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Actual metrological and legal issues of non-destructive testing

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Abstract. The article is devoted to analyzing problems of metrological support and legal regulation in the sphere of non-destructive testing (NDT). Differences between the measurement technique and NDT have been analyzed. The necessity to apply the principles of metrological traceability to the NDT technique, equipment and test pieces has been announced. It has been suggested to view NDT as multi-parameter measurements. An example of the reference measuring system for complex calibrations of metal coatings measures on metal bases to calibrate eddy-current thickness gages of coatings has been given.

1. Introduction

The modern development of NDT tools and methods is inseparably linked to the tendencies and challenges of the 4th industrial revolution taking place presently. It is underlain by the principles of digitization, i.e. a transfer to the digital methods of collection, transfer and processing of all data obtained, as well as of automation of processes in all spheres of industry, including design, development, manufacture, and use of products. In this connection the role of NDT considerably increases at all life cycle stages.

2. Specifics of legal regulation of NDT

Difficulties of metrological and legal support of NDT are related to the fact that NDT includes several mutually complementary concepts:

Testing is an experimental determination of quantitative and (or) qualitative characteristics of the properties of a test object as a result of it being affected by various physical fields (acoustic, electromagnet, irradiation, thermal radiation etc.).

Inspection is a verification of the object compliance with the established technical requirements. The requirements to material and products established in the manufacturing process critically depend on the specifics of the materials themselves, processes in the manufacture of the products and the conditions of their subsequent use. In this connection the material or end-product suitability criteria depends on many factors and can be identified only in the process of scientific and engineering research and trial operation. If NDT methods are applied for process inspection, only the manufacturer is responsible for their use. However, if NDT is applied for inspection of the technical state of potentially dangerous objects, such as: railway transport, nuclear power etc., the procedures and equipment applied must undergo attestation and certification in accordance with the legislation.

Evaluation is a quantitative assessment of the characteristics of an object closest to the concept of **measurement** in terms of metrology as a process of experimental obtainment of quantitative values of a quantity (hereinafter metrological terms are given in accordance with VIM [1]). In this case the



mandatory requirement is to ensure metrological traceability of the result of the measurements to the reference through a documented unbroken chain of calibrations (VIM 2.41).

Thus, one and the same NDT procedure can be used for in-process testing, checking compliance with legal requirements and measurements of object parameters. A similar combination leads to significant problems both in methodological and legal aspects.

In accordance with the International Classification for Standards of the International Organization for Standardization (ICS ISO) [1], there are two different fields of standardization: 17 – Metrology and measurement. Physical phenomena and 19 – Testing, which includes the field 19.100 – Non-destructive testing. In the field of legal metrology, it is necessary to note the documents developed by the International Organization of Legal Metrology (OIML). The uses of measuring tools in Europe are regulated by international [3] and national [4] legislation. The requirements to the NDT systems are formulated in the document ENIQ (European Network for Inspection and Qualification) [5]. Even a shallow analysis of the basic terms and definitions in the field of measuring facilities and NDT demonstrates the essential similarity of approaches (table 1):

Table 1. Comparison of terms and definitions in metrology and NDT.

Terms Metrology/NDT	Definitions	
	Metrology (VIM)	NDT
Measuring instrument/ Inspection equipment	Device used for making measurements, alone or in conjunction with one or more supplementary devices	The means by which the inspection is implemented. For example, in the case of automated ultrasonics and eddy currents, the inspection equipment consists of cables, probes, pulser-receiver (only for ultrasonics), data acquisition and data processing tools and scanner[5]
Measurement procedure/ Inspection procedure	Detailed description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result	A definition of how an inspection is implemented for a specific inspection situation; a written description specifying all essential parameters and setting out the detailed steps and precautions to be taken when applying the specified inspection technique to the inspection situation [5]
Reference material/ Reference block	Material, sufficiently homogeneous and stable with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties	Piece of material, with specified metallurgical, geometrical and dimensional characteristics, used for the calibration and assessment of equipment [6]

At the same time, NDT has a number of specific features making it different from measurements. The NDT specifics are reflected in the definition given in [5]: “**Inspection System** - All parts of the non-destructive inspection including equipment, inspection procedure and personnel which can influence the outcome and quality of the inspection”. Unlike the measuring equipment subject to voluntary calibration or verification in accordance with the applicable legislation, the same document introduces the concept of **Inspection Qualification** - The systematic assessment, by all those methods that are needed to provide reliable confirmation, of an inspection system to ensure that it is capable of achieving the required performance under real inspection conditions.

Qualification of an inspection may require assessment of any NDT system, composed of any combination of NDT procedure, equipment and personnel. This qualification or assessment can be considered as the sum of the following items:

i) Technical justification, which involves assembling all evidence on the effectiveness of the inspection, including previous experience of its application, laboratory studies, mathematical modeling, physical reasoning and so on.

ii) Practical trials (blind or open) conducted on simplified or representative test pieces resembling the component to be inspected.

In the fields of industry which actively introduce new NDT technologies, guidance for application and validation of NDT systems, [7], as well as design and attestation of test specimens [8] are developed.

A consequence of NDT complexity and versatility is that for it, as compared to other types of measurement, testing and inspection, a multistage system for certification of NDT specialists has been created [9].

The above special features of legal regulation in the NDT field engender a series of problems related to the main tendencies of the 4th industrial revolution [10]. The necessity to automate NDT processes requires a reduction of human factor in measurements and inspection. As a consequence, the processes of initial setting at an object, measurement procedure, taking into account of the effects of parameters, processing of the measurement results should be automated. At the same time, there is a growing necessity to create means of objective quality control of the measurements being conducted and ensuring traceability of the obtained results.

In the authors' opinion, the above situation with the NDT procedures makes it difficult to use them in automated system of inspection and condition monitoring (CM) due to an individual approach to qualification of the inspection procedure and significant influence of human factor on the results of their application. To solve this problem, it is suggested to implement the concept of metrological traceability (VIM 2.41) in qualification of NDT procedure and test pieces.

3. Introduction of the principles of metrological traceability for NDT procedure

Non-destructive testing can be conditionally divided into flaw detection and measurements by NDT methods. In case of flaw detection, as a rule, certain objects are detected that are discontinuities or imperfections of materials (pores, caverns, disintegrations, cracks, foreign inclusions etc.), which are often problematic to characterize by any dimensional quantity. In case of measurements by NDT methods certain physical quantity (such as coating or tube wall thickness) can be determined objectively in units of measurement. However, there is no clear boundary between flaw detection and measurements. Thus, for instance, one and the same echo method in ultrasonic inspection and the respective equipment can be used to detect flaws in the volume of a part and to measure its linear dimensions. In the first case the indicator of a flaw is a reflected acoustic wave, in the second case the reflection time is measured, in which case it is necessary to know the ultrasonic velocity in the material in order to measure thickness. But in the cited example as well the problem of finding a flaw is easily transformed into a measuring task, namely, the determination of the flaw depth and its sizes. For flaw detection a key problem is the definition of the concept of a flaw itself. In terms of process inspection, not any detected flaw (discontinuity) is a defect (terms according to [6]), which is a cause of rejection or necessity to replace the part. Often a necessity arises to rank the detected defects by their influence on the suitability of the product or hazard of its use. It is in this that the NDT inspection and technical diagnostic critically differ from the measurement procedure. For the latter the basic indicators are their metrological characteristics.

The specifics of NDT procedures and measurements consist in a multitude of factors to be taken into account and controlled simultaneously during their performance. Apart from standard parameters taken into account during normal measurements such as metrological characteristics of measuring instruments and environmental conditions, they include: properties of the controlled object, material of which it is made, nature of possible defects, sounding signal parameters and many other things. A vivid example of effect of material properties on the NDT is the specifics of inspection of carbon-carbon composite

materials (CCCM) actively replacing metal in aviation and space industry [11]. NDT ultrasonic methods are widely used for such products. Spatially reinforced carbon plastic materials fundamentally differ from the metal ones by a spatial anisotropy of the structure and mechanical properties and, as a consequence, ultrasonic velocity. Ultrasonic wave diffusion and attenuation pattern in CCCM also cardinally differs from metals and alloys, consequently, it is necessary to use transducers of another frequency and power. In no less degree the characteristic defects are different in these materials: the basic types of defects in metals are cracks; in carbon fiber-reinforced plastics, as a rule, disintegrations and irregularities of structure are observed. Thus, in qualification of a NDT procedure it is necessary to take into account specifics of the test object, the material of which it is made, defects characteristic for this material and product, and other factors able to have effects on the result of the inspection. At the same time, the solution of problems of qualification and validation requires a certain level of abstraction when describing the NDT procedures. As the overview of a NDT system generally the diagram of operation can be given from [7] (figure 1).

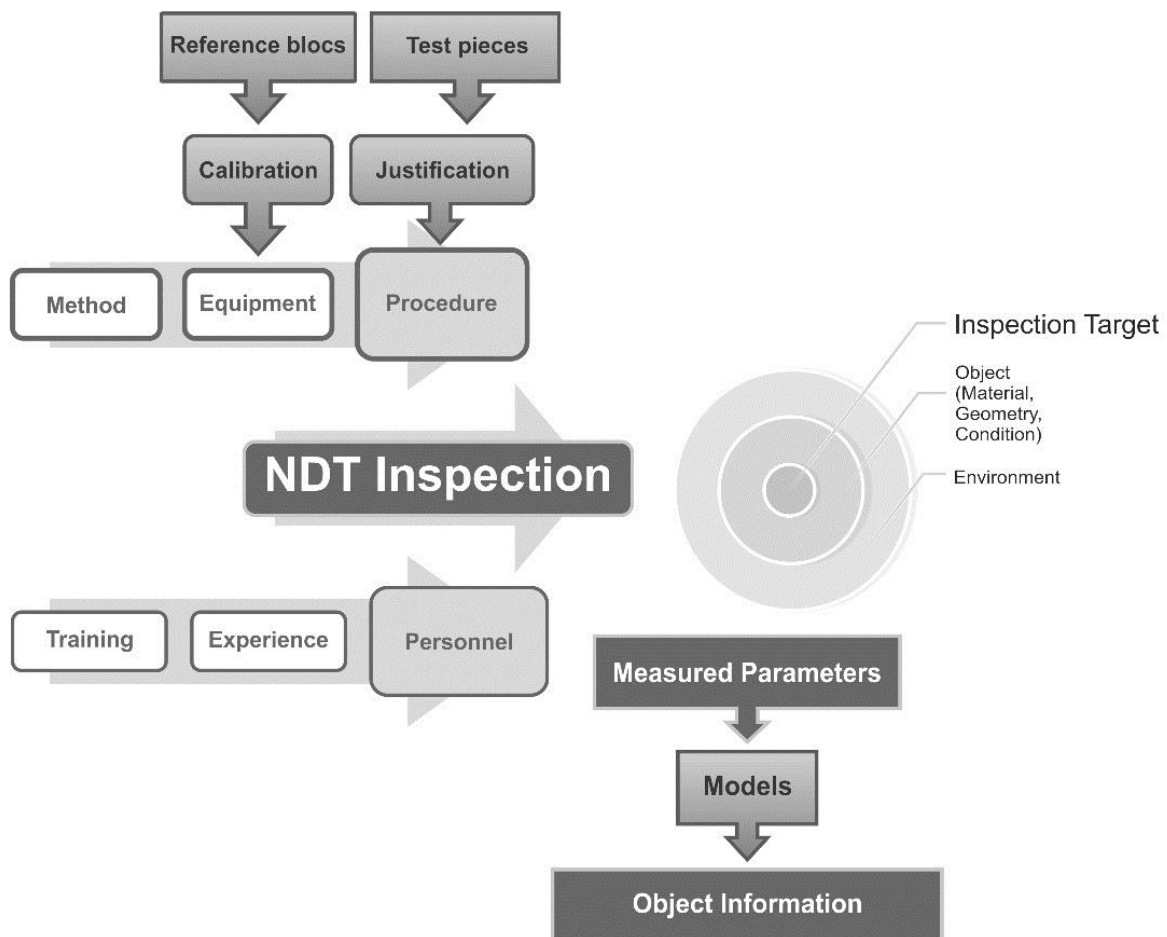


Figure 1. NDT as a provider of information regarding a defined object parameter.

In accordance with this diagram the inspection system consists of the components:

1. Procedure based on a specific method or several methods which are implemented in a set of respective equipment;
2. personnel having respective training and experience.

Information on the test object is calculated on the basis of the measured parameters taking into account the properties of the test object and the environmental parameters.

The authors deem it possible to add to the given diagram:

- reference blocks used to calibrate testing equipment and test pieces to determine the procedure characteristics in general;
- mathematical (physical) model used to calculate the results of inspection on the basis of the measured parameters as part of the inspection procedure. There is a modern tendency to use digital models describing the control object, the method and tool of inspection, and informative parameters of physical fields interacting with the controlled object, recorded by primary measuring transducers in the process of inspection.

In the system in question, to ensure unification and uniformity of NDT results, the equipment and procedure must be subjected to metrological attestation in order to ensure metrological traceability of the measurement results. Also in a number of cases reference blocks for NDT can be viewed as measurement standard (realized as material measure) in accordance with (VIM, 5.1) with the assigned values of the respective quantities with the known uncertainty and ensured traceability.

A similar approach is used in the Russian Federation. However, a reservation should be made here: the authors consider inefficient the practice to attest reference blocks of defects as reference standard of linear dimensions, for these specimens do not transmit linear dimensions to NDT tools (fault detectors). Such specimen can be deemed a «standard reference block» of defect taking into account the geometry of the entire specimen only, not only the defect itself, and the properties of the material of which it is made. In a similar way, it is not correct, by all appearances, to characterize the NDT procedure as the measurements procedure with typical metrological characteristics only. For many applications it is proposed to consider, as the basic characteristic of the inspection procedure, a probability of finding a defect in the specified range of geometric shapes and dimensions.

4. Non-destructive testing as multi-parameter measurements

As the basic principle of metrological confirmation of NDT equipment, procedures, and reference blocks it is proposed to consider NDT as multi-parameter measurements. The specifics of such measurements are that for the respective primary transducers it is impossible to divide informative and influence parameters unambiguously. These measurements are, as a rule, also indirect measurements. The measurements of the thicknesses of the walls or coatings with ultrasonic and electromagnetic methods can be an example. Particularly, eddy-current thickness gages implementing amplitude-difference, phase, and frequency-response methods of measurement based on an analysis of the electromagnetic field of eddy currents induced in the test object are widely used to measure the thickness of metal coatings [12]. The results of the measurements of these devices depend on several groups of parameters: electro-physical (conductivity of the materials of a coating σ_c and base σ_{base} , and specific permeability of the material of a base μ_{base}) and geometrical (coating thickness T_c , roughness, radius of surface curvature etc.). To ensure the traceability of thickness measurements by the described method, it is necessary to use reference standard assigned (certified) with over all specified parameters [13]. To solve this problem, a reference measuring system is being developed, ensuring measurement of conductivity of the base by Van der Pauw method, measurement of complex specific permeability of the metal on ring specimens using a permeameter, transmission of the value of this parameter to the base of a measure of an arbitrary shape with a flat surface, measurement of conductivity of the material of the cover of the measure using an eddy-current transducer with a wave excitation winding [14].

An approach to NDT as multi-parameter measurements will allow the self-control and metrological correctness maintenance methods applied in intelligent sensors to be used in it [15]. These methods are underlain by a measurement, in addition to the basic informative signal of additional parameters, by the changes in which one can judge whether the sensor readings correspond to the value being measured or they are related to a change in the measurement conditions, inherent characteristics of the sensor etc. This will enable automation of many NDT aspects and development of NDT self-adjustment procedures.

5. Conclusion

The existing specifics of qualification of NDT systems incorporating confirmation of equipment, procedures and personnel hinders their development in terms of automation and ensuring the uniformity

of measurements. As a solution of this problem, it is suggested to introduce the concept of metrological traceability when attesting the NDT equipment, procedures, and reference blocks. It is necessary for solving this problem, in the authors' opinion, to view NDT as multi-parameter measurements. The creation of the respective metrological support tools should promote development of the NDT in accordance with today's requirements.

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