俄罗斯无损检测与技术诊断学会，NDT 领域仪器设备面临的工业 4.0 挑战

- 面向工业 4.0 的 iNDT&E 仪器设备发展机会与挑战（编者注）

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# Challenges of Industry 4.0 for instrument engineering and metrology in the field of NDT and CM

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The measurement technology and metrology, as one of the structural components of the entire modern economy, is involved in the "Fourth Industrial Revolution", better known as "Industry 4.0". Advances in the technologies for digital information generation, transmission, processing and storage (the processes commonly referred to as "digitalization") open up new opportunities for developers of measuring equipment and metrologists. On the other hand, the introduction and development of "smart" systems and digital models requires direct participation of instrument makers and metrologists in the creation of "intelligent" sensors and the development of fundamentally new approaches to ensure the metrological reliability of instruments and measurement techniques, including in the field of non-destructive testing and condition monitoring.

**The main directions of the 4th industrial revolution** technical and technological breakthroughs include the following:

*Digitalization* is the development of technologies for the generation, transmission, processing and storage of digital information. The current stage of digitalization involves the creation of so-called digital platforms for managing processes and information flows in real time. Examples are electronic document management systems or decentralized taxi operators such as Uber. Another aspect of digitalization is the development and application of digital models of various devices, processes and complex systems. Examples include a digital model of the car used for virtual crash tests simulation [1], as well as digital twins of complex engineering objects, which are used to calculate the conditions of load-bearing structures based on data received from a variety of sensors located inside and outside the building structure.

*The Internet of Things* is the ability of some devices and instruments to connect to the Internet, the transfer of information to an external recipient and the receipt of external orders. In our opinion, it is not quite correct to refer to such objects as "smart", as the ability to exchange data does not imply the possibility of making independent decisions, but it makes it possible to automate the transfer of information to databases, include such devices in various hardware and robotic systems, use them to construct digital models and create cyberphysical systems.

*Cyber-physical systems (CFS)* is a complex of physical objects (devices, machines) and computer systems that control them. A simple example of a CFS is a robotic production complex where the production (physical operations) is carried out by robotic machines under the control of a computer (cybernetic system). Examples of such systems have been known for a long time, and in the future it is expected that global cyber-production is created, with the automation of all processes, from the preparation of the production assignment to the delivery to the end user.

*Smart systems* combines the three previous concept: a digital platform for data flow control; a number of "things" (sensors and actuators) connected to a network (the Internet); and a cyber-physical system that controls the process on the basis of incoming information from the sensors by sending commands to the actuators. An example of a system which is really "smart" may be a power distribution grid (Smart Grid) [2].

*The main trend in the development of NDT* methods and tools as measuring technologies is an active transition, from non-destructive testing to condition monitoring of products, engineering facilities, technological processes and environmental systems. In the field of metrology, the main directions are the development of metrological support for measuring transducers and non-destructive testing devices as a means of measuring multiparametric and multidimensional quantities..

**The impact of "digitalization" on the infrastructure of instrument-making and metrology.**

The metrological infrastructure which ensures the unity of measurements includes several intersecting levels generating large information flows that require systematization with the use of electronic information systems. To meet this challenge, the German National Metrology Institute Physikalisch-Technische Bundesanstalt (PTB) has put forward an initiative for the development of a common European digital quality infrastructure for innovative products and services called the European Metrology Cloud. [3]. PTB is also working on the creation of a digital calibration certificate (DCS) [4]. The machine-readable format of such DCSs is especially important for the digitalization of production and quality control processes. The ultimate goal of the work is to develop universal formats for the DSC data exchange to be used in all sectors of metrology.

There is a related trend for the "digitalization" of operation and metrological certification of measuring instruments (MI) in the sphere of state regulation: provision of unique marks for all MIs, and further MI equipment with the means to connect to telecommunications networks for the transmission of information to a single database. All the technical solutions for this already exist, but it is necessary to create an appropriate information system, solve the problems of standardization and make appropriate changes to the legislation.

**The tasks of instrument engineering for the 4th industrial revolution.**

*Creation of measuring instruments which can connect to the Internet (the Internet of MI)* is require for the solution of tasks for the remote monitoring of technical conditions and metrological characteristics of measuring transducers and devices, and integration of MI into the "smart" and distributed cyber-physical systems. There are several levels for the construction of the hierarchical structure of the "Internet of MI": the hardware (physical) level, network protocol of the Internet, the applied (user-oriented) level.

*Creation of MI adapted for the use in robotic systems.* MI for these systems should have some specific features which make them different from traditional devices: full automation of measurements and testing and calibration, increased reliability, the possibility of autonomous operation and integration into other systems, the availability of means of transmission of measurement information, etc. An example is an ultrasonic device for real-time spot welding quality control [5].

*Development of universal sensors for "smart" systems with the possibility of self-testing and remote calibration (verification).* The practice of integration of measuring instruments or primary measuring transducers directly into the elements of technological equipment, structures and products has become widespread. On the one hand, it creates new markets for instrument makers, and, on the other hand, forces developers to shift towards new approaches and concepts [6, 7]. Existing developments in the field of smart sensors have made it possible to develop and approve two standards of the Russian Federation [8, 9], provides the following definition of a smart sensor: an smart sensor is an adaptive sensor with the function of metrological self-control, which has a digital output and provides the transmission of primary measurement information and information about proper metrological functionality through the interface. At the same time, a smart sensor with computational capabilities makes it possible to perform the following tasks: automatic correction of errors resulting from exposure to influencing quantities and/or aging of components, self-repair in the case of a single defect in the sensor, self-learning.

*Digital industry establishment.* Digitalization of industry, which is the basis of the fourth industrial revolution, is the integration of the measurement results obtained with the use of a network of measuring transducers and other sources of information into a single whole and their processing with smart machine algorithms for automated control and decision-making. Based on these technologies, non-destructive testing which is now applied to finished products at the final stage may be replaced in the future by an operational interrelated analysis of data for optimization and flexible operational changes in the required parameters of products at each stage of their manufacture, including taking due account of customers requirements [10].

The key to the implementation of this concept is the entity of a "digital twin", which is the basis for the vast majority of all modern practical digital applications from technological processes and production lines to entire enterprises.

**The tasks of metrology for the 4th industrial revolution.**

*New principles for metrological support of smart sensor distributed networks.*

The use of sensor networks instead of single measurement tools in combination with large data sets, cloud computing and remote services poses a number of new requirements for metrology. Standardization and legal metrology of non-destructive testing and condition monitoring must also undergo changes in the conditions of the fourth industrial revolution. The main trend will be an increase in the use of distributed measurements and remote data processing. That is, the structural elements of measurement systems, in general, will be distributed over long distances in different regions or even countries. For example, calibration of the sensor network must take into account the measurement possibilities of individual transducers, communication issues and approaches to aggregated data.

*Metrological support of digital models.*

The technology of virtual measurements or simulations of measuring devices should be considered as the measuring instruments, and appropriate metrological maintenance must be applied to them. Thus, in the future, traceable calibration (verification) for virtual measurements and calculation of measurement uncertainties in modelling have to be provided in the structure of the hierarchy scheme of the traceability chain

Promising programmes that will allow the creation of digital models of distributed measuring instruments and objects of control and the calculation of controlled parameters for them and the parameters for the reliability of objects, as well as the digital models themselves, have a number of limitations, including the following factors: appropriateness and completeness of the physical models used; applicability of the mathematical methods used; the accuracy of the parameters of the simulated objects and the boundary conditions of their application.

In the context of a broad introduction of digital models, it is necessary, for the purposes of prediction of the future behaviour and decision-making in relation to potentially dangerous objects, to take measures for the prevention of their uncontrolled and improper use. This will require the creation of an organizational and legal system and engineering infrastructure for the determination of the completeness and adequacy of digital models (verification), the establishment of restrictions on their applicability (validation), and the control over the correct application of digital models in real-life conditions.

*From non-destructive testing to condition monitoring.*

It is necessary to note the trend of transition from classical non-destructive testing, localized in terms of time and space, to condition monitoring. The essence of this process is the creation of automated information/measurement systems which can operate in a continuous mode without direct human intervention, analyzing the measurement information on the basis of digital models of controlled objects and measuring instruments and ultimately developing management recommendations and solutions based on the processing of the data. This definition implies the following tasks:

- development and production of self-calibrating measuring transducers with an extended service life;
- creation of the equipment for automated non-destructive inspection, connected to telecommunication networks with the use of standardized protocols through a universal hardware and software platform;
- development of digital models of objects of non-destructive testing, including models of defects to be determined by non-destructive testing methods;
- development of digital models of measuring instruments in the field of non-destructive testing;
- development of algorithms for the automatic processing of measurement information based on digital models of objects and non-destructive testing for immediate decision-making.

*Metrological support of non-destructive testing devices as the means of measurement of multivariable (multidimensional) quantities.*

Most measurement techniques for non-destructive control are multidimensional and multivariable. For example, in the widespread eddy current method of measuring the thickness of coatings, the readings of the device depend not only on the geometric dimensions of the coating, but also on the properties of the coating materials and the base (substrate): electrical conductivity, magnetic permeability, density, etc. [11]. A large number of factors have an impact upon the results of mechanical stress measurements: the geometry of the controlled object and its location in space (multidimensionality), its electrical, magnetic, and mechanical properties (multiparameter nature).

Measurements in automated mode require automatic adaptation of the sensors to changes in the properties of the controlled object. This problem is solved by the development of multiparameter sensors which make it possible to take into account the main factors which affect the measurement result.

**Conclusion**

The 4th industrial revolution is not some abstract future but a practical process which is taking place right now, affecting all spheres of human life. We can enjoy its fruits, and, at the same time, we must take part in it in the most effective manner. The commercial success of instrument-making companies and the demand for the services of metrological organizations directly depend on how their work meets the new requirements.

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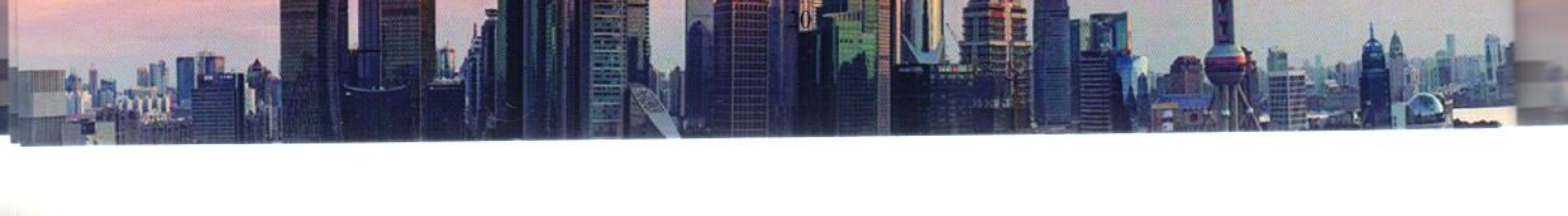

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## 3. Acoustic microscopy application for observing structural changes resulted from joint climatic and mechanical loading

声学显微镜在观察结构变化中的应用

-面向复合材料 iNDT&E 的应用基础（编者注）

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**Abstract:** Airframes are continuously exposed to effect of environmental and operational conditions, some of which are potentially harmful, including extreme weather events, maintenance errors or other accidents. Many of external factors result in structure bearing capacity reduction that follows in unexpected changes in material structure. In view of rapid growth of polymer composites application in aircraft industry the thorough multiscale study of external factors and their combinations effect on PCMs functionality and