'Imported' uncertainties …*
- *Operator skill …*
- *Sampling issues …*
- *The environment …*"

Important expression in [4] is that errors and uncertainties came from the same sources. The classifications of errors depends on:

- Origin (In measurement process): be defined hereinafter;
- Appearance (In measurement result): random, systematic, rude;
- Dimensionality: absolute, relative, reduced;
- Observation: static and dynamic;
- Function to the input: additive, multiplicative, non-linear;
- Conditions: intrinsic, complementary (additional);
- Etc.

As the errors originate in the measurement process means that identified sources of errors in the measurement process define sources of uncertainty.

Close to the idea to focus the sources of uncertainty to the elements of the measurement process, while talking about calibration uncertainty, is the very popular blog [5]: "*Sources of Uncertainty. Uncertainty in measurement can be influenced by many different factors. Below is a list of the 6 most common*

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sources of uncertainty in measurement. When you begin to identify sources of measurement uncertainty, you should start by think about influences that are in these categories.

Six common sources of uncertainty in measurement:

- *Equipment*
- *Unit Under Test*
- *Operator*
- *Method*
- *Calibration*
- *Environment*"

The specification in [5] is kind of intuitive, without analysis. Hereinafter the analysis is based on the prerequisites in the measurement process.

The next explanation is dedicated to the elements of the measurement process from the point of view of measurement philosophy in view of the claim that the sources of uncertainty are due to the elements of the measurement process and the final representation of uncertainty is an element of the measurement result.

According to VIM [6] § 2.1 the measurement is a "*process of experimentally obtaining one or more quantity values that can be reasonably attributed to a quantity*".

II. OBJECT AND SUBJECT OF THE MEASUREMENT PROCESS

Talking about the measurement process, adhering to VIM [6], instead of quantity is preferably usage of the term "*measurand*" where in § 2.3 it is defined as a "*quantity intended to be measured*". Considering the most abstract definition according NOTE 3 to the same paragraph (2.3) of VIM [6] here the measurand is named OBJECT of the measurement.

Considering the measurement process as an abstract process it is an interaction between the OBJECT and the SUBJECT of the process (Fig. 1). In the measurement case, the SUBJECT of the measurement process could be an operator, device, controller, algorithm or any subject who is using the measurement result.

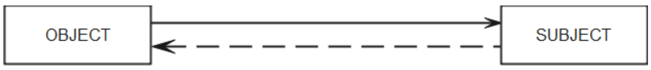

Fig. 1. Interaction between the object and the subject of the measurement process.

The interaction in the process is always both ways, even often in the measurements the influence of the SUBJECT over the OBJECT is negligible.

The measurement is a quantitative process. Before obtaining the digital values of the quantities (of the OBJECT), the SUBJECT shall pass the qualification of the OBJECT. That means the SUBJECT has an a priori imagination about the OBJECT before measurements. This a priori imagination is related with the identification of the OBJECT and its classification to a group of OBJECTS.

The a priori imagination for the object is named a "Model" of the OBJECT [12]. The model, more or less adequate to the OBJECT qualifies it to a group of objects having the same quantity or set of quantities (in the most sophisticated cases), possible to be measured.

III. MEASUREMENT PROCESS – MEASUREMENT RESULT DUALITY

As it was mentioned above, the role of the SUBJECT is to obtain and use the measurement result. Depending on how the SUBJECT uses the result, we talk about measurement, test, control, calibration etc. always based on the measurement process.

The measurement result is a product of the measurement process after the interaction between the OBJECT and the SUBJECT i.e. the product is coming after the process of interaction is finished. So the **RESULT can not be an element of the measurement process – it is a product of the process**.

Some literature sources classify the measurement result as an element of the measurement process [15]. This misunderstanding is more popular in 60-s and 70-s of the last century before introducing the conception of uncertainties. Most of the contemporary documents [1, 2] define the uncertainty as a parameter of the result of the measurement and separate in this way the result from the process.

IV. MEASUREMENT METHOD AND MEASURING INSTRUMENT

The interaction between the OBJECT and the SUBJECT always happens according to any METHOD, named measurement METHOD (Fig. 2). VIM [6] § 2.5 says "*measurement method*" or "*method of measurement*" is a "*generic description of a logical organization of operations used in a measurement*".

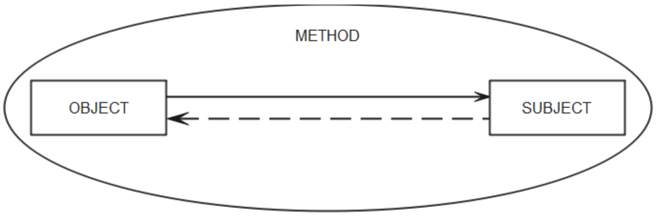

Fig. 2. Interaction between the object and the subject according a method of measurement

The METHOD is based on the key principles [1, 6, 7] of interaction between the OBJECT and the SUBJECT of the measurement process. All qualifications of the OBJECT shall be considered in the METHOD of measurement. So, some authors unreasonably refer the model of the OBJECT to the description of the METHOD [15]. In this case VIM [6] with the NOTE to § 2.5 is definitely clear.

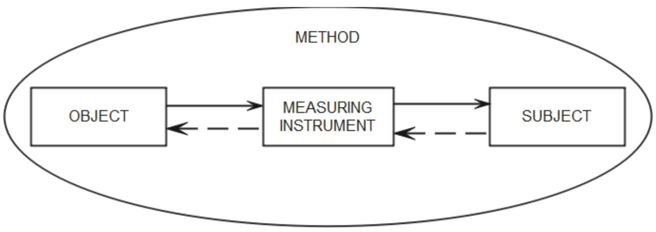

Fig. 3. Measuring instrument in the process of interaction between the object and the subject according to the measurement method.

The interaction between the OBJECT and the SUBJECT according to the chosen METHOD is realized with measurement tool/s named MEASURING INSTRUMENT/s (Fig. 3).

The definition for MEASURING INSTRUMENT in VIM [6] § 3.1 is a "*device used for making measurements, alone or in conjunction with one or more supplementary devices*".

As much complex is the device (instrument), as more the measurement METHOD is built into its action. In some cases, the realization of the measurement method needs several simple devices. In other cases, the METHOD requires just one complex device. Than METHOD is implemented in the device (Fig. 4).

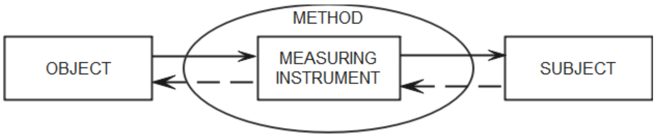

Fig. 4. Realization of the measurement method in the process with a complex measuring instrument (measuring system according VIM).

Such complex devices, often used in on-site measurements, in VIM [6] are named "*measuring systems*" with a respective definition in § 3.2. To simplify the exposition here is used the name MEASURING INSTRUMENT only.

V. INFLUENCE FACTORS

The INFLUENCE FACTORS are circumstances and respective quantities, which deviation affects the measurement result. VIM [6] § 2.52 is talking about "*influence quantities*" with a definition: "*quantity that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the indication and the measurement result*". The exposition here prefers the GUM's definition for "*influence quantity*" as a "*quantity that is not the measurand but that affects the result of the measurement*" [1]. In this way the INFLUENCE FACTORS impact over the MEASURING INSTRUMENT, over the OBJECT of measurement, and could influent over the SUBJECT (Fig. 5).

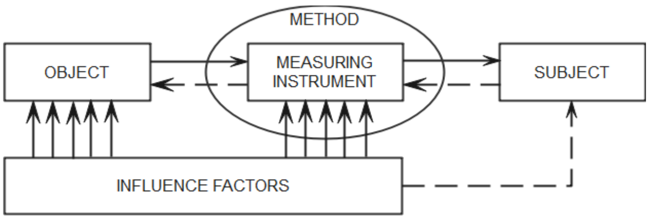

Fig. 5. Impact of the influence factors over the object, measuring instrument and subject of the measurement process.

VI. THE ELEMENTS OF THE MEASUREMENT PROCESS

The specified five elements of the measurement process: OBJECT, SUBJECT, METHOD, MEASURING INSTRUMENT and INFLUENCE FACTORS exist and can be analyzed in all cases of measurement processes.

For example, in calibration (Fig. 6), the OBJECT is the device being tested (most popular as device under test – DUT or unit under test UUT), the MEASURING INSTRUMENT is the reference tool (calibrator, reference measure etc.) and the SUBJECT is an operator.

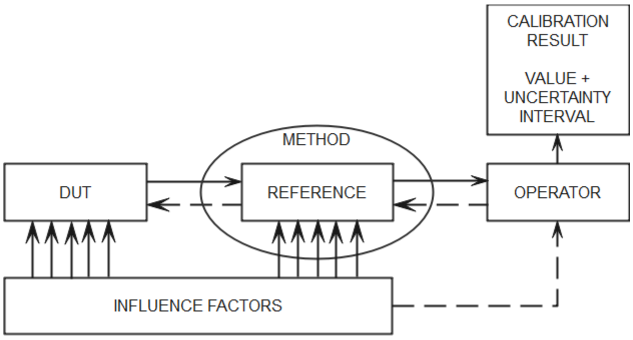

Fig. 6. Measurment process and its elements in calibration

The result in calibration is a value and inherent uncertainty for each calibration point.

In testing and inspections we add a NORM to compare with the indication of the MEASURING INSTRUMENT. The elements of the measurement process are the same

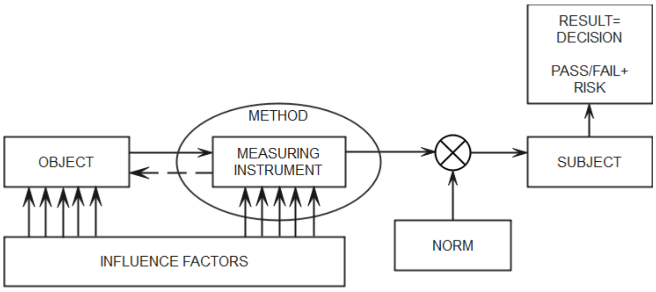

Fig. 7. Measurment process and its elements in testing and inspection

In this case, the result is a decision from the type PASS/FAIL and the measurement uncertainty reflects on the risk type α or β.

In case of control of a process, the result from the measurement process is used to form an IMPACT over the OBJECT.

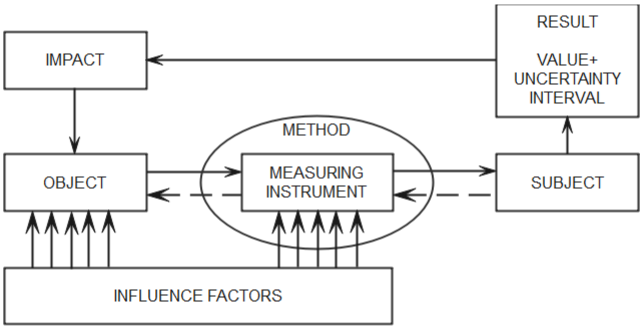

Fig. 8. Measurment process and it's elements in control of a process

The uncertainty of the result here reflects on stability of the control and often leads to inaccurate process stabilization.

VII. THE ELEMENTS OF THE MEASUREMENT PROCESS AND THE THEORY OF ERRORS

In the errors theory the specified five elements of the measurement process have typical well studied [13] correspondent errors types as follow:

- INSTRUMENT – Instrumental errors;
- METHOD – Methodological errors;
- SUBJECT – Subjective errors;
- INFLUENCE FACTORS – Complementary errors;
- OBJECT – is not an error generating element of the process, but here the specific error of inadequacy of the model to the OBJECT could be classified.

All sources of errors in the measurement process are potential sources of uncertainties. Preparing the uncertainty model for each type of measurement we can start the study with the five elements of the measurement process.

VIII. How the GUM Sources Correspond to the Elements of the Measurement process?

Let briefly make a correspondence between mentioned above GUM's sources and the elements of the measurement process:

a) incomplete definition of the measurand – **Inadequacy of the model**;

b) imperfect realization of the definition of the measurand – **Inadequacy of the model**;

c) non representative sampling — the sample measured may not represent the defined measurand – **Subject**;

d) inadequate knowledge of the effects of environmental conditions on the measurement or imperfect measurement of environmental conditions – **Influence Factors**;

e) personal bias in reading analogue instruments - **Instrument**;

f) finite instrument resolution or discrimination threshold – **Method**;

g) inexact values of measurement standards and reference materials - **Instrument**;

h) inexact values of constants and other parameters obtained from external sources and used in the data-reduction algorithm – **Inadequacy of the model**;

i) approximations and assumptions incorporated in the measurement method and procedure - **Method**;

j) variations in repeated observations of the measurand under apparently identical conditions – **Influence Factors**.

IX. Conclusion

The sources of uncertainty are defined in the measurement process. These fractions of uncertainty form the combined uncertainty and finally expressed in measurement result via expanded uncertainty.

Each specific source of uncertainty refers to the respective element of the measurement process. It is much easy for the laboratory metrologists, preparing the budget of uncertainties, to start analysis of the sources of uncertainty with the well specified and universal five element of the measurement process:

OBJECT

METHOD

MEASURING INSTRUMENT

SUBJECT

INFLUENCE FACTORS

Then the analysis could be deeper with the specific appearance of the factors of each element.

The approach of this concept is universal for all types of measurements on the stage of determining the uncertainties.

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