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MODERN DIAGNOSTICS OF AIRCRAFT GAS TURBINE ENGINES – SOME SELECTED ISSUES

NOWOCZESNA DIAGNOSTYKA LOTNICZYCH SILNIKÓW TURBINOWYCH - WYBRANE ZAGADNIENIA

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Abstract: *In aeronautics, the question of maintaining the highest possible level of flight safety is the most crucial issue. This is the reason why the scientists, engineers, and aerospace/aviation engineering staff keep searching for ever newer and more reliable methods of increasing the safety level. Therefore, new methods – primarily non-destructive ones – to diagnose aircraft turbine engines are looked for. These methods are expected to prove useful for the real-time monitoring of actual health of the engine and its assemblies. The paper has been intended to outline the most recent methods of diagnosing aircraft turbine engines, including the computed tomography methods as applied to assess health/maintenance status of turbine blades, for the phase mapping of increments in the engine's rotational speed, to diagnose health/maintenance status of the compressor's 1st stage rotor blades in pure jets. Other methods discussed are, e.g. vibroacoustic and tribological ones.*

Keywords*: diagnostics, aircraft engine*

Streszczenie: *W lotnictwie utrzymywanie bardzo wysokiego poziomu bezpieczeństwa lotów jest podstawowym zadaniem. Z tego powodu naukowcy, inżynierowie i personel służby inżynieryjno-lotniczej poszukuje coraz to nowszych i bardziej niezawodnych metod zwiększania tego poziomu bezpieczeństwa. W tym celu poszukuje się głównie bezinwazyjnych metod diagnozowania turbinowych silników lotniczych, z pomocą których można monitorować aktualny stan techniczny silnika i jego zespołów. W referacie przedstawiono skrótowo nowoczesne metody diagnozowania lotniczych silników turbinowych, w tym tomografię komputerową do oceny stanu technicznego łopatek turbin, odwzorowania fazowego przyrostu prędkości obrotowej silnika do diagnozowania głównie stanu technicznego łopatek pierwszego stopnia wirnika sprężarki turbinowych silników odrzutowych jednoprzepływowych, wibroakustyczne, tribologiczne itp.*

Słowa kluczowe: *diagnostyka, silnik lotniczy*

1. Introduction

Flight safety is an issue most vital to aviation. To provide high level thereof, many and various diagnostic methods are used. All of them are expected, and in fact, serve one aim: to detect any case of the structural component/assembly being unserviceable, or any failure/damage thereto. Then, using the recognised condition of the component as the basis, one is able to formulate forecasts on further reliable operation of the item. What has been given consideration in the paper is new methods of diagnosing structural components of gas turbine engines[1] that compose propulsion systems of civilian and military aircraft of various types, and those used in marine engineering (marine propulsion systems) and power industry. The methods in question can be classified into three categories: non-destructive testing methods, vibroacoustic methods, and tribological test methods.
The first category comprises the following methods: termography - and tomography-based methods, graphical mapping of component's health/maintenance status, visual techniques. The second category includes, e.g. vibroacoustic techniques that make use of vibration sensors, phase-mapping techniques, whereas the third one – tribological test methods.

2. Non-destructive methods of testing automatic control systems, turbine and compressor blades

„Tomography" is a comprehensive term for diagnostic methods used to get spatial (3D) images that present cross-sections of details. This enables detection of, e.g. internal cracks, loss of material, thicknesses of material layers, and even material's structure. A number of tomographic techniques may be distinguished. These are as follows [2]:

- conventional X-ray tomography,
- two-dimensional ultrasound imaging (ultrasonography) (2D USG),
- computed tomography (CT, KT, TK),
- magnetic resonance tomography (MRI, MR, NMR, MRT),
- positron emission tomography (PET),
- single photon emission computed tomography (SPECT),
- optical coherence tomography (OCT).

The computed tomography as applied to diagnose turbine blades allows of the observation of actual thicknesses of internal, usually unobservable, blade walls. Images of the scanned item can be presented using various shades of colour; also, dimensions of any detail can be given (Fig. 1).

[1] The paper has been based on the multi-authored study on "*Problemy badań I eksploatacji techniki lotnicz*ej" ("*The Problems of Studying, Testing, and Operating/Maintaining Aeronautical Systems*"), vol. 8, edited by Jerzy Lewitowicz, Leszek Cwojdziński, Mirosław Kowalski, Ryszard Szczepanik, Publishing Office of ITWL, Warszawa 2012, ISBN 978-83-61021-60-5

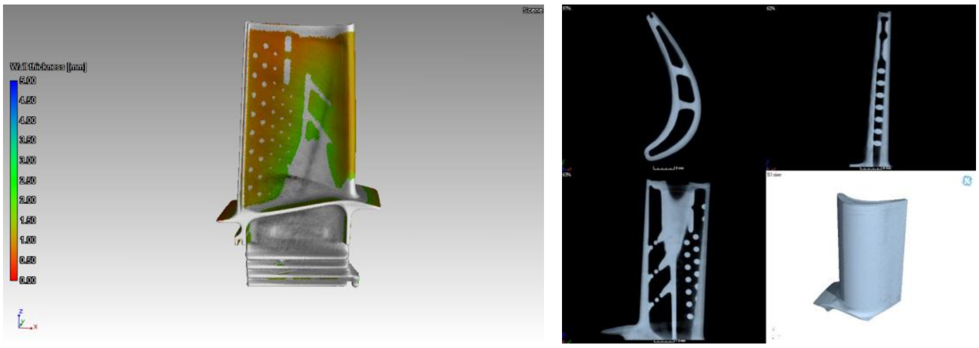

Fig. 1. Tomograms of turbine blades showing:
thickness of turbine blade walls (left), internal blade walls [2]

The non-destructive computed tomography (CT) method enables fast acquisition of highly reliable 3D images of internal condition of objects under examination. This technique looks very promising and is expected to find its applications to many and various objects to be examined, e.g. components of gas turbines, other engine components, composite skin airframe, etc.

Another method among non-destructive diagnostic techniques is one based on thermography – it is capable of revealing flaws in the blade's material [1, 5]. Thermography enables both temperature measurements and determination of temperature distribution. Both are based on detection of infrared radiation (IR) emitted by the surface under examination. Power of the electromagnetic radiation emitted by the surface of a given object over the whole spectral range depends on temperature of this surface; maxima of the power of radiation remain within the infrared range. The IR radiation extends from 0.75 to 100 μm.

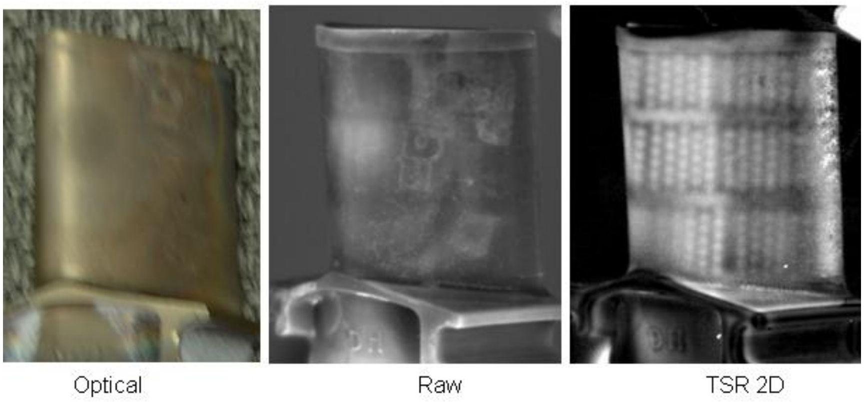

Fig. 2. Images of a high-pressure turbine blade examined with different methods:
an optical method, RAW, TSR 2D [3]

A sample application of this method has been shown in Fig. 2. One can easily notice differences between possible assessments of condition (health or maintenance status) of the blade under examination with an optical, RAW, or a thermography-based method, the latter allowing the assessment of condition of internal channels in this blade.

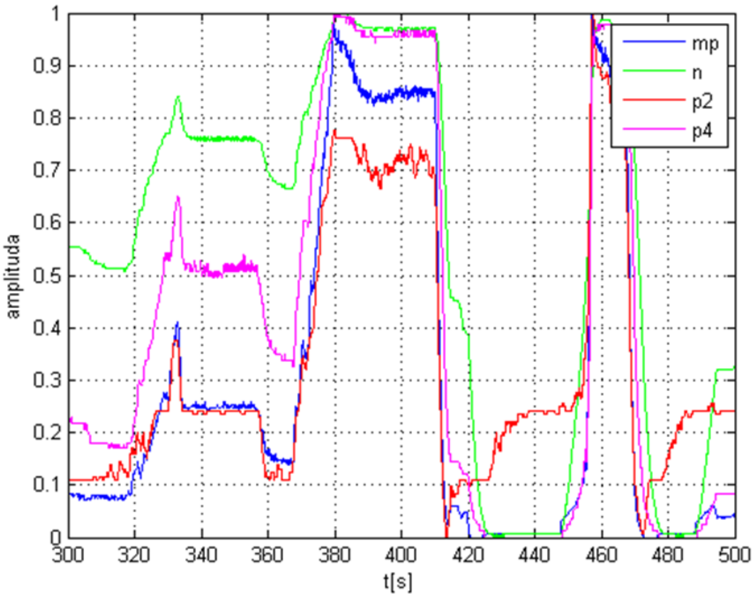

Fig. 3. Plots of standardised signals from turbojet engine's automatic control system (mp – standard, n – rotational speed, p – pressures)

The method of graphical mapping of component's health/maintenance status is mainly used to assess condition (health) of the engine's automatic control system. Fig. 3 shows sample plots of standardised signals from the automated control system of a turbojet engine. The simplest way to assess condition of the system is to visually compare the recorded plots with standard (master) ones. The visual method is a direct method. It consists in visual observation and assessment of plots of primary signals from the automatic control system as recorded during the engine's operation, with no processing/transformations applied. Comparative analyses are carried out for plots of signals recorded in the course of actual service tests as referred to earlier recorded and described standard (master) plots for fully serviceable engines (of high quality of performance) and to plots for signals from engines with typical failures (of low quality of performance). The method requires rich practical knowledge from those who perform the testing work. Since the burden of potential subjectivity is great, the analyses may result in poor inferences [4]. This technique has been developed into a more sophisticated method of graphical mapping of blade vibration profiles [8].

The method uses values of σ, 2σ, and 3σ separately, for each parameter being a criterion for the assessment of the blade's health. This in turn gives grounds for the decision whether the blade under examination can be allowed of further operational use, or not.

3. Vibroacoustic methods

Rich experience gained in the course of jet engines operation and maintenance prove that measurements and analyses of vibration are pretty good criteria for the assessment of engine health/maintenance status. The reason is that major portions of failures/damages to the engines are reflected by vibration levels. Owing to integral vibration-measuring (maintenance) systems that are components of the process monitoring and control systems, most often it is possible to detect changes in the engine's health/ maintenance status with no need to interfere in its structure. By means of simple arrays (single- or multi-sensor ones, with both fixed filtering units and simple signal-processing algorithms) one can measure changes in general vibration level. The method only provides quantitative information, i.e. on the fact that the object's condition has been changed, with no indication of any cause for that change, i.e. with no qualitative information [11]. The method is commonly used in the course of engine maintenance and while bench testing after overhaul. It is considered sufficient for fast verification. More complex measuring arrays (single - or multi-sensor ones, with moving filters and complex signal-processing algorithms) allow us to determine what follows: changes in rotor unbalance, the rotor being out of alignment, condition of the bearing system and mating components (clutches, gears, driving shafts), i.e. contrary to simple methods, they provide qualitative information. The practice proves that complex arrays are used as soon as changes shown (diagnosed) by simple arrays occur, or symptoms of untypical of correct engine performance are found (engine knocking, vibration sensed upon the airframe, etc.). They may also be used to assess possible and probable changes in the engine's health.

To examine and assess, for example, condition of the engine control system, the phase-portrait (phase-mapping) method [8] is used. The method enables analyses of quality of engine adjustments under transient conditions, the engine being assumed a system of a non-periodic type, with equal values of time constants of the combustion process and inertial portion of the rotor assembly [5].

Selection of coordinates of state is particularly suitable if these coordinates are subsequent derivatives of the most interesting variable, e.g. an output variable of the system. In the case of aircraft turbine engines, rotational speed is the most characteristic output variable. Such coordinates are usually termed „phase coordinates". In the case of the second-order system, there are only two coordinates of state (the so-called phase coordinates). The state space can be determined as the phase plane. Fig. 4 presents phase portraits for rotational speed of engines as envelopes of boundary states [9].

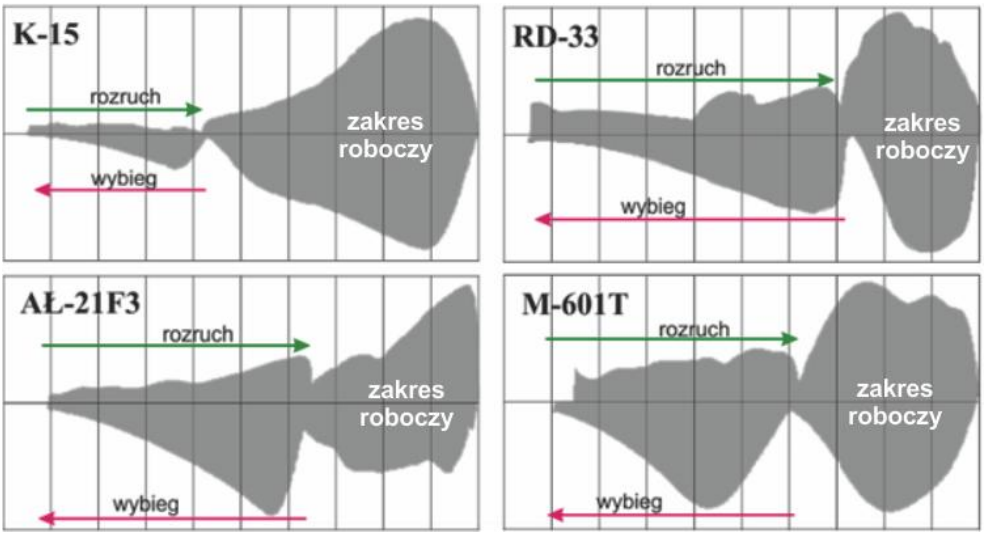

Fig. 4. Phase portraits for rotational speeds of engines

As Author of [4] states, "a normalised phase portrait of rotational speed of an engine, found for transient states (engine starting, acceleration, deceleration, and shut-down), is like a 'fingerprint line' for a given type of engine. It means that such visualisation of measurements covertly represents (maps) a mathematical model of the engine as an object under control". The phase-mapping method allows us to find standard (master) characteristics of changes in the most essential parameters of power-plant operation, which gives grounds for correct identification of power-plant's health/maintenance status and adjustments; also, to assess phenomena that accompany operation of these propulsion systems under atypical conditions.

Throughout the time the aircraft turboprops remain in service, in use are diagnostic methods based on tribological examination/tests and vibroacoustic methods to measure vibration on the engine block at the engine's shaft support bearing. Application of two methods intended to examine phenomena of different nature allows the question of the diagnosing of aircraft propulsion systems to be made universal. Up to the present, both the methods, i.e. the vibroacoustic technique and the tribological testing technique have been used to diagnose engineered systems independently of each other. However, there are some practical and analytical prerequisites that prove both the methods can be complementary. In the vibroacoustic method, the vibration-generated signal reflects physical processes that take place in the engine; it is these processes that correct functioning of the engine depends on. The method is widely applied to examine engine condition under natural service conditions; it quite often happens, however, that it does not provide any explicit information on how extensive is the worn-out area of the item

exposed to wear-and-tear processes, e.g. whether the hardened surfaces of the mating components have already been damaged due to friction. This is the kind of information generated by the tribological testing methods.
Tribological systems in turboprops (bearing systems, gears) consist of components of well-known parameters and characteristics (sizes of clearances, materials of mating items, etc.). Changes in parameters and characteristics thereof result from the wear and friction-induced processes. They can be detected with spectral methods [12].

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