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DATABASE OF EXPERT DIAGNOSTIC SYSTEM IN THE FIELD OF TURBINE BLADES NON-DESTRUCTIVE TESTING

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Abstract

The article presents selected problems in the synthesis of the database of expert diagnostic system of gas turbine blades in the field of non-destructive testing. The source of data is optical methods and computed tomography methods. Optical tests can be carried out on the blades of the turbine built in the engine and after their disassembly. Optical tests provide diagnostic information in the form of an image of the blade surface. This makes it possible to identify damage based on changes in the attributes of the image of the blade surface. Computer tomography methods are applied on disassembled blades. Assessment of the technical condition of the blade is made on the basis of individual two-dimensional X-ray scans or on the basis of a three-dimensional image of the blade generated by the computer software from the set of X-ray scans taken during the full angle rotation. The computed tomography data set includes a small number of points on the timeline of operation; hence, the correlation of results with optical methods is difficult. Integration of diagnostic data from two or more sources into one expert system requires standardization of data. One possible approach is the use of multi-valued encoding of 2D and 3D image attributes. In this way a multi-valued diagnostic model of the blade is obtained, which can be processed by information theory methods to optimize the set of attributes.

Keywords: *gas turbine, blade, diagnostics, technical condition, expert system, database*

1. Introduction

In the operation of aircraft, turbine engines there are various types of damage to turbine blades. The most frequent cases of damage are overheated material [12, 15], as well as erosion [1, 2, 21, 25] and thermal fatigue of the blades and the vanes [1-3].

The expert diagnostic system (EDS) [6, 7, 10, 20, 22, 23, 26, 27] is an effective tool supporting damage testing. EDS is a computer system dedicated to solving problems of technical condition assessment, identification, and location of damages of considered objects using the methods of artificial intelligence and mathematical logic [9, 11, 19, 20]. The main part of the expert system is the knowledge base. Knowledge is recorded using a specialized language, which consists of, among others description of facts and a set of rules used in the inference process [20].

A convenient tool for creating expert systems is the shell system, e.g. PC-Shell [19]. It is a domain-independent, expert system with hybrid properties. Thanks to the blackboard architecture, the knowledge base can be divided into any number of heterogeneous sources of knowledge developed independently.

The condition for the design of an expert diagnostic system is the identification of knowledge sources about the operational degradation of turbine blades and methods of diagnosis [8]. The results of many years of scientific and research work carried out at ITWL [13, 14, 16-18, 24] constitute expert knowledge, which after appropriate formalization can be implemented in the designed diagnostic system. An additional source of knowledge is a bibliographic support module using bibliographic databases, e.g. Scopus [8].

2. Diagnostic experiment

The following types of experiments can be distinguished in the diagnostics of technical objects [5]:

– research – determining the values of symptoms for known states of the object, which allows to build a diagnostic model – relations between states and symptoms,
– operational – determining the current values of symptoms, and then determining the current state of the object using the diagnostic model,
– complex - combines the features of an operational and research experiment.

A complex experiment consists of two phases: operational and research. If the symptoms from the current diagnostic test are consistent with the current knowledge – the condition of the object is identified. Otherwise, a research phase is started, under which the diagnostic knowledge is updated using information from the operational phase, the renewal process, direct assessment methods (including control disassembly) and simulation tests.

The formal description of the basic types of experiments in the NDT area is shown by equations (1-9).

Research experiment $NDT_B(\theta_e)$:

$$NDT_B(\theta_e) = \left\langle E_{BNDT}(\theta_e),\ \{Y_{BNDT}(\theta_e)\}\right\rangle, \tag{1}$$

where:
$E_{BNDT}(\theta_e)$ – collection of introduced damage of elements,
$Y_{BNDT}(\theta_e)$ – a set of diagnostic signals,
θ_e – generalized life of the diagnosed object.

The operating experiment $NDT_O(\theta_e)$ is carried out on a real object of unknown apriority technical condition:

$$NDT_O(\theta_e) = \left\langle e^{?}_{ONDT}(\theta_e),\ Y_{ONDT}(\theta_e)\right\rangle. \tag{2}$$

If the obtained results of diagnostic tests can be agreed with knowledge base, i.e.:

$$Y_{ONDT}(\theta_e) \subseteq \{Y_{BNDT}(\theta_e)\}, \tag{3}$$

the current state of the object is:

$$e^{?}_{ONDT}(\theta_e) = \left(e^{i}_{BNDT}(\theta_e) \in E_{BNDT}(\theta_e)\right). \tag{4}$$

Otherwise, the object's condition remains unknown.

The complex experiment $NDT_Z(\theta_e)$ is carried out on a real object of unknown apriority technical condition:

$$NDT_Z(\theta_e) = \left\langle e^{*}_{ZNDT}(\theta_e),\ Y_{ZNDT}(\theta_e)\right\rangle. \tag{5}$$

If relationship is met:

$$Y_{ZNDT}(\theta_e) \subseteq \{Y_{BNDT}(\theta_e)\}, \tag{6}$$

the current state is an element of a set of known states:

$$e^{*}_{ZNDT}\left(\theta_e\right) = \left(e^{i}_{BNDT}\left(\theta_e\right) \in E_{BNDT}\left(\theta_e\right)\right). \tag{7}$$

Otherwise, the knowledge base update procedure is run:

$$\{Y_{BNDT}(\theta_e)\}' = \{Y_{BNDT}(\theta_e)\} \cup Y_{ZNDT}(\theta_e), \tag{8}$$

$$E'_{BNDT}(\theta_e) = E_{BNDT}(\theta_e) \cup e^{*}_{ZNDT}(\theta_e). \tag{9}$$

As a result, the sets of diagnostic signals and the collection of states are growing.

3. Acquisition of diagnostic signals

Optical methods enable obtaining two-dimensional images of turbine blade surface. For this purpose, digital cameras or videoscopes are used.

Figure 1 shows the surface image of samples from a turbine rotor blade taken with a digital camera. The data comes from a research experiment carried out in [4], the aim of which was to determine the influence of sample heating temperature on the parameters of the blade image. The tests covered new turbine rotor blades made of EI-867WD alloy.

Fig. 1. Images of sample surface from the turbine rotor blade heated at different temperature [4]

As a result of heating the blades in the furnace, a change in the colour of their surface was observed.

Figure 2 shows the results of recording the images of the surface of the set of 5 blades of the turbine nozzle apparatus. The blades were ordered according to the increasing degree of overheating – I-V condition.

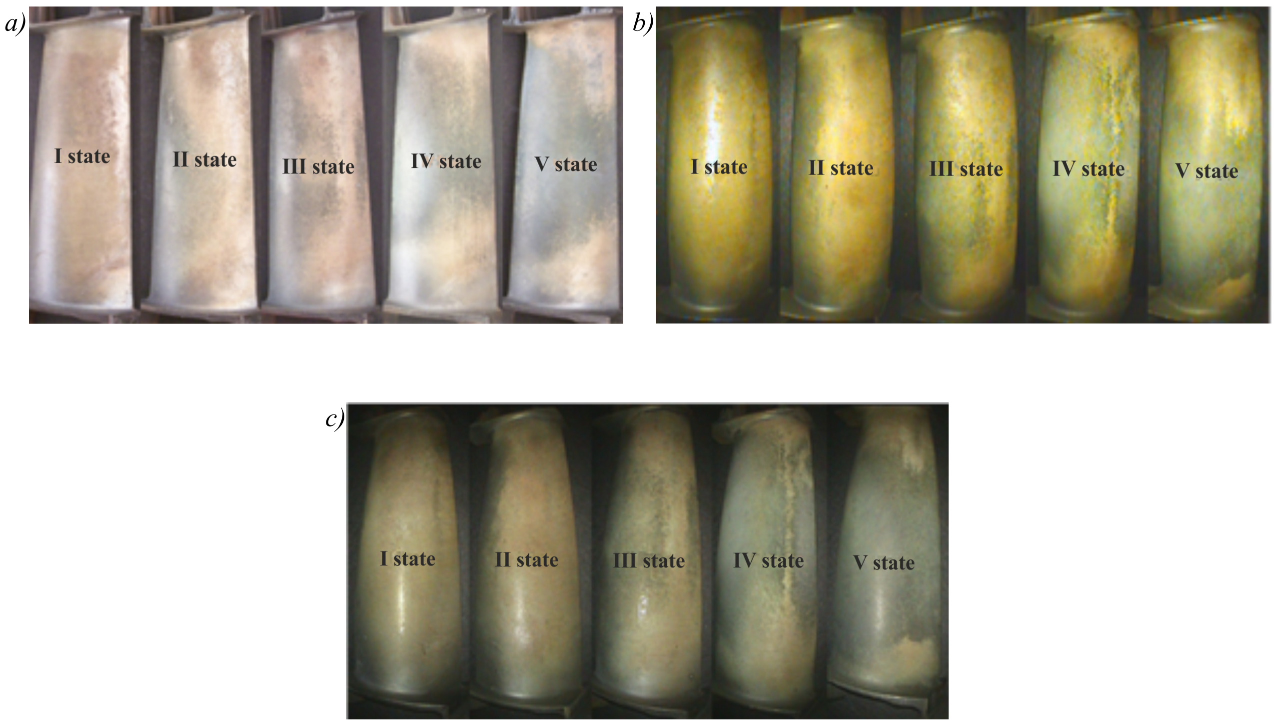


Fig. 2. Images of the surface of the turbine vanes obtained by means of: a) a digital camera, b) videoscope No. 1, c) videoscope No. 2 (according to the increasing degree of overheat condition – I-V) [4]

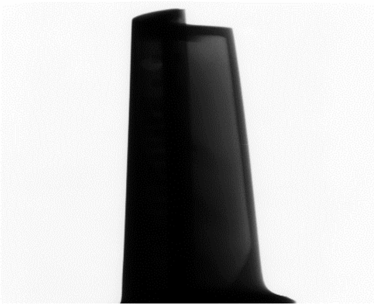
The data comes from a combined experiment carried out in [4], the aim of which was to determine the relationship between the parameters of the image of the blade and the degree of its overheating. The blades (made of ZS-6K alloy) were dismantled from end-of-life engines.

Differences in the colour of images of the blade surfaces in the same overheat state result from the properties of optoelectronic systems and from the method of lighting used in individual test equipment. In the case of image acquisition using a digital camera, the light was evenly dispersed over the entire surface of the blade; the light coming from the video frames is focused. In addition, wide-angle lenses, used in videoscopes, cause distortion of image geometry.

The above observations must be taken into account in the process of image processing in order to identify the discriminatory features necessary to infer about the condition of the blade.

The computed tomography method uses X-ray images of the element obtained during X-ray screening for a set of angular positions of the element from 0º to 360º with a fixed alpha step – Fig. 3.

a)



b)

Fig. 3. Example projections of the turbine rotor blade: a) – 355, b) – 850 [16]

Based on the set of two-dimensional projections, a three-dimensional image of the blade is synthesized. For the purposes of diagnostic inference, two-dimensional and three-dimensional images can be used.

The presented examples of projections allow for a quick analysis of the leading edge condition of the turbine blade. The obtained information allows limiting the area of searching for damage using a three-dimensional image.

4. Processing of diagnostic signals

The result of diagnostic tests is the sets of primary signals that must be processed into a form that enables effective diagnostic inference.

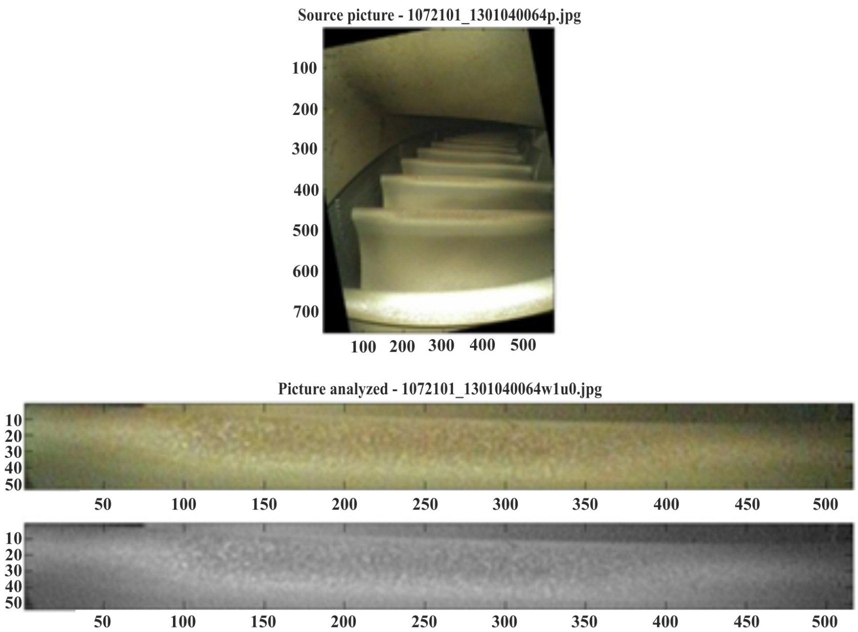


Fig. 4. Analyzed image: 1072101_1301040064w1u0.jpg

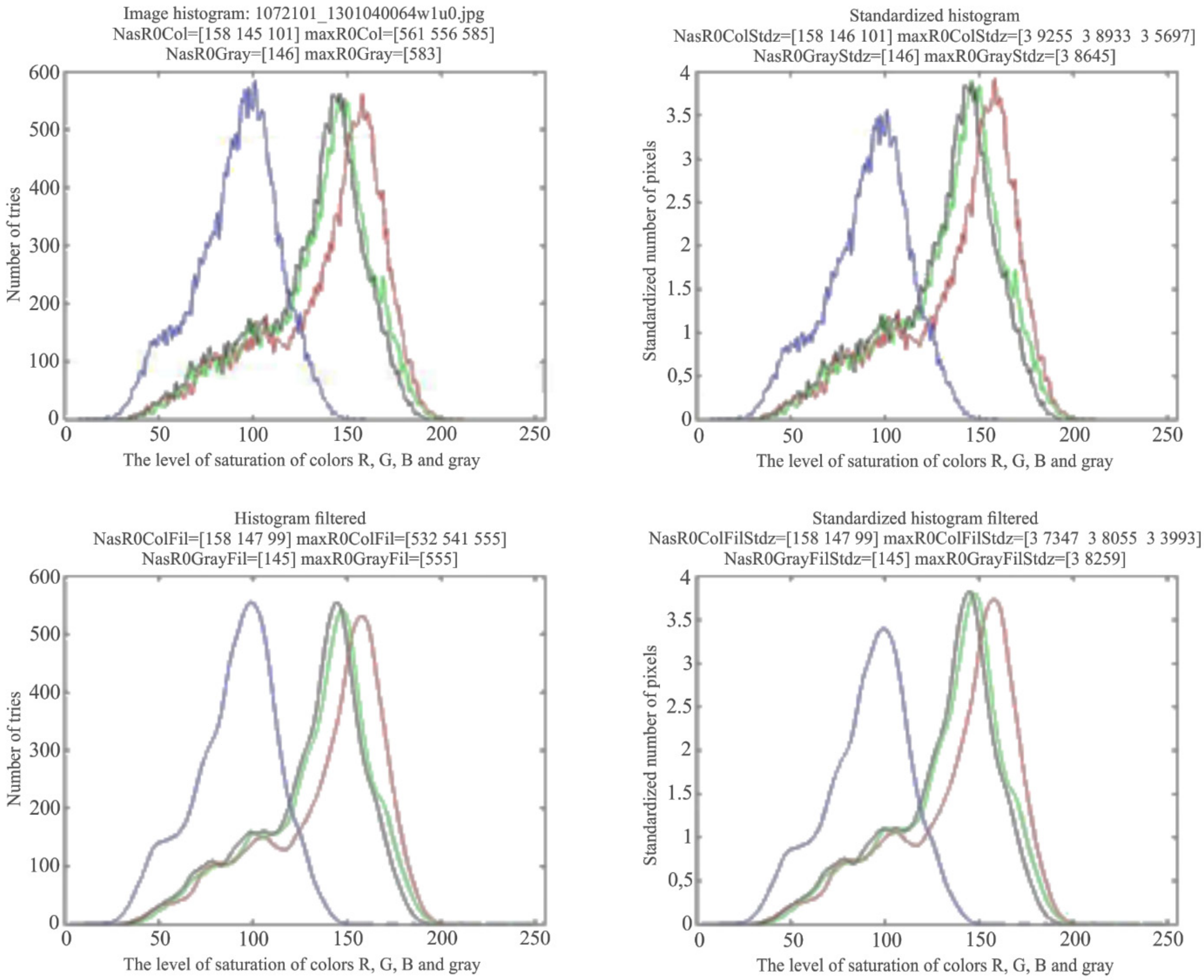


Fig. 5. Image 1072101_1301040064w1u0.jpg histograms

Obtained images are subjected to analysis aimed at separating the features characterizing the course of blade state change during operation. Below is an example of the turbine blade leading edge image analysis. The quantitative assessment of the condition using the image parameters of the examined element and histograms increases the objectivity of the test results and enables the use of formal methods in the process of generating a set of rules for diagnostic inference.

Tab. 1. Image 1072101_1301040064w1u0.jpg parameters

	grey	R	G	B
mean	129.44	137.60	132.78	90.72
median	137	148	140	94
std dev.	29.80	32.52	30.15	22.47
skew	-0.77	-0.88	-0.75	-0.41
kurt	3.02	3.03	3.03	2.82

Tab. 2. Parameters of histograms 1072101_1301040064w1u0.jpg

	grey	R	G	B
NasR0Stdz	146	158	146	101
maxR0Stdz	3.87	3.93	3.89	3.57
NasR0FiltrStdz	145	158	147	99
maxR0FiltrStdz	3.83	3.74	3.81	3.40

Computer tomography images are subjected to analysis aimed at uncovering the features characterizing damage to the element, e.g. location and dimensions – Fig. 6.

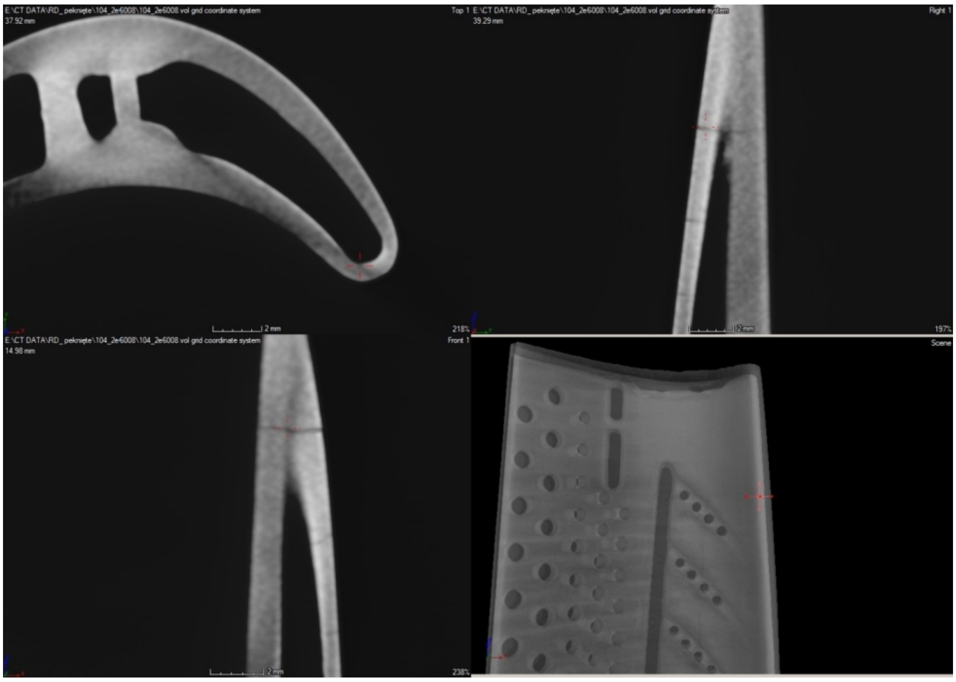


Fig. 6. Projections and cross-sections of the blade with damage [16]

5. Database of expert diagnostic system

Based on the adopted concept of the diagnostic experiment, the generalized database of expert turbine blades diagnostic system consists of the following modules:

A. Permanent database:
- the set of classes of diagnosed blades,
- a set of construction and material data for blades of individual classes,
- a collection of fault classes included in the expert diagnostic system,
- a set of attribute classes,
- a set of diagnostic symptom classes,
- collection of sources of diagnostic signals.

B. Variable database – results of experiments:

B.1. Primary data:
- organizational data of the experiment,
- images of blade surfaces obtained by optical methods,
- images of blades sourced by computed tomography methods.

B.2. Processed data:
- a set of attributes implementation,
- a set of realizing diagnostic symptoms.

C. Reference database:
- a set of diagnostic thresholds – correlated with a permanent database,
- collection of damage patterns.

D. Decision database:
- a set of implementation of multi-valued attributes,
- a set of implementation of diagnostic symptoms encoded in a multi-valued manner.

If a shell expert system [19] enables dynamic data exchange (DDE), a relational database model is used. Individual sets (modules) of data are stored in tables related by appropriate identifiers.

Each diagnostic experiment should be unambiguously described by the object data, the data of the signal acquisition system and the set of primary results.

A separate module consists of the object's attributes and statuses as well as threshold values. On their basis, a synthesis of a set of attributes prepared for use in the process of diagnostic inference performed by an expert diagnostic system is constructed.

6. Summary

The synthesis of an expert diagnostic system in the field of non-destructive testing (NDT/E) requires the development of a database enabling the storage and processing of a broad spectrum of data. In the case of optical methods and computed tomography, it is necessary to store the original images obtained from digital cameras and videoscopes and two-dimensional tomograms. Three-dimensional representations of blades examined with computed tomography usually require specialized software.

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