Digital technologies in non-destructive testing

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Abstract. This paper considers the problems of development and application of digital technologies in non-destructive testing (NDT). Conducting NDT is represented as some generalized information process. A specific object is represented in the form of digital stages: obtaining accessible, reliable and sufficient information about the properties and state of the object of testing, processing the received primary information, analyzing the processed information, making decisions about further actions with the testing object. In the paper at the system level, the formalization of an urgent and important scientific problem is proposed - the problems of developing digital technology (technologies) for each of the stages of the NDT information process. It is shown that a systematic approach to resolving a problem allows one to formulate a morphological, functional and informational description of the problem, as well as to find hypotheses for solving the problem by carrying out a sequence of operations that solve the problem. A universal structural scheme has been developed for solving scientific problems in the development of digital technologies at the stages of the NDT information process. An example of the practical application of the above approach for one of the NDT methods - functional vibro-acoustic diagnosis of objects is given.

1. Introduction

It is difficult to overestimate the importance and role of digital technologies in solving the problems of improving the quality of modern materials, products and systems, increasing their efficiency and reliability.

The use of digital (computer) technologies in methods and means of non-destructive testing (NDT) allows you to quickly receive, process and analyze information flows about the processes and phenomena occurring in the objects of control.

Digital technologies in NDT allow to take effective and efficient management decisions, both at the level of developing and manufacture of testing objects, and at the level of their operation.

2. Formalization of the process of non-destructive testing

Consider the NDT process as some generalized digital informational process. In this case, the process of NDT of some object can be represented as the following steps (operations):

1. obtaining accessible, reliable and sufficient information about the properties and state of the test object in a digital form;
2. digital processing of information obtained in the first stage;
3. analysis of the information processed at the second stage;
4. making decisions on further actions with the object of control.
Improving the efficiency of NDT for various purposes requires solving an important and relevant scientific problem – the problem of developing digital technology (technologies) for each of the stages of the NDT information process. The problem is the discrepancy (difference) between the necessary (desired) and the real (existing).

The problem $H$ may be represented as a set:

$$H = \{Q, F, V\};$$

where $Q = \{Q_i\}$ – problem resolution goals; $F = \{F_j\}$ – description of the problem; $V = \{V_k\}$ – achievement hypotheses $Q = \{Q_i\}$.

Since the further presentation is based on the so-called "system terminology, we will clarify the meaning of some concepts of systems analysis and systems approach.

Systems analysis is based on traditional research methods: abstraction and concretization, induction and deduction, analysis and synthesis, methods of the theory of operations research and control theory, and the system paradigm. The system paradigm is a set of concepts, principles and methods (techniques) that describe the specifics of the study of an object in a particular subject area as a system. The system paradigm is the result of generalizing the results of practical application of the principles and methods of system research. One of the main tasks of system analysis is the combination of formal (mathematical) and informal (heuristic, verbal, descriptive) analysis methods in the study of complex problems.

The systemic paradigm involves the widespread use of systemic, structural, targeted, situational approaches and qualitative comparative analysis. Creating a systemic paradigm made it possible to formulate the so-called systemic approach, the essence of which is the study of objects from various points of view (often called aspects of the study of objects), comprehensively analyze their behavior, considering the relationships and properties of the objects being studied from system positions.

The system approach is a synthesizing approach that allows not only to study the state of the object, the occurring phenomena and processes, but also to see the prospects for their development, to take into account their interdependence. The constant development of a systems approach is stimulated by the requirements of its applications, the practice of significantly complicating problems that need to be resolved.

Thus, the system paradigm underlies both the systems analysis and the systems approach. However, the ultimate goal of system analysis, in contrast to the systems approach, is to resolve the problem under study.

Resolving the problem, the problem situation of developing digital technology (technologies) for each of the stages of the NDT information process, based on system analysis, involves the development of a logical and procedurally organized sequence of operations (steps) aimed at choosing the preferred alternative (hypothesis) to solve the problem. Thus, system analysis acts as a tool for creating a system that solves the problem. A problem situation is a certain state of affairs, a real set of circumstances that determines the problem under investigation.

Note that at present time there is no unity in system analysis regarding the number of operations and their content. This is primarily due to the properties and level of structuredness of problems to be solved, problem situations and problems (unstructured, ill-structured, well-structured) arising in specific subject areas. This leads to a different number of operations and their content.

Thus, system analysis acts as a tool for creating a system that solves the problem. Figure 1 shows a universal block diagram of a phased resolution of scientific problems, problem situations and problems in the development of digital technologies in NDT.

Problem-solving based on system analysis consists in formulating a morphological, functional, and informational description of a problem, finding a problem-solving hypothesis by conducting a sequence of operations, which fulfillment solves the problem.
As a working hypothesis is proposed to adopt a universal phase resolution problems and problem situations in digital technology in NDT by creating the theory and methods of one and two-dimensional digital signal processing in the Fourier bases with variable parameters [1-15].

Figure 1. The Structural diagram of the resolution of scientific problems of digital technology development in NDT.

NDT systems are fundamentally complex technical systems, equipped with special mathematical and algorithmic software and containing subsystems, functional devices and processor measurement tools that differ both in structure, properties, and the nature of connections and parameters. Analysis of systems of this class is preferable to conduct on the basis of a systematic approach.

Consider an example of the practical application of the above approach for one of the methods of NDT - functional vibro-acoustic object diagnosis. Functional vibroacoustic diagnostics of objects - vibroacoustic diagnostics of objects, carried out in the process of the implementation of objects of their direct functions based on the analysis of the generated information signals.

3. Functional, morphological and informational description of non-destructive testing systems
In the systems approach, it is customary to describe a complex system from three points of view: functional, morphological, and informational. Based on this general methodology and taking into account the fact that according to the theory of complex systems, the levels of system decomposition
(the boundaries of systems of different levels) should coincide with the levels of the hierarchy, let us present the hierarchical functional morphologically-information model of the system of vibro-acoustic functional diagnostics of objects in the following descriptions.

1. Functional description $S_\Phi$ of the system of vibro-acoustic functional diagnostics of objects – a triplet of finite sets reflecting the functions $\Phi$, transformation operators $R$ and system hierarchy $G$ of the system:

$$S_\Phi = \{\Phi, R, G\}$$  \hspace{1cm} (2)

2. Morphological and informational description $S_{M,E}$ of the system of vibro-acoustic functional diagnostics of objects - five finite sets reflecting elements $M$ (subsystems into which the morphological and informational description does not apply), their properties, connections $V$, structures $E$, composition $K$ and organization of the system $I$ of vibro-acoustic functional diagnostics of objects:

$$S_{M,E} = \{M, V, E, K, I\}.$$  \hspace{1cm} (3)

On the basis of the above descriptions, the authors have created a hierarchical functional morphological-information model of a vibro-acoustic functional diagnostics system for objects, which is implemented in manufacturing.

Figure 2 shows a generalized functional-structural diagram of the system of vibro-acoustic functional diagnostics of objects.

In the generalized functional-structural scheme of the system of vibro-acoustic functional diagnostics of objects, the following notation is used:
Supersystems.

A - Supersystem of vibro-acoustic functional diagnostics of objects;
B - Supersystem for processing vibro-acoustic signals;
C - Supersystem pattern recognition.

Subsystems of the above supersystems.

1 - Subsystem of control of the testing object (may be absent); 2 - the testing object; 3 - subsystem of primary vibration sensors and input circuits; 4 - subsystem of processor measuring instruments for evaluating parameters of the vibro-acoustic signal; 5 - diagnostic model; 6 - subsystem of the formation of a dictionary of diagnostic model; 7 - subsystem of pattern classification; 8 - the subsystem of decision making and diagnosis; 9 - a subsystem of forming the alphabet of classes (diagnoses).

L - solutions, J - control information.

We will give a brief functional description of each of the subsystems of the supersystem A.

The subsystem of primary vibration sensors and input circuits 3 includes primary converters of vibro-acoustic signals into their electrical equivalents, matching devices, normalizing converters, switches and other converters of primary information.

The subsystem of a processor measuring instrument for measuring a vibroacoustic signal 4 measures various parameters and functional characteristics (including spectral and temporal) of a vibroacoustic signal based on selected methods and algorithms.

The subsystem of the formation of a dictionary of diagnostic features 6 forms a dictionary of diagnostic features based on measured parameters and functional characteristics of the vibroacoustic signal, taking into account the diagnostic model of the object.

We make one important remark. In works on the theory of pattern recognition (supersystem C), the problem of recognition is identified with the construction in one sense or another of the optimal recognition algorithms, with the study of the conditions that make it possible to construct such algorithms. In this case, the default is assumed to be autonomy of pattern recognition systems, which, naturally, is not legitimate in applied tasks. For the first time in the pattern recognition theory was formulated an unconventional problem statement of object recognition by the authors of the work, which takes into account the fact that the pattern recognition system is not in general an autonomous system. The authors also showed that progress in the development and application of pattern recognition systems as a part of super-systems is associated primarily with a systems approach to the problem of recognition, the development of its system aspects.

The alphabet formation subsystem - 9 is intended to form the alphabet of classes. In the case when the concept of a class coincides with the concept of diagnosis (for example, in differential diagnosis), then we talk about the formation of the alphabet of diagnoses.

The morphological and informational description of the system gives an idea of its structure and organization. The morphological and informational description, as well as the functional description, is hierarchical, with the hierarchy levels in the descriptions coinciding (Figure 2). The supersystem A is mixed in its elemental composition and contains both homogeneous elements (of the same type in terms of the proximity of their basic properties) and heterogeneous (of different types) elements. An important feature of morphology is the properties of the elements, which, for the supersystem B, are mainly informational, since they are intended for receiving, transmitting and transforming information.

The morphological properties of the system essentially depend on the purpose of the connections and the nature of the connections (direct and inverse). For a supersystem, B is basically also informational links (Figure 1). In this case, feedback is mainly a control function. For targeted systems, such as supersystem A, the presence of these connections is mandatory.

The structure of supersystem A is hierarchical, deterministic, adaptive. Compositional properties are determined by combining elements into subsystems. The composition of supersystem A is determined mainly by receptor subsystems (are capable to transform external influences into information signals, for example, subsystem 3) and reflexive subsystems (are capable to transform
processes at the information level). The informational description should give an idea of the organization of the supersystem under study.

A peculiar moment of the systems approach is the introduction of the so-called “control information” - J, which is understood as the set of control information signals transmitted from one super-system (subsystem) to another, with the aim of changing their behavior and development.

4. Conclusion
The adoption of digital (computer) technologies in methods and means of non-destructive testing as one of the most important areas of scientific research is not only relevant, but also a timely step, because digital technologies in NDT make it possible to take effective management decisions, both at the level of development and production objects of testing, and at the level of their operation.

An analysis of the current state of the problem of developing and adoption digital technologies has revealed a tendency of formal transfer of methods and algorithms for processing signals from one area to another, without taking into account the specifics of information signals in a particular subject area. As a result - a decrease in performance and effectiveness.

To solve this problem, it is necessary (on the basis of system analysis) to further develop the theory of digital signal processing, carrying a set of studies on the development and implementation of methods, signal analysis algorithms, focused on the use of non-destructive testing and with extensive functionality.

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