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CONCEPT OF AN EXPERT DIAGNOSTIC SYSTEM OF THE TURBINE ENGINE'S FLOW PATH ELEMENTS

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Abstract

The article presents a concept of an expert diagnostic system of the turbine engine's flow path (compressor – combustion chamber – turbine) elements. The system adopts diagnostic signals obtained with the use of non-destructive methods implemented on the non-operating engine. The aim is to detect and assess early stages of damage to selected elements of the engine. The achievement of a reliable diagnosis on the condition of the elements requires the application of a set of diagnostic methods and carrying out the inference, including knowledge about the degradation processes of elements and correlation of the diagnostic (signals) tests results obtained with various methods. A convenient tool, which supports solution of such a set problem is an expert system, which on the one hand, makes it possible to organise the existing formal knowledge, and on the other hand – to use non-formal, or even uncertain, knowledge. The presented concept of the expert diagnostic system is based on PC-Shell system of AITECH Polish Company.

Keywords: *engine, diagnostics, expert system, knowledge base*

1. Introduction

During the aircraft operation, the engine construction damage constitutes the most common technical causes of aviation accidents. The provision of a high level of flying reliability and safety requires efficient and objective determination of the damage causes. Such tests are carried out with the use of technical methods and measures, and also special methodologies, which make it possible to obtain the maximum amount of objective information on the tested element, component or the entire engine [3-5, 9-12, 15].

The expert diagnostic system constitutes an effective tool for supporting the tests of damage causes [15, 25, 27, 28, 33, 34].

The expert diagnostic system is a computer system dedicated to solving the problems related to the technical condition assessment, identification and location of damage of the examined objects with the use of artificial intelligence and mathematical logic methods [13, 17, 18, 20]. The main part of the expert system is a knowledge base. Knowledge is saved with the use of a specialised language, which consists of, among others, a description of facts and a set of rules used in the inferencing process [25].

A convenient tool for creation of the expert systems is a shell system, e.g. PC-Shell by AITech, a Polish company [24]. It is an independent, in terms of fields, expert shell system with hybrid properties. Owing to the use of a blackboard system, the knowledge base can be divided into any number of heterogeneous knowledge sources, which are relatively independently developed.

The system's knowledge base is saved with the use of Sphinx language that combines a declarative language of the knowledge representation and a structural programming language.

The use of the shell system allows accelerating works on the construction of expert diagnostic systems because it is limited to the acquisition of data and knowledge bases of a specific field [17-19].

2. Diagnosed objects

The test objects include the engine's flow path elements – compressor blades, a combustion chamber, and turbine blades. The diagnostic tests are aimed at determination of the tested object's technical condition.

A factor, which affects operating parameters, includes extremely variable operating conditions of individual elements and components. The operational reliability and durability degradation depends on many factors, but the basic one is a material criterion [10, 11, 29-31].

In the operation process of aircraft turbine engines, there are different types of damage. The most frequent cases of damage include the material overheating [6-8], as well as [21, 22, 26, 32] erosion and thermal fatigue of blades, the nozzle system and the rotor [2, 6, 7].

The condition for designing the expert diagnostic system includes identification of knowledge sources on operational degradation of the turbine engine's flow path elements and diagnosis methods [16]. The results of long-term scientific and research articles carried out in Air Force Institute of Technology [1] constitutes expertise, which can be implemented in the designed diagnostic system after the appropriate formalisation. A module for bibliographic support, which uses bibliographic bases, e.g. Scopus [16], constitutes an additional knowledge source.

3. Diagnosis methods

The technical condition test of the flow path elements requires the use of a set of methods providing information on the condition of the micro- and macrostructure – the so-called non-destructive testing methods [3-5, 9-12].

The non-destructive tests allow detecting different types of surface and subsurface defects of elements, e.g. cracking, corrosion, precipitation, non-uniformity of the structure, etc. The stress measurements, thickness of the applied layer, and hardness evaluation are also important.

Among the non-destructive testing methods, in order to assess the state of the turbine engines' elements, the visual methods were the most widely used. The visual test results usually allow for (condition) the use of other methods in order to determine the causes of the observed irregularities of the technical condition.

The direct visual test methods allow for testing the surface with the use of a naked eye or with the use of magnifying glasses and microscopes. However, the indirect visual methods allow for testing the surface of hard-to-reach elements with the use of optoelectronic devices. These tests are carried out with the use of periscopes, endoscopes, videoscopes, and also video analysers. Their scope of operation is primarily dependent on the engine diagnostic susceptibility. The turbine engines are equipped with sight glasses, which allow for CCD camera access, e.g. videoscope to the elements of the compressor, combustion chamber, turbine, and even to the inside of the equipment of fuel and oil systems. It is possible successfully to carry out the inspection and record of the surface condition, the condition of the fuselage welds, as well as mutual position of some elements.

On the basis of the non-destructive testing results, it is possible to obtain the information on the objects' defects, owing to the possibility of dimensioning and determination of the nature of the defect and its visualisation. It is possible thanks to archiving and computer processing of the test results, which are obtained with the use of some non-destructive testing methods and digital flaw detectors and automated test systems.

The individual non-destructive testing methods generally do not compete with each other. Some of them can be used in the control of the same class of objects, providing an alternative or mutual complement. In case of jet turbine engines, in order to increase the probability of detecting a defect, the tests with the use of more than one method are conducted, that is, the complex tests are then carried out. It makes it possible to increase the probability of detecting a defect and confirmation of the occurrence of discontinuities, detected with one method by using another one.

Therefore, the use of a computed tomography method is stipulated. It is a type of x-ray tomography that allows obtaining spatial images (3D) from the x-ray of the tested object taken from different directions. With the use of the CT scanner and the implemented computer programme, the object's tomogram is obtained.

The choice of a method for specific tests depends mainly on a research task as well as advantages and limitations of the non-destructive testing methods. In summary, it can be concluded that:

– there is no universal method of non-destructive tests, both in relation to the types of objects, materials, and the types of discontinuities, as well as to the possibilities of determining the dimensions and assessment of the nature of discontinuities that should be detected,
– there are no ideal test methods – in order to obtain great detection of discontinuities, it is best to carry out the tests with the use of several methods.

The diagnostic inference is usually conducted with great participation of a man- diagnostician. The reliability of the condition assessment depends on many factors, i.e. diagnostician's training and experience, the applied diagnosis methodology, the condition of diagnostic tools, the experiment conditions and others.

4. Comprehensive diagnosis premises

The diagnosis methods can exist on its own, independently of each other. Each of them is, by definition, specialised for specific purposes. As a result of the carried out analyses, a possibility of information flow between various diagnosis methods – connection of these methods into their information entirety, and also the necessity to increase the power of a set of methods, which as a result, provides new diagnostic quality – a comprehensive diagnostic system, were observed [14, 23].

The comprehensive diagnostic system's components include:

– a diagnosed technical object,
– methods and measures of obtaining diagnostic information,
– methods and measures of processing diagnostic information,
– a diagnostician.

The synthesis of the comprehensive diagnostic system requires the development of models of the diagnosed object and its components (modules), technical models of the diagnostic measures and processing models of diagnostic information obtained with the use of different methods. The models should include various levels of the representation detail (e.g. engine – rotor – blade) and the applied diagnostic methods.

For the diagnosed technical object, a set of S states, which should be identified in the diagnosing process [14], is determined:

$$S = \{s_i\}; i = 1, 2, ..., n \,. \tag{1}$$

In the set of S states, one state of usability and $n-1$ states of unfitness and/or incomplete usability are generally distinguished. The S set is determined on the basis of an analysis of the reliability and operational characteristics of the diagnosed object.

The object's state is specified as a result of the diagnosing process, which involves the implementation of a set of checks in a fixed order, and the analysis of the obtained results. Any method of diagnosis can be presented in the form of ordered three:

$$M_j = \langle D_j, R_j, \Psi_j \rangle, \tag{2}$$

where:

M_j – j method of diagnosis,

D_j – a set of permitted checks of j method,

R_j – a set of results of j method checks,

Ψ_j – relationship of representation of the sets of checks in a set of states of j method:

$$\Psi_j : D_j \times R_j \to S. \tag{3}$$

The performance of permitted checks of j method of diagnosis usually does not allow for identification of the object's state with the required accuracy, by the described relationship (1).

The identification accuracy of the state, which is possible to be obtained with the use of M_j method, is described by the following relationship:

$$\bigcup S_k^j \subseteq S, \tag{4}$$

where: $\bigcup S_k^j$ – a family of subsets of a set of S states; S_k^j k subset of a set of S states, generated by M_j method, where:

$$S_k^j = \{s_i\}; i = 1, 2, ..., n_k. \tag{5}$$

It follows that, in order to determine the object's state with the required accuracy, it is necessary to use a set of diagnostic methods (6) and to apply processing algorithms and fusion of information obtained from the whole set of methods.

$$M = \{M_j\}. \tag{6}$$

The complexity and multiplicity of diagnosis methods and diagnostic inference algorithms indicate the necessity and desirability of using the expert diagnostic system.

6. The concept of the expert diagnostic system (ESD-TPST)

The concept of the expert diagnostic system of the turbine engine's flow path elements (ESD-TPST) was based on PC-Shell expert shell system [24].

The design assumptions are as follows:

- the possibility of detection and identification of a determined set of damage,
- determination of a degree of damage,
- the possibility of incremental construction of the knowledge base,
- explicit knowledge representation in the form understandable for the end user.

In order to make a decision on the state of elements, the system uses data provided from the outside. The diagnosis is carried out on the basis of the knowledge base and the results of the current diagnostic tests. In case of non-destructive tests, these are the images of elements obtained with the use of optical and computed tomography methods.

Database

The database stores specific, detailed information, saved in an orderly manner. The type of data is usually numerical. The operations performed on this base are determined by the system. In the expert system's database, the following information is included:

- data on the object,
- current measurement results,
- reference values of diagnostic signals.

The data are subjected to processing characteristic for each diagnosis method.

Knowledge base

The PC Shell system [24] makes it possible to use many knowledge sources at the same time. It allows for decomposition of expertise to the specialised modules for solving the problems with a varying complexity degree, in different areas. The considered diagnosis problem of the flow path elements can be divided into:

- subproblems within the diagnosed objects (elements):
  - diagnosis of the compressor blades,
  - diagnosis of the turbine blades,
  - diagnosis of the combustion chamber,
- subproblems within the diagnosis methods:
  - optical method,
  - computed tomography method,
  - … .

Therefore, it is convenient to create a separate knowledge source, which constitutes an independent file in the computer's non-volatile memory and consists of a block of facets and a block of rules, for each subproblem.

The declaration example of knowledge sources in PC Shell system:

sources
- *uszkodzenieŁopatkiSprezarki [damage to the compressor blade]:*
  type kb,
  file „uszkodzenieŁopatkiSprezarki.zw",
- *uszkodzenieŁopatkiTurbiny [damage to the turbine blade]:*
  type kb,
  file „uszkodzenieŁopatkiTurbiny.zw",
- *uszkodzenieKomorySpalania [damage to the combustion chamber]:*
  type kb,
  file „uszkodzenieKomorySpalania.zw",
- *metodaOptyczna [optical method]:*
  type kb,
  file „metodaOptyczna.zw",
- *metodaTomografii [tompography method]:*
  type kb,
  file „metodaTomografii.zw",
- *end.*

Owing to the modular construction of the knowledge base, it is possible easily to develop the designed expert system, while maintaining the independence of individual knowledge sources.

Base of facts

The base of facts is created on the basis of parametrised diagnostic signals. The parameters of signals constitute attributes, the numerical or symbolic value of which is referred to a limit or calibration value.

The names of all the attributes are placed in the knowledge source in the block of facets. The attributes are described with a facet of *Val one of* type, which declares a permitted set of the attributes' values.

The facts are added in a dynamic manner during the performance of the programme from the control block, which is located in the main module.

Base of rules

In PC-shell system, the formalism of rules is independent in terms of fields, and it allows encoding knowledge in any field. The rules consist of a conclusion and a conditional part

separated by *if* word. The premises in the conditional part are connected with the use of AND and OR of the Boolean algebra. The block of rules is included in all knowledge sources.
4001: uszkodzenieŁopatkiSprezarki [damage to the Compressor Blade] = "uszkodzenie krawędzi natarcia" ["damage to the leading edge"] if … .

The creation of a set of rules is included in the tasks of an expert and a knowledge engineer. As the expert system develops, it may occur necessary to use automated generators of rules on the basis of experimental data [25].

As a result of the construction of a set of rules defining the considered damage, an algorithm of searching for damage with the use of the expert system is created – search order corresponds to the order on the list of rules.

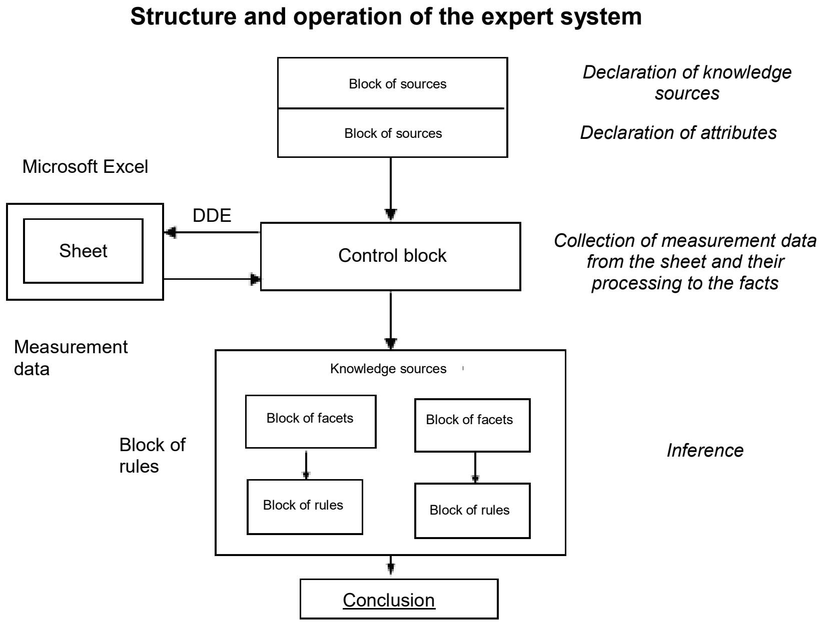

Fig. 1. Structure and operation of the expert system

Figure 1 presents a diagram of the expert system. In the main module of the system, there are the declarations of the knowledge sources and facets describing the used attributes and their properties. The control block provides the retrieval of data from a spreadsheet and calling up the knowledge sources. The diagnosis of the tested element condition is presented in the form of the conclusion.

8. Conclusion

The presented concept uses the idea of the developing comprehensive expert diagnostic system. The application of a modular structure of the knowledge base allows adjusting a set of diagnosis methods to a set of diagnosed elements.

The procedural programming module provides the processing of data necessary for inference implemented in the modules of the knowledge sources.

The correlation of diagnostic signals obtained with the use of a set of methods will allow increasing confidence of the commonly used visual method, as well as elimination of errors resulting from subjective assessment of the observed abnormal symptoms.

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