EXAMINATION OF CHANGES IN THE MICROSTRUCTURE OF GAS TURBINE BLADES WITH VISUAL AND THERMOGRAPHIC METHODS

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Abstract

The processes associated with operation of turbine avionic engines entail the occurrence of various defects affecting turbine components, in particular turbine vanes. The main reasons for defects and deterioration of gas turbine vanes include thermal fatigue and overheating of the vane material.

This paper outlines the non-destructive test methods that are currently in use and that are based on an analysis of surface images obtained from the examined parts within the visible bandwidth with the use of a ring-wedge detector. Particular attention is paid to opportunities that enable unbiased diagnostics of changes in the microscopic structure of vanes with the use of the non-destructive thermographic method. Initial examinations of the gas turbine vanes, both new ones and those already in operation, have demonstrated the existence of interrelations and dependency between the thermal strain during the turbine operation, changes of signals associated with the thermal response from the material and the condition of the vane microstructures. The results of these examinations have been successfully verified with the use of the metallographic method. The demonstrated interrelations and dependency shall serve as a basis to develop fundamentals for a non-destructive thermographic test method intended to assess the overheating condition of the material for gas turbine vanes.

Keywords: *gas turbine, vane, diagnostics, thermographic method*

1. Introduction

Reliability and durability of aircraft turbine and turbojet engines highly depend, apart from many and various structural components ‘responsible’ for the efficiency of the whole structure, upon the gas turbine, the blades of which suffer high thermal loads in aggressive environments, i.e. affected by combustion products. Structural materials used nowadays in turbine blades, in particular their creep resistance, resistance to thermal cycling (i.e. thermal endurance), high-temperature sulphur corrosion, and erosion, build up a barrier to the increase in temperature of gases in front of the turbine. High operating temperatures and high rotational speeds of the gas-turbine rotor force application of expensive heat-resisting and high-temperature creep resisting alloys, as well as designs of gas-turbine blades of complex and complicated geometric shapes. The ultimate objective is that functional qualities of these blades are significantly improved.

The main cause of damages/failures to gas turbine blades is thermal fatigue. Also, blade material overheating, while initiating microcraks, considerably contributes to changes in microstructure and deterioration in functional properties of the material, since the propagating microcracks may pretty often result in total failure of the component. Numerous instances of material overheating as well as burn-outs and, in consequence, break-offs of turbine rotor blades in jet engines. The reasons for such failures are highly disadvantageous operating conditions (Fig. 1) and manufacturing defects, e.g. application of protective coatings of insufficient strength, or coatings incorrectly spread on the blade material (Fig. 2).

Fig. 1. Temperature-attributable damages to edges of attack of turbine rotor blades, exemplary videoscope records [1]

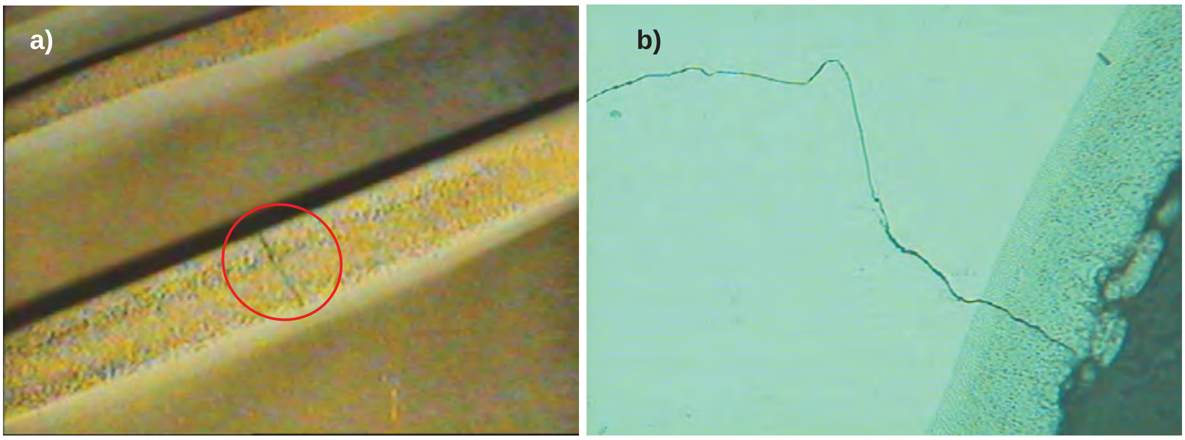

Fig. 2. A protective coating with a crack that propagates into the parent material of the blade

Therefore, early detection and correct interpretation of any symptoms of probable hazards, carried out with any available, non-destructive diagnostic methods, is for any user of an aircraft engine extremely important. All such actions are intended to prevent any severe damages/failures, and to make any repair(s) in the way most advantageous from the point of view of the minimisation of losses.

2. Reasons for changes in the microstructure of a gas- turbine blade

Experience gained up to the present in the course of research work carried out at Instytut Techniczny Wojsk Lotniczych (Air Force Institute of Technology) [1- 3] proves most of damages/failures to gas turbine blades directly result from improper adjustments (temperature) and the composition of an aircraft fuel blend.

Improper fuel pressure, physical and chemical properties deteriorated due to impurities of any kind, fuel injector in the flame tube head out of position – all these significantly contribute to carbon deposit formation on the injector (Fig. 3) and other subassemblies. A direct consequence of the presence of carbon deposits is improper fuel spray pattern. This results in disturbances in both the combustion process, and hence, the thermal-field distribution in the engine's hot section (Fig. 4).

In effect, disadvantageous changes in the microstructure of gas-turbine blades take place. Examination of the microstructures of blades made from the EI-867WD alloy, visually qualified either as 'fit for use/serviceable' (new) or 'unfit for use' (worked out), has delivered images of the microstructure of this alloy that show growth of the strengthening gamma prime γ' phase (Fig. 5). What the morphology of the gamma prime phase points to is a change in the material of a blade recognized as ‘unfit for use’, i.e. transition from the common cuboidal shape (Fig. 5a) to the lamellar one (Fig. 5b). It proves some disadvantageous change to the microstructure has occurred due to high temperature of exhaust gas.

Fig. 3. Carbon deposit on the fuel injector in the gas turbine engine [2]

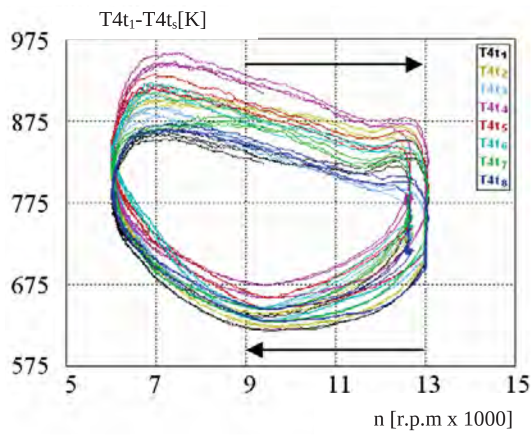

Fig. 4. The actual temperature distribution behind the turbine, measured with thermoelements [3]

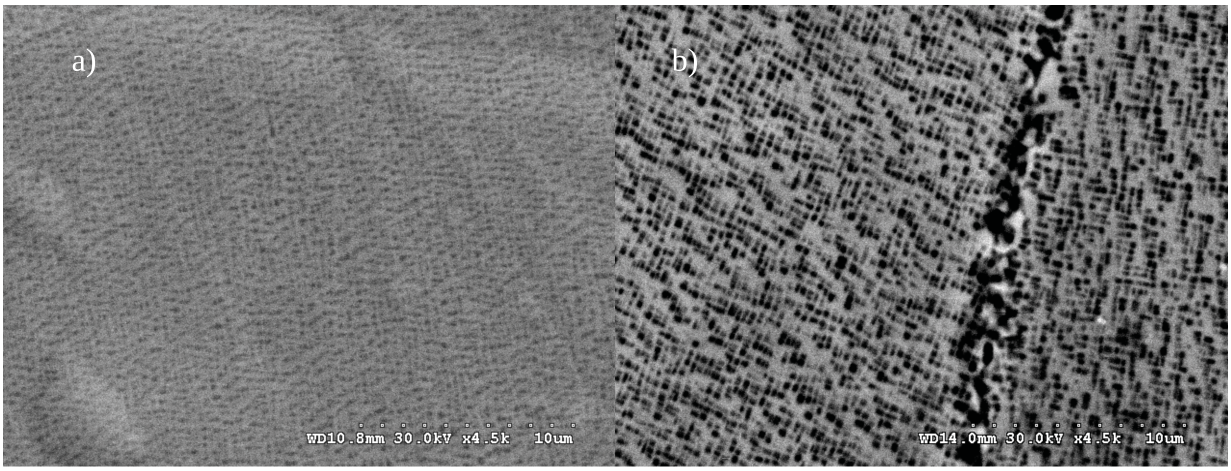

Fig. 5. The EI-867WD alloy microstructure (magn. x 4500): a) correct, b) overheated

After the critical temperature has been exceeded, the alloy suffers overheating, which results in the deterioration in mechanical properties (Fig. 6). Such being the case, the turbine blade cannot be acknowledged as ‘fit for use’, since condition thereof is hazardous to safe operation.

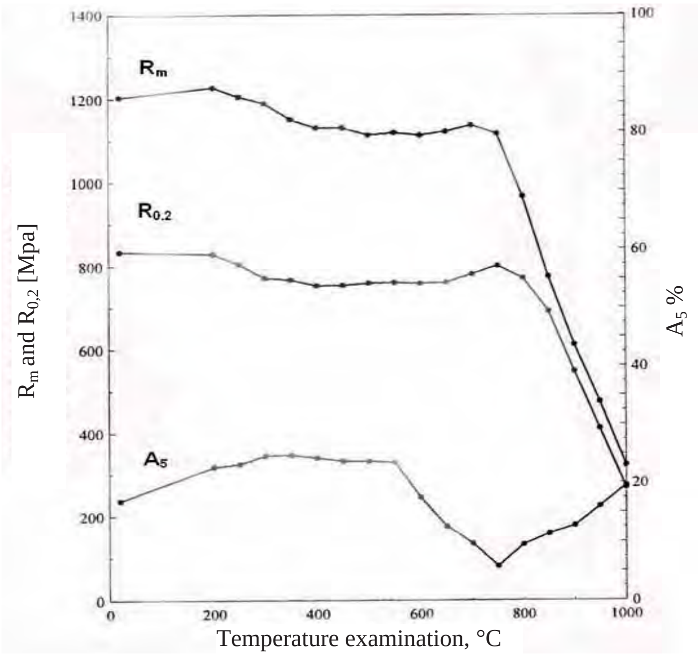

Fig. 6. Mechanical properties of alloys versus temperature [11]

3. A method to assess changes in the microstructure of a gas turbine blade

Many and various methods are used to diagnose condition of gas turbine blades. These are as follows: visual inspection, penetrant testing, ultrasonic testing, radiographic testing, thermographic inspection, leak testing/detection, and eddy-current testing techniques. Quite recently several new non-destructive testing methods have been developed and implemented, see [4-6, 9]:

- analysis of the object surface image gained in white light – the RGB method,
- detection of infrared radiation emitted by the object under examination - a thermographic method.

The RGB method

A visual RGB method based on three additive primary colours (red - R, green - G, blue - B) makes use of relationships between light's properties of wave and physical-and-chemical properties of surfaces under examination. These relationships prove essential to properties of the incident and reflected light, and to absorption of particular wavelengths of the electromagnetic radiation spectrum [4]. The assessment of the blade condition consists in the colour analysis of images of the surface in question, and is closely related with the material criterion, i.e. a change in the γ' precipitates morphology .

Using a nomogram that presents the relationship between change(s) in the blade-surface colour and the blade-heating temperature, one can assess changes in the microstructure of an alloy in question. Images recorded by means of the CCD matrix are analysed with dedicated computer software that makes use of image-processing algorithms and earlier developed master (standard) images, which allows of qualitative assessment of the surface under examination. This method has been applied to assess gas turbine blades made from the ŻS6-K alloy.

Active thermography

Quite recently, a new non-destructive method, the so-called 'active thermography', has been developed to examine internal defects of materials. Unlike the passive thermography where measurements are taken under conditions of natural differentiation between temperature of objects under examination and that of the ambient air, in active thermography an energy source is required to produce a thermal contrast between the feature of interest and the background; in other words, an external source of thermal excitation is necessary. On the account of the type of an exciting pulse and the way of thermographic data processing and analysis, the following types of thermography are distinguished: pulsed thermography, lock-in thermography, vibrothermography, step-heating thermography, and pulsed phase thermography [5].

Examination of gas turbine blades has been carried out with the Echo Term System equipment applied, with the pulsed thermography method. It consists I finding and analysing temperature distribution on the surface under examination in the course of its being cooled down, after having it earlier heated uniformly up with a heat pulse (Fig. 7).

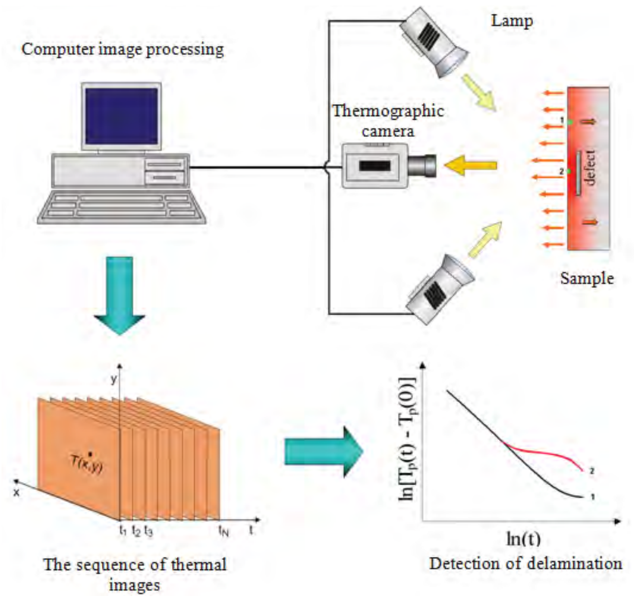

Fig. 7. A diagram of the pulsed thermography measuring system [6]

Heat penetrates into the object under examination by means of diffusion, what is represented on the surface with a local change in temperature to generate then a thermal contrast between the defected region and the region of correctly arranged structure that surrounds the defect. This technique has its limitations, since along with depth the absolute contrast rapidly decays; the absolute contrast ΔT results from the difference between temperatures of the defected area T_d and the defect-free area T_{bd} . Hence, it only allows of the detection of near-to-surface defects [5].

$$\Delta T = T_d - T_{bd}. \tag{1}$$

Heat flow within a solid body is strongly conditioned with thermal as well as many other physical properties of the object in question. Apart from thermal properties, the following physical properties affect it: size (dimensions), shape, weight, volume, internal structure, chemical composition, thickness of protective coatings. Thermal properties of great significance to thermographic inspection and conducive to heat conduction through the medium are: thermal conductivity *k*, i.e. the property of a material that indicates its ability to conduct heat, and thermal activity (thermal effusion) *e* that describes the ability of a material to exchange heat with the neighbourhood [5].

$$k = \frac{q}{gradT}, \tag{2}$$

where:
q - density of conducted heat flux [W/m^2],
$grad\ T$ - thermal (temperature) gradient [K].

$$e = \sqrt{kqc}, \tag{3}$$

where:
c - specific heat of the material [J/kg · K].

Diversified physical properties of materials enable special-line diagnostic methods to be applied to evaluate materials health, structural condition, material identification, etc. The pulsed-thermography technique was applied to get discrepancies in temperature values in the course of cooling down the material samples' surfaces earlier subjected to excitation with a thermal pulse. Information gained from thermal responses of the examined surfaces allows other material brands/grades to be found (Fig. 8).

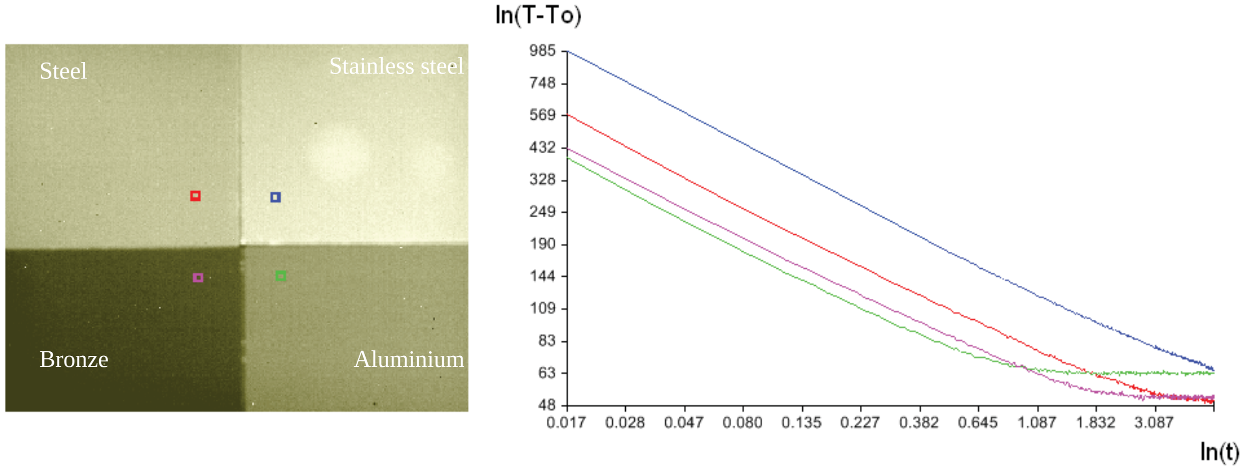

Fig. 8. Thermal response of some selected materials to thermal pulse [6]

4. Pre-evaluation of changes in the microstructures of gas turbine blades with a thermographic method

Studies have been undertaken at the Instytut Techniczny Wojsk Lotniczych (Air Force Institute of Technology) to determine capabilities to evaluate changes in microstructures of gas turbine blades with the thermographic method, with the "Echo Therm System" applied. The system is furnished with a high-class FLIR thermal imaging camera, two xenon lamps that jointly generate 5 kJ heat energy, and software to aid captured data processing and plotting of the temperature curves. Subject to thermographic examination were gas turbine blades made of the El-867WD alloy classified into the following categories: new, in service and fit for use, damaged in the course of turbine engine operation. The results gained have shown changes in the dependences between parameters of thermal responses of materials of blades under examination to a stimulating thermal pulse(Fig. 9).

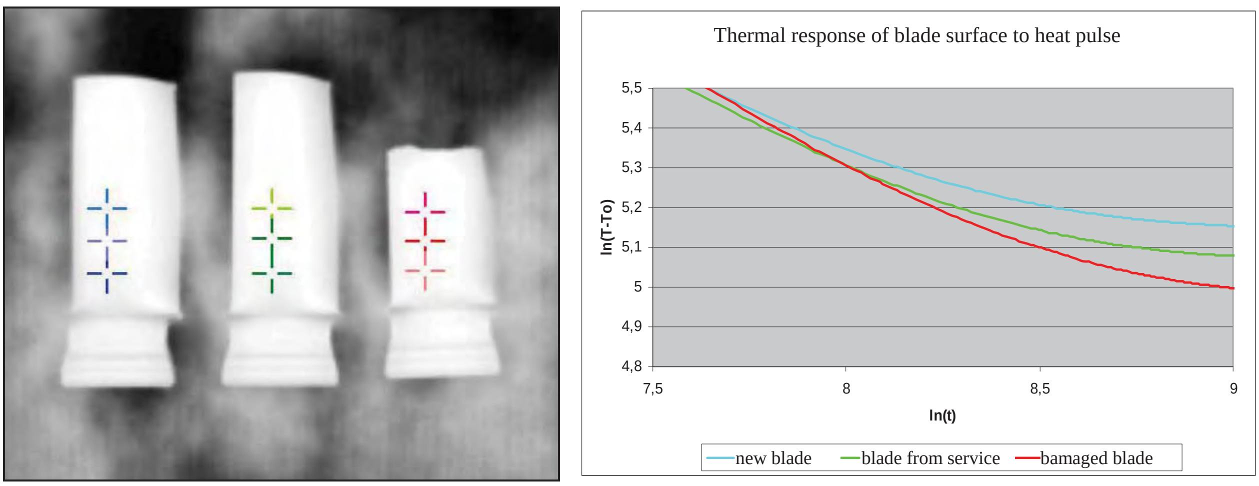

Fig. 9. Thermograms from blades examination, and temperature curves for a selected location upon the blade surface

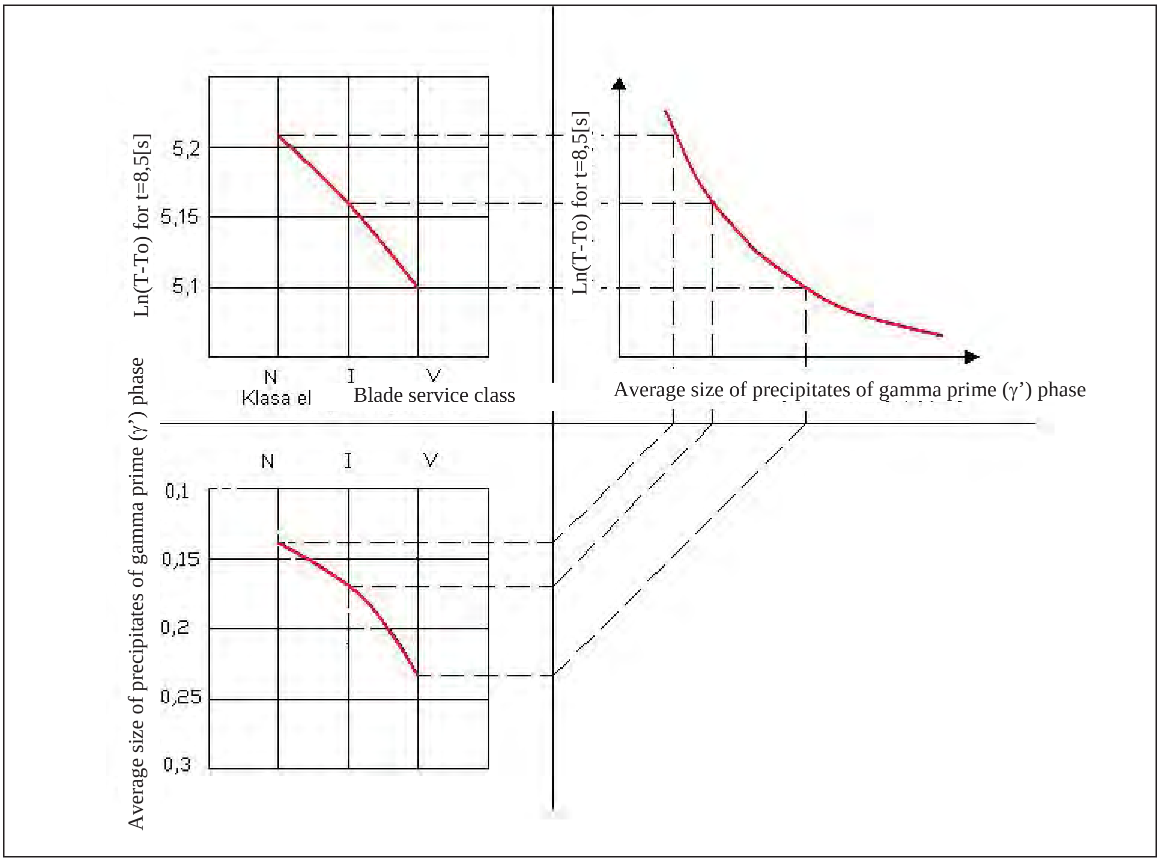

Fig. 10. Thermal response of the blade's El-867WD alloy in the form of ln(T-To) against average size of precipitates of the γ' phase

The dependence of the blade material's thermal response in the form of *ln(T-To)* against average size of precipitates of the γ' phase allows of the evaluation of the blade material's condition. On the basis of this dependence, if permissible changes in the microstructure are known, one can evaluate whether the blade(s) are fit for use (serviceable), or unfit for use (unserviceable). High working temperature, of the 1200 K order and higher [4, 10], results in disadvantageous changes in the alloy microstructure and that of the protective coating. With account taken of the material criterion, i.e. a disadvantageous change in the morphology of precipitates of the γ' phase, one can evaluate the 'fit for further use' threshold. Results for the assumed concept have been presented in Fig. 10, in the form of a nomogram.

5. Summary

In the process of operating aircraft gas-turbine engines there occur instances of turbine blades heating up to temperatures that exceed the rated value of the working temperature. Disadvantageous changes in the microstructure, ones resulting from the overheating of the gas-turbine blade material, quite often are initiated with the protective coating getting damaged. This causes the blade's parent material to become directly exposed to aggressive combustion products that affect it. Possible consequences are as follows: overheating of the alloy, blade fracture, blade break-out, etc., which may result in a damage/failure to an engine, or even a fatal air accident.

Therefore, there is an urgent need to make a much more wider use of non-destructive testing methods as applied to routine evaluation of the overheating of blades of an aircraft gas turbine. With the thermographic method applied, preliminary examination of gas turbine blades (both new and operated ones) has proved there are close relationships between in-service heat loads on the one hand, and on the other hand, changes in signals of the material thermal response and condition of the blade microstructure. The dependences shown will be used to develop a thermographic non-destructive method of evaluating the level of overheating of the gas-turbine blade's material.

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