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On the Way to the Ontology of Test and Diagnostics Systems for Blading Power Plants

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***Abstract*—The article is an attempt to create ontology of test and diagnostics systems for blading power plants. Ontology is considered as a formal construction that combines understanding of the object model (more adequately - the subject area) from a logical point of view (as interpretation of a formal system that satisfies the axioms), from an algebraic point of view (as a set of objects belonging to certain classes with certain relations), in general scientific terms (as a simplified representation of objects, phenomena and processes of the real world). The prospective use of the model is associated with support for the development of test and diagnostics systems for blading power plants. The support is interpreted as a process of meeting the technical requirements, certain methods implemented by certain means.**

Keywords—test, diagnostics, blading power plant, modeling, ontology, formalism of descriptive logics

I. INTRODUCTION

Modern blading power plants (BPP) are complex technical objects, widely used in various sectors of the national economy, including industry, energy and transport [1]. While their operation, the structural elements and components are inevitably exposed to loads, vibrations, elastic and thermal deformations, undergo aging, lose strength and resource. It is obvious that such situations are especially dangerous when exploiting aviation power plants (for example, aviation gas turbine engines). Their failure at best can lead to an emergency landing of the aircraft, and at worst – to an aviation accident with human victims. Therefore, diagnostics of the BPP technical state is an urgent problem [2-5]. Its solution allows to make well-timed maintenance and eliminate emergencies associated with premature destruction of the power plant before reaching the calculated lifetime resource.

It should be noted that test and diagnostics systems (TDS) of power plants often operate in conditions of incompletely measured information, combined with the high complexity of the processes occurring in the objects [5]. In [6], technologies of knowledge-based systems are noted to be applied to improve the efficiency of assessing the technical state of such complex objects. Such systems allow to consider a significant number of diagnostic features and minimize errors due to subjective factors. It is also noted that one of the important advantages of such intelligent systems practical application is "transparency for domain experts and the system's reasoning process with an explanation of the diagnostics results". And it can be provided by an ontological approach that allows creating "knowledge bases understandable to specialists and forming an explanation of the work process in familiar professional terms". To a greater extent, the use of intelligent technologies is relevant in development of power plants TDS. The process of meeting the established requirements by certain methods implemented by certain means can be understood as in [7].

This article is the first attempt to formally describe the BPP TDS based on the application of ontological approach. A formal and at the same time substantial model of the corresponding subject area is presented.

The formality of the proposed description is provided by the use of the language of descriptive logics (DL) [8]. Being syntactically formed, for example, in the language OWL (which is based on DL), such descriptions can be loaded into the semantic reasoner (a set of corresponding freely available reasoner programs can be found in [9]) and checked for consistency. On the other hand, the proposed description is substantial, since it is quite easily read and interpreted by a person.

II. FORMAL MODEL

The model of BPP TDS is built by knowledge extraction from special texts, including a monograph, articles, textbooks, and state standards. The basic concepts were identified, as well as explicit and implicit relations between them. To describe the TDS model, we consider the formal system:

$$\langle C, R, A\rangle \tag{1}$$

where C is the set of atomic concepts, R is the set of atomic roles describing the properties of concepts and their relations, A is the set of axioms which limit the possible interpretations of concepts and roles. The axioms contain descriptions composed of atomic concepts and role restrictions using the syntactic rules of the descriptive logic SOIN (D) [7, 10].

The C and R sets of the system (1) include the following basic concepts and roles:

C = {BPP_diagnostics_purpose,
BPP_diagnostics_task,
BPP_diagnostics_method,

BPP_diagnostics_completeness,
BPP_indirect_test_parameter,
BPP_direct_test_parameter,
BPP_testability_indicator,
BPP_diagnostics_problem,
BPP_diagnostics_tool,
Hardware_tool,
Measuring_information_conversion_and_processing_tool,
BPP_operation_modeling_tool,
BPP_residual_operation_time_prediction_tool,
BPP_diagnostics_algorithm,
BPP_diagnostics_quality_indicator,
BPP_technical_state_prediction,
BPP_technical_state_test,
BPP_diagnostics_problem,
Measuring_experiment,
Measuring_experiment_operator,
Measuring_experiment_organization_and_planning,
Experimental_data_processing,
BPP_behavior_modeling,
BPP_identification,
BPP_technical_state_comparison_with_norms_requirements,
BPP_of_technical_state,
BPP_technical_state_external_factor,
BPP_diagnostics_result_decision-maker,
BPP_diagnostics_result,
BPP_diagnostics_validation,
TDS_developer,
TDS_developer's_need,
TDS_development_principle,
TDS_development_approach,
TDS_development_method,
TDS_development_technology,
TDS_architecture};

R = {dependsOn, sets, expresses, calculates, influences, needs, basedOn, uses, offers, solves, includes, includes (partOf), provides (partOf), sets (partOf), checks, determines, concretizes, compares, realizes, takes into account, precedes}.

Formal system (1) interpretation I, determining semantics of the system, is given by:

$$I = \langle \Delta, f \rangle,$$

where Δ is the domain, the set of all model instances (individuals), f is the interpretation function:

- $f: C \cup R \rightarrow (2^{\Delta}) \cup (2^{\Delta} \times 2^{\Delta})$;
- $f(C_i) \subseteq \Delta, C_i \in C$ — each set corresponds to the set of its instances;
- $f(R_i) \subseteq \Delta \times \Delta, R_i \in R$ — each role corresponds to binary relation – the set of instance pairs linked by it.

Function f is dilated to interpret constituent concepts in accordance with inductive rules of SOIN(D) logics.

A. *Basic elements of BPP diagnostics*

The main concepts relating to BPP TDS include purposes, methods, tasks, problems, tools, algorithms and validation. These concepts, as well as their relations (Fig. 1), were clarified in [11–13]. Setting diagnostics tasks allows to specify the problems of BPP diagnostics (they are described in [14] in detail) and to realize its purpose. According to [14] the main problems of BPP diagnostics include multidimensional movements of elements, limited measuring space, the need for non-contact measurements, the influence of BPP operation mode, the impact of extreme conditions, and the variety of existing BPP. In turn, diagnostics tools, including hardware for converting and processing measuring

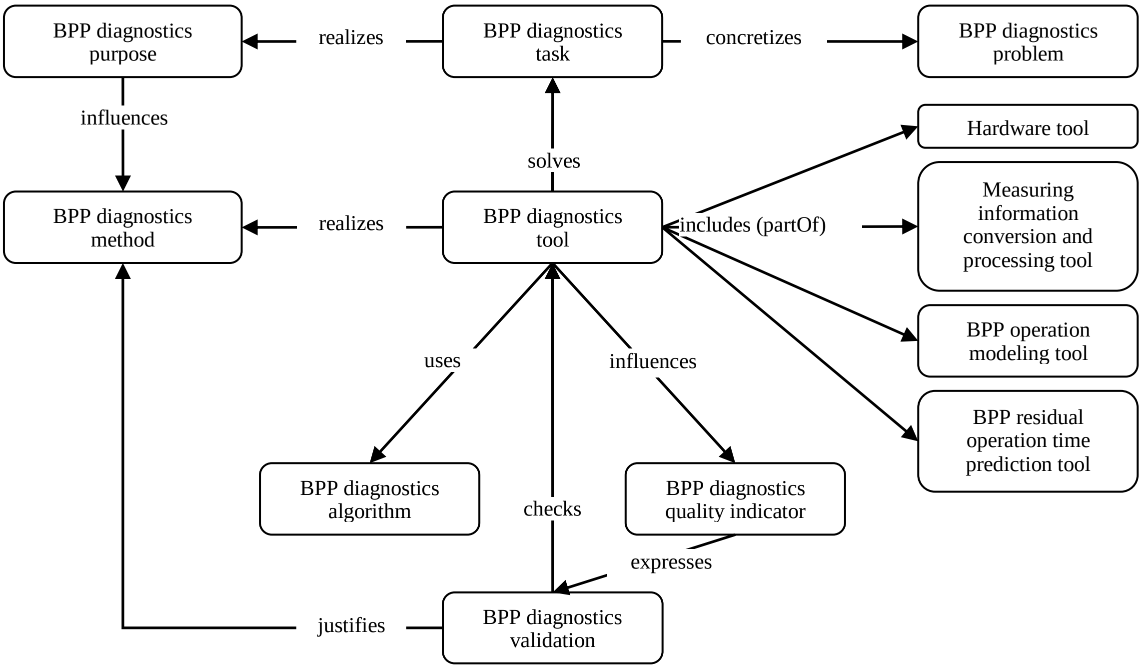

Fig. 1. Basic elements of the model relating to BPP diagnostics

information, operation modeling and prediction of BPP residual operation time, allow solving diagnostics problems. In details one can write:

f(BPP_diagnostics_purpose) = {
BPP_RELIABILITY_INCREASE,
BPP_COST-EFFECTIVENESS_INCREASE},

f(BPP_diagnostics_method) = {
VIBRATIONAL, ULTRASONIC, EDDY-CURRENT,
VISUAL_AND_MEASURING, RADIOGRAPHIC,
CAPILLARY, MAGNETIC, HEAT},

f(BPP_diagnostics_problem) = {
BPP_ELEMENTS_MULTI-
DIMENSIONAL_MOVEMENTS,
LIMITED_MEASUREMENT_SPACE,
NON-CONTACT_MEASUREMENTS,
EXTREMAL_CONDITIONS_INFLUENCE,
BPP_VARIETY}.

B. *BPP technical state test and prediction.*

The tasks of BPP diagnostics are test and prediction of the BPP technical state [11, 12]. BPP technical state testing includes detection of technical state and comparing it with established norms and requirements [15]. Such an analysis together with the modeling of BPP behavior and considering the influence of external factors, allows predicting the BPP technical state. The knowledge obtained from [11–13, 16–18] made it possible to supplement the discovered relations between basic concepts, as well as to correct and confirm hypotheses regarding the relations of the model concepts (Fig. 2):

f(BPP_technical_state_test) ={
BPP_TEST_PARAMETERS_MEASUREMENT,
BPP_DIAGNOSTICS_
PARAMETERS_EVALUATION,
BPP_TECHNICAL_STATE_DETECTION,
BPP_TECHNICAL_STATE_
TEST MANAGEMENT},

f(BPP_operation_modeling) = {
SIMULATION_MODELING,
PHYSICAL_MODELING},

f(BPP_technical_state = {
OPERABILITY, CONDITIONAL_OPERABILITY,
FAILURE_1, FAILURE_2, ..., FAILURE_N,
NECESSITY_OF_CONFIGURATION
REQUIREMENT_OF_RESERVATION,
FULL_INOPERABILITY}.

The knowledge on methods and tools that ensure test of technical state of various classes of BPP in severe and extreme conditions was obtained from [14]. The identification of the model as a whole and parameters in particular were clarified to be the basis for BPP behavior modeling and to clarify direct test parameters — coordinate multidimensional movements and their factor components.

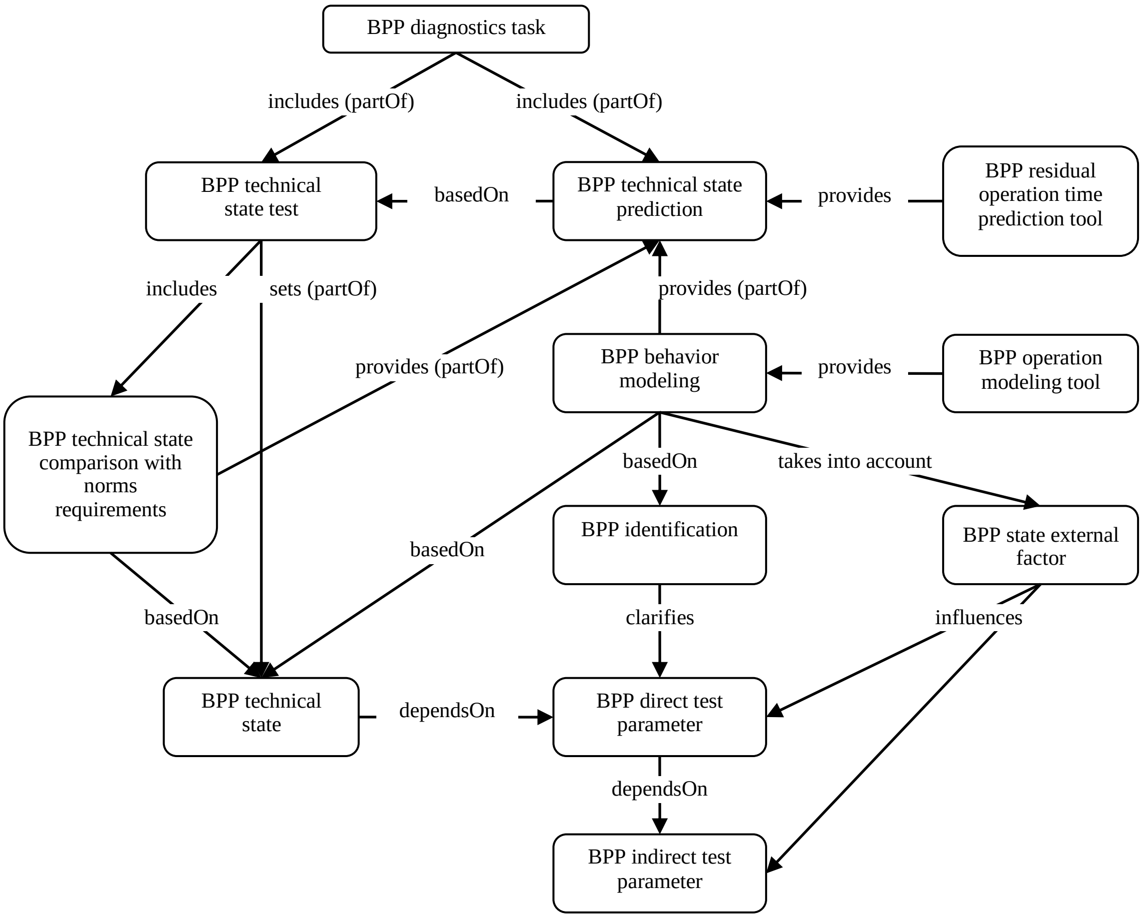

Fig. 2. Basic elements of the model relating to BPP technical state test and prediction

The values of direct test parameters depend on the distinguished indirect ones — the acting power loads, the rotational speed of structural elements, the lubricant state in friction units, the presence of metal particles in the lubricant. External factors of the BPP technical state — BPP operation mode, the operation time, load, vibration, thermal deformation, friction — affect both direct and indirect test parameters of the object. Like so:

f(BPP_operation_modeling_tool) = {
SOFTWARE_TOOLS,
TECHNICAL_TOOLS},*f*(BPP_test_direct_parameter) = {
COORDINATE_MULTIDIMENSIONAL_
MOVEMENTS,
FACTOR_COMPONENT_OF_
MULTIDIMENSIONAL_MOVEMENTS},

f(BPP_technical_state_external_factor) = {
BPP_FUNCTION_ MODE,
BPP_OPERATION_TIME,
LOAD, VIBRATION, HEAT_DEFORMATION,
FRICTION},

f(Object_identification) = {
OBSERVATION_ AND_MEASUREMENT,
STATISTICAL_INFORMATION_COLLECTION_
AND_PROCESSING},

f(BPP_indirect_test_parameter) = {
ACTING_POWER_LOADS,
SPEED_OF_ELEMENTS_ROTATION,
LUBRICANT_STATE_IN_FRICTION_UNITS,
METAL_PARTICLES_PRESENCE_
IN_LUBRICANT}.

C. Measuring experiment

In [15], the concept of measuring experiment is detailed (Fig. 3). It is carried out by an operator with regard to external factors affecting the BPP technical state. The measuring experiment is preceded by a stage of its organization and planning. Experimental data processing allows establishing the sought BPP indirect test parameters after the measuring experiment. Accordingly:

f(Measuring_experiment) = {
MEASURING_ TRANSFORMATIONS,
INDIRECT_PARAMETERS_REPRESENTATION,
VALUES_COMPARISON},

f(Measuring_experiment_organization_and
planning) = {
OBJECT_MODEL_FORMATION
BPP_INDIRECT_TEST_PARAMETERS_
DETERMINATION,
DETECTION _OF_BPP_TECHNICAL_STATE_
EXTERNAL_FACTORS,
MEASURING_TASK_SETTING,
MEASURING_EQUATION_FORMATION,
MESURING_METHODS_CHOICE,
PRIORITY_EVALUATION_
OF_MEASURING_ERROR,
MEASURING_TOOLS_CHOICE,
MEASURING_PARAMETERS_CHOICE,
REQUIRED_CONDITIONS_PROVISION},

f(Experimentl_data_processing) = {
PRELIMINARY_DATA_ANALYSIS_ AND_
PROCESSING,
INTRODUCING_MEASURING_BIAS_
CORRECTION,
DATA_PROCESSING_MATHEMATICAL_
PROBLEM_SETTING,
DATA_PROCESSING_ALGORITHM_

CONSTRUCTION_AND_APPLICATION},*f*{Hardware
_tool} = {
MEASURING_ DEVICE,
MEASURING_CONVERTER, COMPUTER},

f(Measuring_experiment) = {
MEASURING_ TRANSFORMATIONS,
INDIRECT_PARAMETERS_REPRESENTATION,
VALUES_COMPARISON},

f(Measuring_experiment_organization_and_
planning) = {
OBJECT_MODEL_FORMATION,

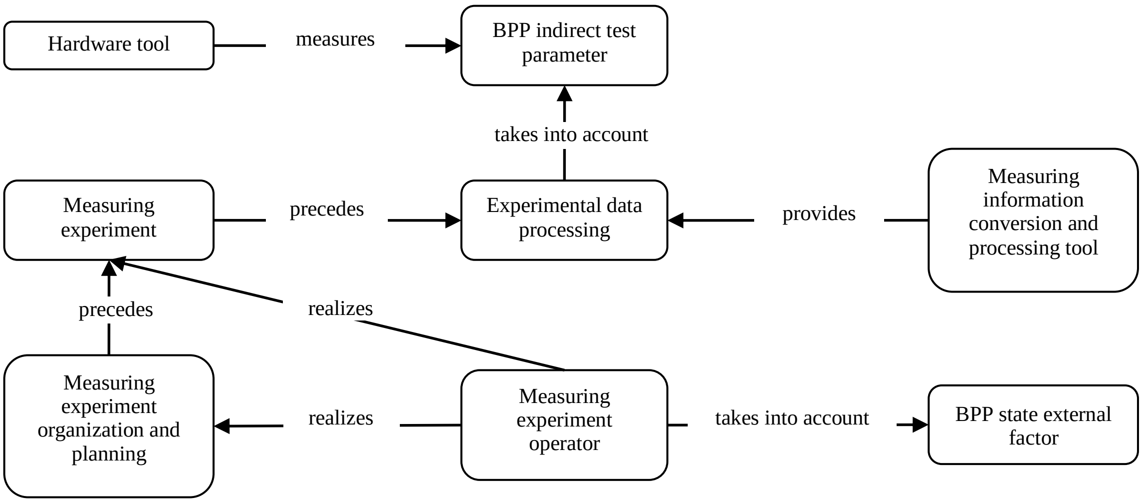

Fig. 3. Basic elements of the model relating to the measuring experiment

BPP_INDIRECT_TEST_PARAMETERS_DETERMINATION,
DETECTION _OF_BPP_TECHNICAL_STATE_EXTERNAL_FACTORS,
MEASURING_TASK_SETTING,
MEASURING_EQUATION_FORMATION,
MESURING_METHODS_CHOICE,
PRIORITY_EVALUATION_OF_MEASURING_ERROR,
MEASURING_TOOLS_CHOICE,
MEASURING_PARAMETERS_CHOICE,
REQUIRED_CONDITIONS_PROVISION},

f(Experimental_data_processing) = {
PRELIMINARY_DATA_ANALYSIS_AND_PROCESSING,
INTRODUCING_MEASURING_BIAS_CORRECTION,
DATA_PROCESSING_MATHEMATICAL_PROBLEM_SETTING,
DATA_PROCESSING_ALGORITHM_CONSTRUCTION_AND_APPLICATION}.

D. Diagnostics result validation

In [11], much attention was paid to the subsystem of BPP diagnostics results evaluation (Fig. 4). The introduction and calculation of quality indicators of BPP diagnostics are necessary to validate experts' decisions. The decision-maker on the results of BPP diagnostics matches the BPP technical state, its technical state prediction, the external factors, quality indicators of the BPP diagnostics, and gives the final diagnostics result: to write off, to introduce the reservation, to replace, to setup or continue operation without changes. So:

f(BPP_diagnostics_result) = {
WRITING_OFF, RESERVATION,
REPLACEMENT, SETUP, OPERATION},

f(BPP_diagnostics_decision-maker) = {
EXPERT_1, EXPERT_2, ..., EXPERT_N},

f(BPP_diagnostics_quality_indicator) = {
EFFICIENCY, RELIABILITY, ACCURACY},

III. TDS DEVELOPMENT LEVEL

In the system (1) presented, one can distinguish the level of concepts related directly to the TDS development: the TDS developer, his need, the development principle, approach, method, technology, and architecture. At this level (Fig. 5), the concepts and roles are partially integrated from the complex development of intellectual computer-aided decision-support systems in [7]. Domain experts, knowledge engineers, and programmers participate in the TDS development. The TDS developer sets the purpose of creating a system. This determines the BPP diagnostics methods. The developer also calculates the achievable completeness of BPP diagnostics of the indirect test parameters with available methods. The BPP diagnostics completeness is expressed in terms of testability indicators. Formally, we get:

f(TDS_developer) = {
KNOWLEDGE_ENGINEER, DOMAIN_EXPERT,
PROGRAMMER},

f(TDS_developer's_need) = {
CONCEPTUAL SUPPORT,
INFORMATION SUPPORT,
COMPONENT SUPPORT,
METHODICAL SUPPORT},

f(TDS_development_principle) = {
MAXIMUM_USE_OF_READY_SOLUTIONS,
SCALABILITY, ACCESSIBILITY, OPENNESS,
SIMPLICITY_OF_USE,
INDEPENDENCE_FROM_SOFTWARE,
INFORMATIVENESS},

f(TDS_development_approach) = {
ONTOLOGICAL_APPROACH,
SERVICE-ORIENTED_APPROACH,
QUICK_PROTOTYPING APPROACH,
AGILE_DEVELOPMENT_APPROACH,
FRAMED_APPROACH},

f(TDS_development_method) = {
ONTOLOGICAL_MODELING,
REASONING_BASED_ON_PRECEDENTS,
REASONING_BASED_ON_RULES,

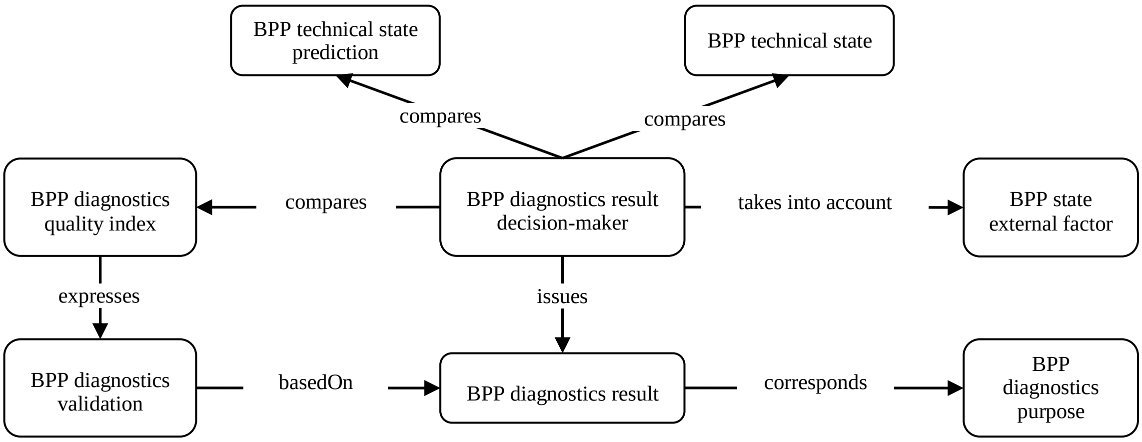

Fig. 4. Basic elements of the model relating to the diagnostics result validation

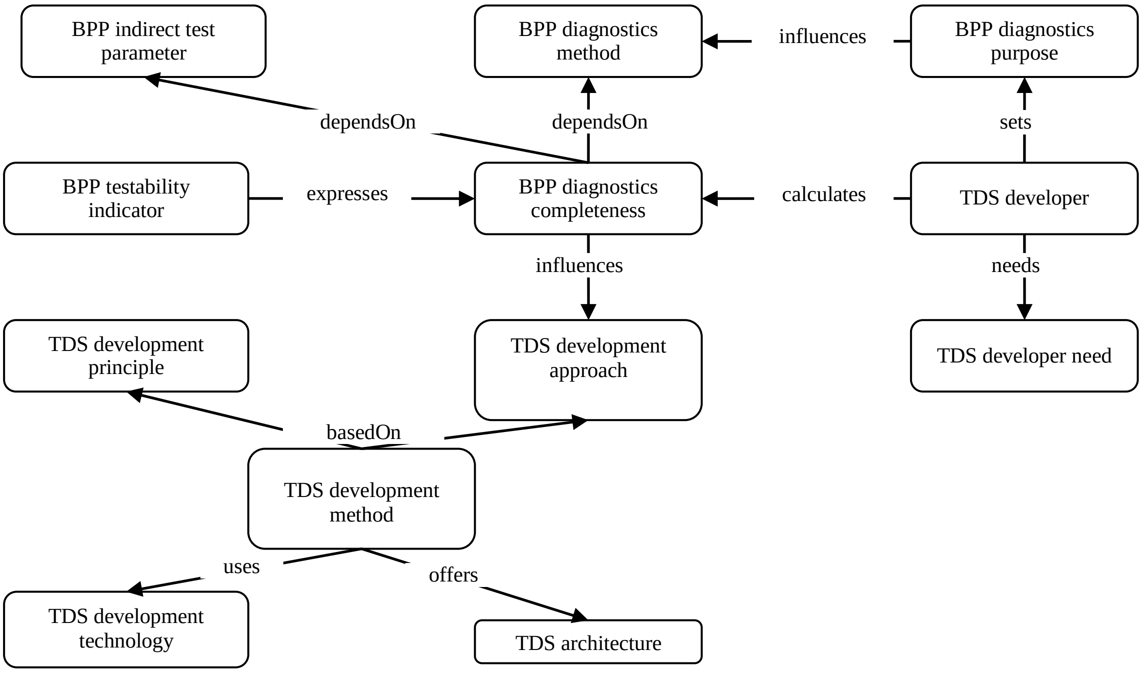

Fig. 5. Basic elements of the model relating to the level of TDS development

PROBABILITY_MODELING,
UNCERTAIN_COMPUTATION_METHOD,
COGNITIVE_MODELING, EVENT_MODELING,
EXPERT_EVALUATION, SURVEY},

f(TDS_development_technology) = {
SEMANTIC_WEB_TECHNOLOGY,
REAL-TIME_SYSTEMS_TECHNOLOGY},

f(TDS_architecture) = {
SUBSYSTEM_OF_DATA_COLLECTION_AND_PROCESSING,
SUBSYSTEM_OF_DETERIORATION_PROCESS_MODELING,
SUBSYSTEM_OF_RESIDUAL_OPERATION_TIME_PREDICTION},

f(BPP_testability_indicator) = {
COEFFICIENT_OF_TEST_COMPLETENESS,
COEFFICIENT_OF_TEST_DEPTH,
AVERAGE_TIME_OF_BPP_TEST_PREPARATION,
AVERAGE_LABOUR_COST_OF_BPP_TEST_PREPARATION,
BPP_REDUNDANCY_COEFFICIENT,
COEFFICIENT_OF_SPECIAL_MEANS_OF_ APPLICATION_OF_BPP_TEST,
LABOUR_COST_ COEFFICIENT_OF_BPP_TEST_PREPARATION}/

Axioms defining the properties of the concepts of TDS model are:

BPP_diagnostics_task ⊇
BPP_technical_state_prediction ∪
BPP_technical_state_test,

BPP_technical_state_prediction ⊇
BPP_behavior_modeling ∪
BPP_technical_state_comparison_with_norms_requirements,

BPP_diagnostics_tool ⊇
Hardware_tool ∪
Measuring_information_conversion_and_processing_tool ∪
BPP_operation_modeling_tool ∪
BPP_residual_operation_time_prediction_tool.

IV. CONCLUSION

- When constructing the BPP TDS model, the basic concepts relating to test and prediction of the BPP technical state, methods and tools for testing technical state of various classes of BPP, the organization and planning of the measuring experiment, the results and indicators of the BPP diagnostics quality, as well as the concepts related directly to the TDS development were detected.
- The presented model can become the basis for the development of new methods and tools, ensuring creation of TDS for different classes of power plants, but having common principles and ideology. This is currently an urgent problem, the solution of which is important to support the TDS development for power plants.

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