Theoretical principles for the diagnostic support development for transport and technological machines

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Abstract Three theoretical principles of developing the diagnostic support for technical objects of diagnosis are formulated, namely: the principle of dominance - knowledge about the set of possible defects of the diagnosis object is dominated by all other types of diagnostic knowledge; the principle of five systemic representations of the diagnostic object - in the problem of finding defects with maximum depth, in the general case, knowledge of the external, degradation, and structural representations of the diagnostic object is necessary; compliance principle - the operational reliability of the diagnostic object is to be supported by an effective maintenance system corresponding to it. The main goal of the work is to establish the interdependence between these principles. In addition, the listed principles are analysed in relation to the main diagnostic tasks and various classes of technical objects of diagnosis, and are also recommended for use in the development of diagnostic support for technical systems, including the development and maintenance of the diagnostic expert systems.

1. Introduction
The theoretical diagnostics according to the used mathematical apparatus is usually divided into several practically unrelated directions (diagnostics of analog and discrete objects, statistical and functional diagnostics, non-destructive testing, etc.). Therefore, the urgent problem of identifying the basic provisions facilitating the integration of known diagnostic areas into a single theory is of importance.

At the same time, the history of technology development suggests that, despite the increasing complexity of objects and the lack of a unified theory, the practice of searching for defects in complex systems, including transport, technological machines and complexes, remains quite successful. The basis of such success is the knowledge of the individual characteristics of the diagnostic object (DO) and the conditions of its operation. Such knowledge is mostly informal, and the practitioners do not acquire it from the print sources, but accumulate it in a long process of professional activity.

There is a well-known generally accepted the way of preserving and accumulating professional formal and informal knowledge - these are expert systems. In the field of diagnostic expert systems, the problem of identifying and analyzing the basic diagnostic provisions contributing to a significant improvement in the consumer properties of such systems is doubly relevant.

In the monograph [1], in technical diagnostics it is proposed to distinguish three types of fundamental knowledge, namely: knowledge of possible defects, knowledge of possible diagnostic checks, and knowledge of the structural organization of DO.

In this paper, each type of this fundamental knowledge is transformed into a separate theoretical principle, and a study of their interdependence is carried out.
The problem of identifying and analyzing the fundamental principles of technical diagnostics in modern sources is not explicitly posed and analyzed. Nevertheless, an indirect discussion of this problem takes place in the monograph [2]. Here we consider the methodology of analysis and synthesis of diagnostic systems, and the research results are presented in the form of basic system-technical solutions. In the monograph [3], the basic questions of physical fields are studied in the framework of the external representation of the DO and its relationship with the maintenance system.

Considerable attention is paid to the use of the basic knowledge in diagnostic applications. It is differentiated by the diagnostic objects’ classes. The monograph [4] summarizes the results of the scientific and methodological foundations’ research on the formation of the agro-industrial complex machine-tractor fleet objects’ structural blocks during their diagnosis and maintenance.

In article [5], the problem of diagnosing the technical condition of a building and its engineering systems during the life cycle is considered, and general methods and methods for monitoring the operational parameters of a building before repair work are investigated. Possible violations in building structures that need to be eliminated during the overhaul are described.

The monograph [6] describes the general tasks of improving the irrigation systems water supply structures technical condition monitoring based on the residual resource and the practical implementation data of measures to extend the life cycle of structures, ensuring an increasing their operational reliability.

The publication [7] summarizes the results of the scientific research aimed at improving the operational reliability of the gearboxes of excavator-car complexes by introducing into the system of maintenance and repair the subsystem for diagnosing their current technical condition.

2. The diagnostic support development theoretical principles

We formulate three fundamental principles for the diagnostic support development for the complex technical systems.

The first is the principle of dominance, the set of possible defects and its features are the main basis for the synthesis of structural concepts of DO and for the possible checks set elements’ appointment. The second is the principle of five system representations; in the problem of finding defects in the general case, it is necessary to distinguish between the five DO representation systems and apply them in a predetermined order.

The third is the principle of compliance, the maintenance system (MS) is to comply with its technical facility.

Let us analyze these principles for their content and interdependence.

2.1 The principle of dominance

In the majority of publications in the field of technical diagnostics of searching for defects problem, the authors proceed from the “set of specified defects”, the elements of which should be identified [8–9]. In addition, in these works the concept of a defect is an abstract entity - a “defect model”, and this approach in practice requires to additionally have a correspondence between model and real physical defects in the search technology. This is a separate complex problem.

In such a situation, it is proposed that the starting point is not to take a lot of the specified model defects, but a lot of really possible defects. In this case, a number of logically interconnected areas of the research appear in technical diagnostics, namely: a description of the possible defects set elements, a study of relationships on the possible defects set, the distribution of the elements of this set according to the DO structural representations, the correspondence analysis of the maintenance system to this DO and the conditions of its operation. The expected results of these studies are determined by the many possible DO defects. Thus, the first proposed principle technologically has a higher status.

In the general case, a formal description of the possible defects set is presented in the form of the following expression.

\[ D = \{d_1, d_2, \ldots, d_n, \{null\}\} \] (1)
In the expression (1), all the elements except the last one are the defects’ identifiers. There are two interrelated issues here, namely: what does each identifier indicate and what is \( n \) equal to? These problems characterize the spatio-temporal certainty of the set of possible defects [1].

Each \( d_i \) element, being the name of a defect, does not generally fix its spatial certainty. For example, a short circuit to the housing of a specific wire in a specific electrical harness of a transport or technological machine specific instance is possible in various places of the housing. Does this defect have one identifier or several? On the other hand, the number of elements in (1) during the operation of this DO class changes, as a rule, increases – the defects from the possible range go to the real one. Many (1) in this respect are characterized by the property of “openness”. To simulate this property, we will include a special element in its composition - the set \{null\}, representing in (1) all the defects that are still unknown.

The subsection 2.4 of this work describes the interdependence of the principle of dominance with other fundamental principles.

2.2. The principle of the five systemic DO representations
The system properties analysis of transport and technological machines as the diagnosis objects made it possible to identify five of their systemic representations. This external, degradation and three structural representations are hierarchical, functional and constructive.

In the general case, the subjects of diagnostic activity take into account all five systemic representations and apply them in a predetermined order. This order is defined by the following sequence of meaningful operations.

- DO instance identification, based on its external presentation, assessment of its external diagnostic indicators.
- Assessment of DO reliability indicators based on its degradation view in order to optimize the search process.
- Localization of a logical defect up to the limit subsystem or coordination relationship of limit subsystems within the DO hierarchical representation.
- Localization of a logical defect up to a functional block or connecting blocks within the functional representation of the current limit system.
- Localization of a defect in the area bounded by a functional block using the constructive representation of this block.

Sufficiently complete characteristics of structural representations are given in [1], and the degradation and external ones in [10] and [11]. In [1], it is also recommended that the above sequence of actions should be taken as the global algorithm basis the for the diagnostic expert systems’ functioning.

2.3 The compliance principle
The main content of the correspondence principle is that, firstly, the more reliable object, the simpler MS it needs; secondly, the adopted repair technology introduces the significant features into the defect search technology.

Let us analyze the first statement. We associate the segment \([t_1, t_2]\), where \( t_1 \) and \( t_2 \), respectively, the moments of the beginning and end of the operating cycle, some generalized reliability indicator \( P \)

\[
P_T = F(t_1, t_2),
\]

where the index \( T \) denotes the required (necessary) level indicator.

Let the current stage of development of engineering and technology make it possible to provide an object without taking into account MS the value of the \( P_D \) indicator (index \( D \) indicates the actually attainable level of the indicator). Then the difference \( \Delta P = P_T - P_D \) allows to evaluate the interdependence between the reliability of the object and its service station. If \( \Delta P < 0 \), then the possible level of reliability of the object exceeds the required (the object does not need a service station). If \( \Delta P > 0 \), possible reliability of the facility is less than that required and the service station
object is needed. To assess the interdependence between the object and its MS, we propose the following linear criterion

\[ K = \frac{P_T - P_C}{P_T - P_D} = \frac{P_T - P_C}{\Delta P} \]

where \( P_C \) – is reliability indicator of an object at a certain service station \((\Delta P > 0)\). At \( P_C = P_T \) we have \( K = 0 \), which corresponds to full compensation service station \( \Delta P \) and this is an ideal option. The following boundary case holds for \( P_C = P_D \). For this \( K = 1 \) and this criterion value indicates the futility of this MS. From the accessories \( P_C \in [P_D, P_T] \) \( K \in [1, 0] \) follows true and characterizes the appropriate values of the criterion. (MS should be considered as a necessary compensator for the lack of inherent reliability of the object).

The second statement (the adopted repair technology introduces the significant features into the defect search technology) characterizes the relationship between the principle of compliance and the principle of five system representations, and it is analyzed in the next subsection.

2.4. The basic principles’ relationship

The proposed theoretical basic principles for the diagnostic support development are organically interconnected. In the general case, for three elements, six abstract channels of mutual influence can be analyzed. Figure 1 shows an illustration of these channels of mutual influence. Below, each channel is analyzed separately.

2.4.1. The first channel. Many possible defects mainly determine the consumer properties of the DO systemic representations. In other words, the objective content of diagnostic tasks - the real possible defects - should be adequately displayed by subjective diagnostic models (DM): external DM-V, degradation DM-D, hierarchical DM-I, functional DM-F and constructive DM-K. The subject of diagnostic activity in the development of diagnostic models should be based on the current set of possible defects, the expansion or refinement of which should activate the corresponding change in DM.

2.4.2. The second channel. Inverse to the previous (first) one. A complete constructive representation of DO (the entire extremely wide structure of a technical object) can have its own elements in expression (1). Such elements are usually called structural or technological defects. If there is feedback from the operation stage with the production stage, the manufacturer usually eliminates such defects.
2.4.3. The third channel. Many possible defects mainly determine the consumer properties of service stations (Maintenance system). The specific content of the set (1) determines a certain set of technical diagnostic tools necessary for this set elements’ localization. And the actual presence or absence of some elements from the set of necessary technical diagnostic tools, in turn, affects the decision-making on the recovery methods (elimination of a physical defect, repair with typical replacement units, complete replacement of an object, etc.).

2.4.4. The fourth channel. Reverse to the third channel. It is appropriate to consider two cases here - “absolute reliability” and “economic feasibility”. The first subject of operational activity under the conditions of intense moral aging of DO can assign a duration \([t_1, t_2]\) such that the set (1) degenerates \((D = \{\text{null}\})\), and MS is not required. The second - it is associated with redundancy technologies. For example, DO is operated by one entity, and served by another. In case of any failure, the servicing entity replaces the failed DO with another operational one within the established time frame. Moreover, for the subject of the operational activity, set (1) also degenerates into \(D = \{\text{null}\}\).

2.4.5. The fifth channel. The adopted recovery technology (elimination of a physical defect, repair with typical replacement blocks, complete replacement of an object, etc.) determines the set of necessary blocks in structural diagnostic models. If DO is completely redundant, then it is sufficient to use only its external representation to solve the problem of health monitoring as a diagnostic model. Repair by typical replacement blocks determines the set of diagnosed blocks in structural diagnostic models. Different situations are possible.

2.4.6. The sixth channel. Reverse to the fifth channel. The external DO representation allows to assign a set of necessary technological operations during its daily maintenance. Structural models perform this function in relation to other types of technical influences (MS-1, MS-2, RS, etc.). The degradation view is the starting point in organizing a system for monitoring the DO technical state.

Summary
At the bottom of the Figure 1, an image of the subject’s symbol is presented in order to emphasize the following statement - when developing diagnostic support for transport and technological objects, it is necessary to distinguish between the subject of operational activity, the subject of diagnostic activity and the subject of repair activity.
Purposeful accounting of the features of the possible defects set and the relationships on this set will significantly increase the results objectivity of the search for defects. The use of various system representations of the DO guarantees at lower resource costs for the search technology that any given practical depth of the search for any set element of possible defects is guaranteed. An adequate and timely assessment of the resource properties of the diagnostic object and the conditions of its operation reduces the cost of its maintenance system.

The issues discussed in this article are consistent with those tasks that have to be addressed by developing an industry policy in the field of ensuring the reliability of technical systems in this industry [12]. The features of the diagnostic objects of the construction industry and their relationship with the maintenance system are explicitly discussed in [13], and a detailed analysis of the possible defects set is given in [14].

The prospect of diagnostic support development processes theoretical studies involves: 1) formalization and analysis of the principles of dominance, five system representations and the correspondence of the object of its MS; 2) formalization of many possible defects and its diagnostic indicators; 3) formalization and analysis of the possible defects relationships set; 4) formalization and analysis of diagnostic circuits within the framework of structural representations; 5) development of a conceptual diagnostic model; 6) the obtained solutions practical feasibility issues study.

One of the main expected integration results is a conceptual diagnostic model of transport and technological machines. This scheme can be adopted as a universal template for developing the logical structure of the knowledge base of the diagnostic expert systems’ prototypes.

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