Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

THE CONDITION ASSESSMENT OF IN-SERVICE VANES OF GAS TURBINE NOZZLE UNIT WITH HELP OF DIGITAL ANALYSIS OF VANE SURFACE

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Summary

The paper presents the methodology of condition assessment of in-service vanes of gas turbine nozzle unit with help of digital processing and analysis of vane surface. Included are 3D distribution graphs of basic RGB component colours (red, green and blue) for vane surface images registered with a digital camera (lab conditions) and with two types of commonly used videoscopes (working conditions). The graphs are coupled with results of examination of vane material. Considered were also both alteration of protective coating and core microstructure. The examinations were realised on metallographic sections with help of a SEM. The core microstructure was analysed mainly from the standpoint of modification of reinforcing phase γ' and alteration of phase γ and carbides. Size and distribution of phase γ' particles determines creep resistance properties (material criterion as the assessment criterion of vane condition). The analysis of images of gas turbine nozzle guide vane surface consists in counting of overheating area in relation to non-overheated area – the ratio is expressed in percentage terms (the criterion – the colour of the surface of a vane considered serviceable in relation to other distributions of colours on surfaces of vanes of different degree of overheating). The proposed approach is aimed at assessment of degree of overheating by reference to discolouration of vane surfaces after certain operational period.

Keywords: *gas turbine vanes, digital image, phase γ'*

1. The matter of considered problem

Turbine vanes are made of creep-resistant alloys with a nickel or cobalt matrix basis (superalloys). Their condition is examined (diagnosed) during operation or overhaul. The cause of damage to turbine vanes is often the material overheating as well as thermal fatigue caused by both excessive temperature and duration of its action, and also chemical aggressiveness of exhaust gas. As a result vane structure becomes modified, what leads to loss of material resistance. In general the structure modification consists in expansion of the *γ'* phase precipitations (the reinforcing phase – the component of microstructure having greatest influence on properties of superalloys). In special cases the expansion of the *γ'* phase leads to coagulation of precipitations and their dissolving in solid solution. In such conditions the material is characterised by lower creep resistance and the element, where this effect occurs, is exposed to damage, what generally results in dangerous turbine failure.

Generally, the overheating of vanes results from exceedance of admissible average temperature of exhaust gas as well as from irregular temperature distribution on the circumference: e.g. as a result of improper fuel atomisation due to carbon deposit on injectors (fig. 1).

During operation and in repair workshops applied is the manual containing description of procedure for examination of turbine vanes overheating. According to the manual the preliminary examination of material overheating consists in visual inspection of vanes for detection of deformations, material defects, and before all, change of surface colour indicating the overheating of material.

The verification of diagnostician's decision is realised with a destructive method. The microstructure of examined element is analysed on metallographic section. In diagnostic examinations the vision

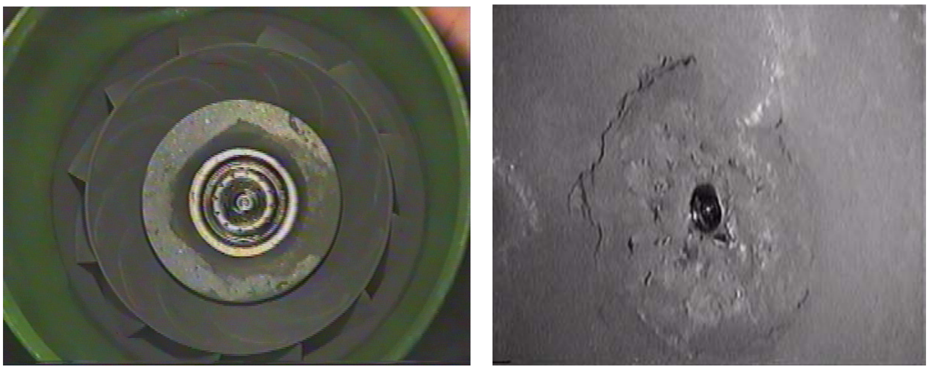

Fig. 1. General view of a combustion chamber injector: a – clean, b – covered with carbon deposit [1]

(the organoleptic method of condition assessment) is a subjective factor. Additionally, the colour is a physicopsychological phenomenon [2]. These facts cause that the assessment of vane condition made by a diagnostician can be crippled with great error. Therefore necessary is to develop an objective non-destructive computer-aided method of assessment of vane condition. Application of digital image recording technology combined with computer image analysis will contribute to higher credibility of results of turbine elements diagnostic as compared to currently used method of subjective assessment of condition made by a diagnostician. Additionally, application of a videoscope as an appliance for recording of vane surface image enables diagnosing of vanes without disassembly of a turbine.

2. Characteristics of examined object

Examined were stator vanes of a gas turbine of an aircraft jet engine. The vanes are made of ŻS-6K alloy of chemical composition shown in the table 1.

Tab. 1. Chemical composition of ŻS-6K alloy [3]

Chemical composition [%]										
C	**Mo**	**Cr**	**Ni**	**Co**	**Mo**	**W**	**Nb**	**Ti**	**Al**	**Fe**
0,16	4,0	11,0	the rest	4,5	10,3	5,0	-	3,0	5,5	1,0

The examined alloy is reinforced with cube-shaped γ' phase particles. The content of this phase amounts to ca. 64%. The alloy belongs to the group of cast nickel alloys (fig. 2).

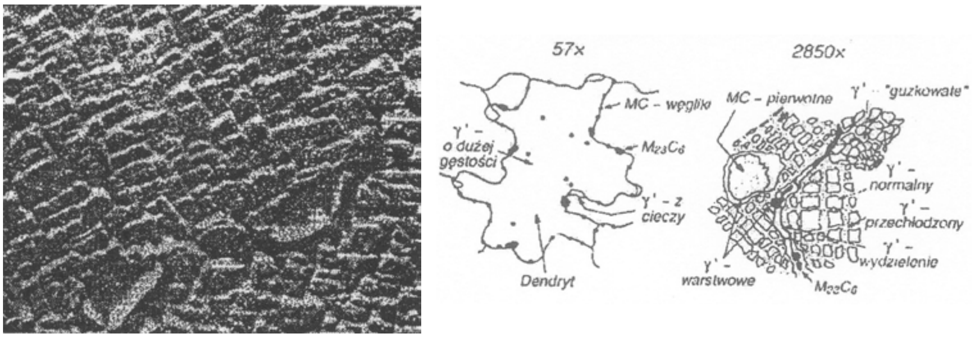

Fig. 2. Typical elements of the structure of cast nickel alloy [4, 5]

The important technological problem for this type of alloys it the thermal treatment, consisting mainly in homogenising annealing (structure homogenisation, increase of resistance and plasticity) [4]. The purpose of thermal treatment is also to obtain correct dispersion and shape of precipitations of *γ'* phase i.e. the main reinforcing phase. In many cases applied is also the protective coating, which allows increase of working temperature (by ca. 100K) and additionally protects the native material against harmful influence of high-temperature working medium (exhaust gas). During operation the coating changes its colour constantly. For recording of nature of these changes and acquisition of vane surface images used was following research equipment:

- digital camera Kodak Easy Share DX 7590;
- videoscope Olympus Iplex SA II (made in Japan);
- videoscope Everest XLG3™ VideoProbe (made in USA).

Fig. 3 shows an exemplary set of vane surface images of various overheating degree (according to hitherto applied classification of their technical condition). After long-standing operation the vanes made of ŻS-6K alloy are in various technical condition.

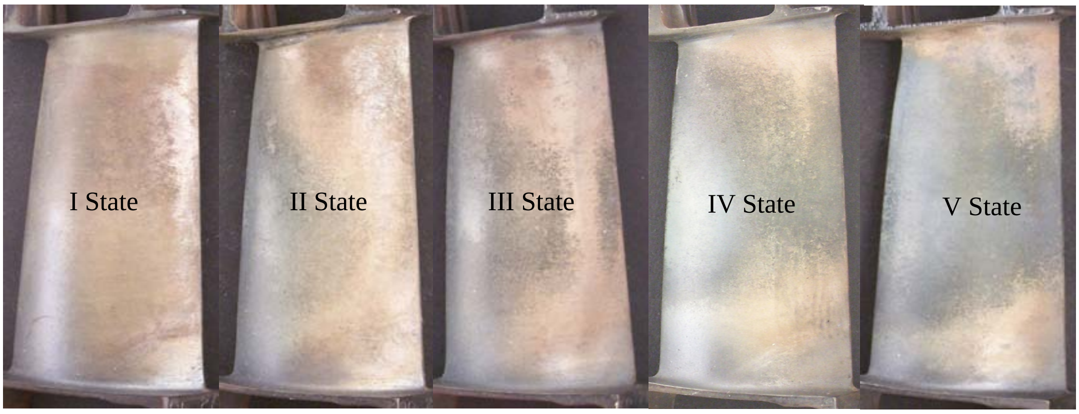

Fig. 3. Surface images made with digital camera Kodak Easy Share DX7590

3. Metallographic examination of in-service vanes of nozzle unit

To examine the microstructure of in-service vanes carried out were metallographic examination in laboratory conditions. The examinations were realised on metallographic sections with help of an optical microscope Neophot and a scanning microscope Hitachi S-3000N.

Fig. 4 shows the microstructure of coating and ŻS-6K alloy of a turbine vane in state I (vanes of uniform surface colour), and fig. 5 – in state V (vanes of multicoloured surface).

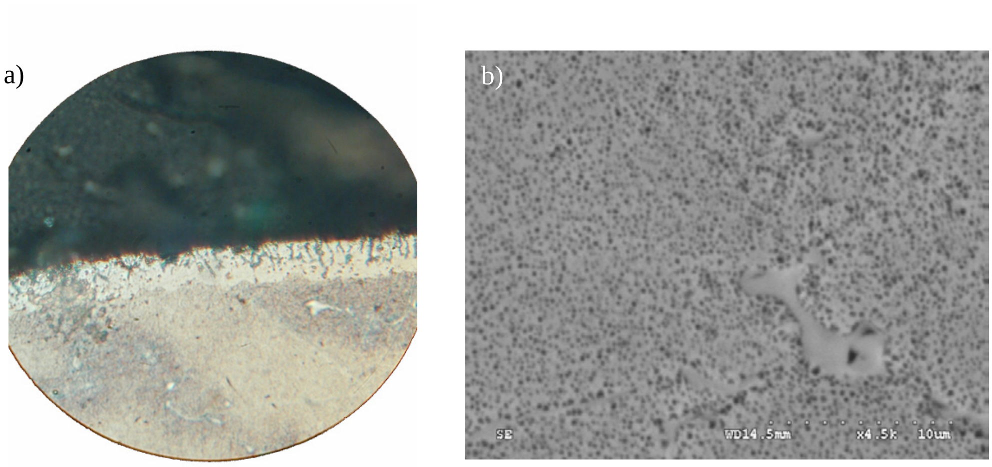

Fig. 4. Correct microstructure of turbine vane (state I): a) coating (magn. x450);
b) alloy ŻS-6K (magn. x4500)

Initially, after certain period of operation, the vane coating (fig. 4a) was not subject of degradation and its thickness differs only slightly from the thickness of the brand new coating. In the course of further operation the coating swells, and cracks appear due to thermal fatigue (fig. 5a).

The coating thickness gradually changes as a result of influence of working medium (exhaust gas) of high kinetic energy on vane material. The coating becomes thinner (fig. 6a), what results in loss of protective properties. As a result the temperature of vane material grows and the vane losses protection against chemical influence of exhaust gas. The vane becomes very sensitive to influence of exhaust gas. This leads to degradation of coating as well as of native material (fig. 6b).

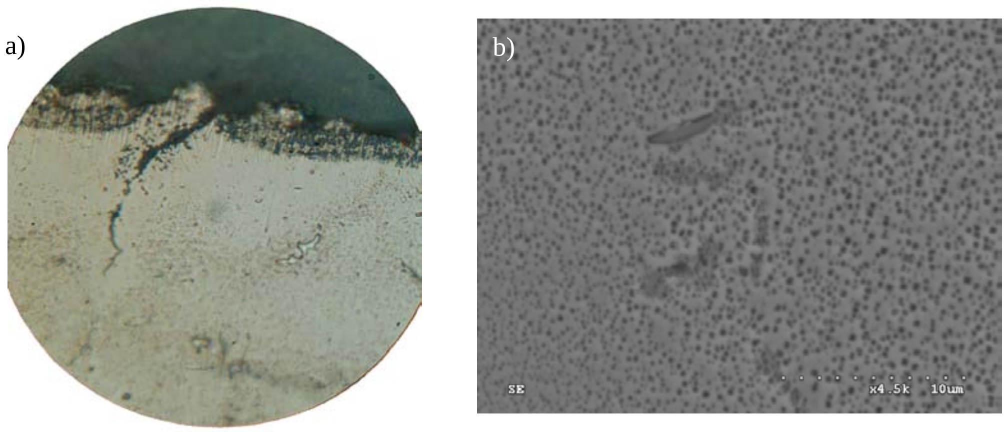

Fig. 5. Overheated microstructure of turbine vane (state V): a) coating (magn. x450);
b) alloy ŻS-6K (magn. x4500)

On the image of microstructure of ŻS-6K alloy were detected secondary precipitations of fine dispersion phase *γ'* (fig. 5b) formed after action of high-temperature exhaust gas. The morphology of *γ'* proves that if the critical temperature is exceeded, the alloy becomes overheated and in such case the vane cannot be considered as a serviceable one [6].

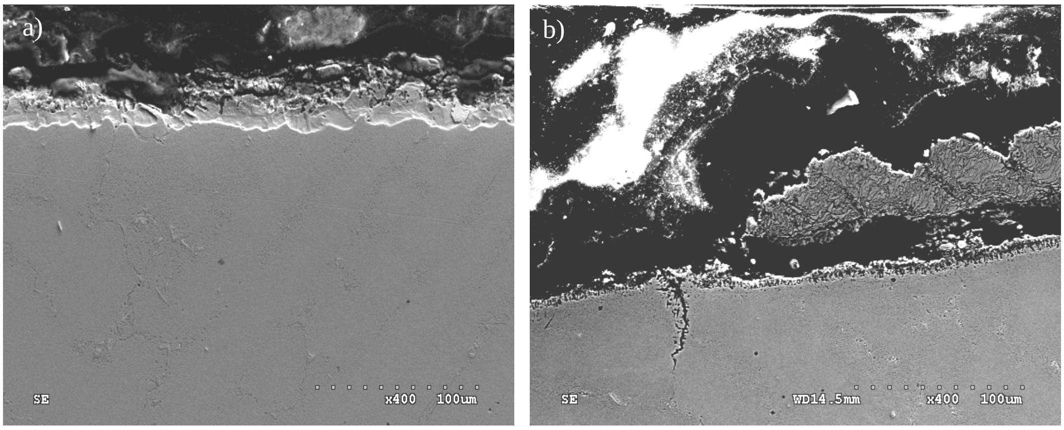

Fig. 6. Metallographic structure of surface layer of an in-service vane (state V):
a) reduction of coating thickness (magn. x450); b) thermal crack in coating, penetrating inside the vane material (magn. x4500)

The examinations of coating microstructure (protective layer) and Ż6-SK alloy proved that influence of high-temperature exhaust gas caused decohesion of coating (fig. 5a, fig. 6) and modification of reinforcing phase γ' (fig. 5b). Results of examinations of vane microstructure proved that the vane No. 1 has correct structure and the vane No. 5 has overheated structure.

3. Method of scanning of images of in-service vanes surface

The process of destruction of a gas turbine vane starts with destruction of aluminium coating (shown on images of surface in the form of colour change – fig. 3). Digital images of surface of in-service stator vanes of a turbojet turbine were analysed for the purpose of determination of size of local overheating areas. Altogether were made five expositions for each state in guaranteed repeatable recording conditions for each appliance [7]. The stages of realisation of diagnostic method developed for the purpose of assessment of technical condition of examined turbine element (size of local overheating areas) are shown on fig. 7. As a criterion of degree of overheating was used the colour of vane surface in state V (overheated structure – metallographic examinations). Basing on prepared histograms (for each channel of digital image, i.e. red, green and blue – the RGB model) determined was the criterion threshold, which value was calculated on the base of saturation (position of maximum amplitude) for each individual component of RGB colour (R+G+B/3=162) – fig. 8.

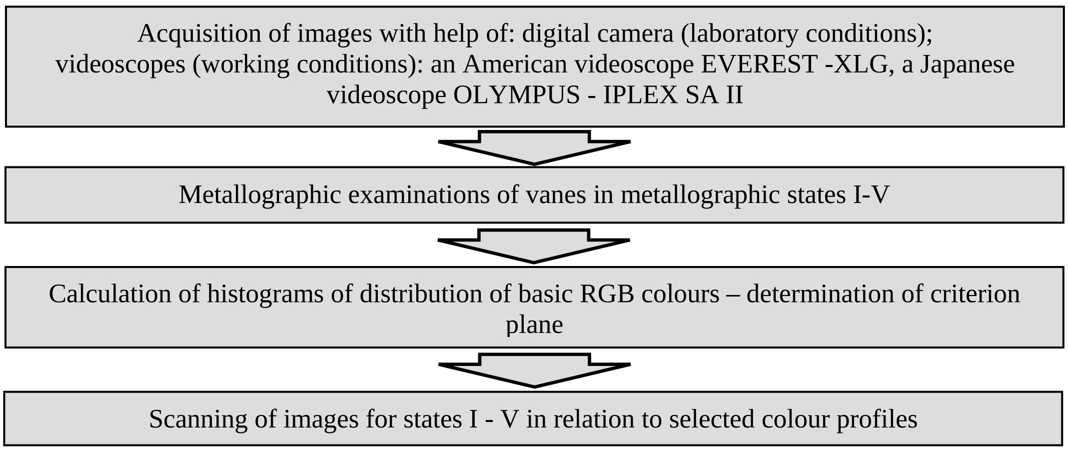

Fig. 7. Realisation stages of diagnostic method of examination of in-service turbine vanes

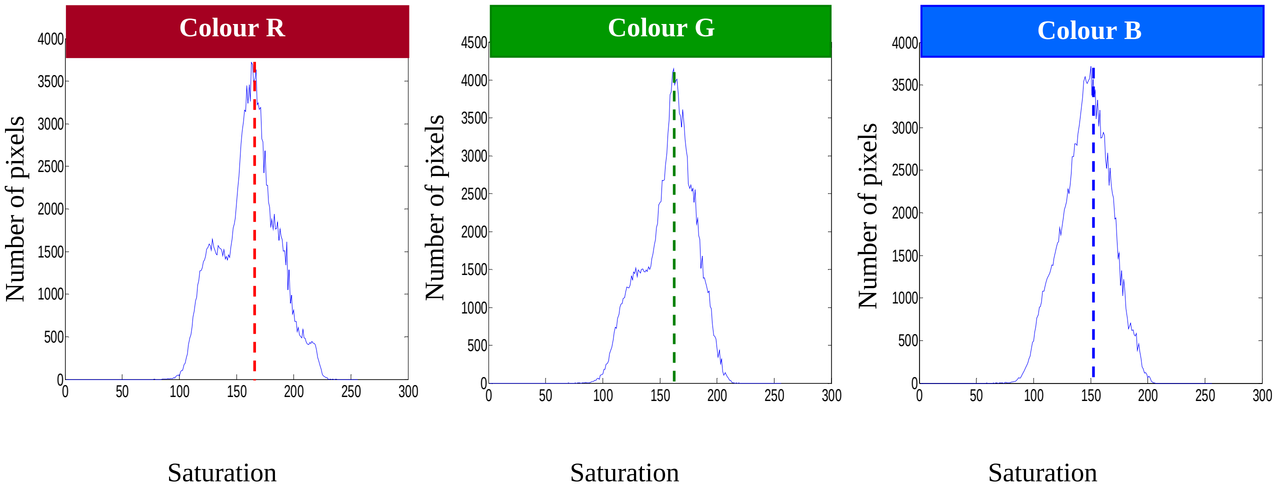

Fig. 8. Histograms of distribution of basic RGB colours for the vane in state V

The criterion threshold (plane value) was linked with 3D distribution of colour on surfaces of individual vanes in states I-V. As overheated surface points (pixels) were assumed these points, which value lies below determined plane. Figs. 9 and 10 shows graphical presentation of an exemplary assessment of overheated area for vanes in states I and VI, which images were recorded with digital camera. For better orientation adopted was the system of coordinates (where: *x*, *y* – size of vane image in pixels, *z* – saturation of RGB colour). The dashed line indicates irregular influence of temperature on examined vanes caused by wrong operation of injectors – disturbances in combustion process in combustion chamber.

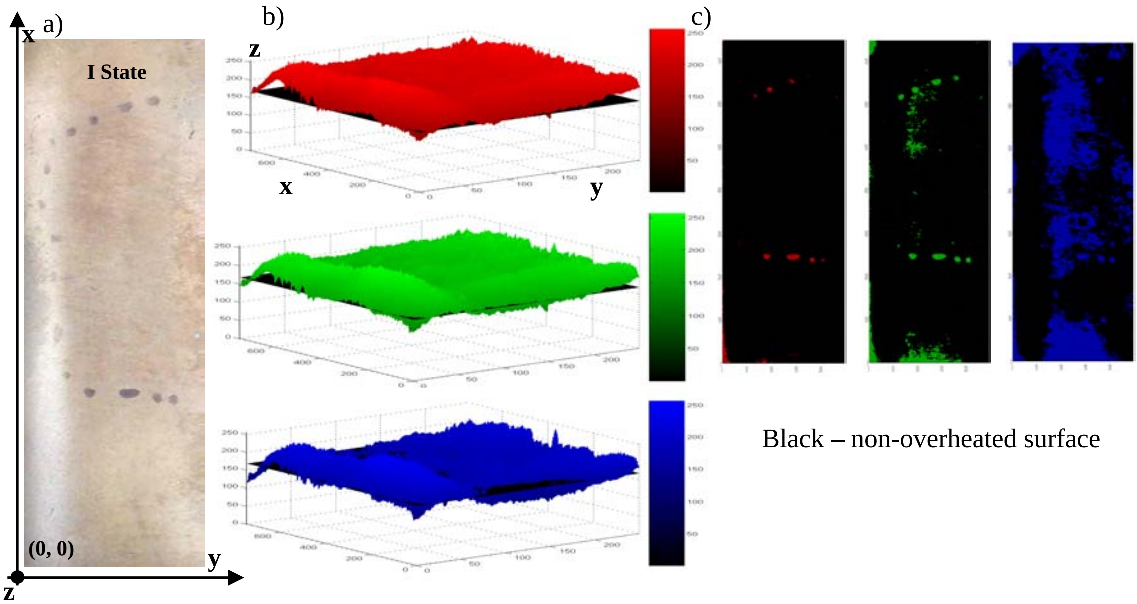

Fig. 9. Vane in state I: a) surface image; b) 3D distribution of basic RGB components; c) vane surface viewed from below – the result of introduction of criterion plane

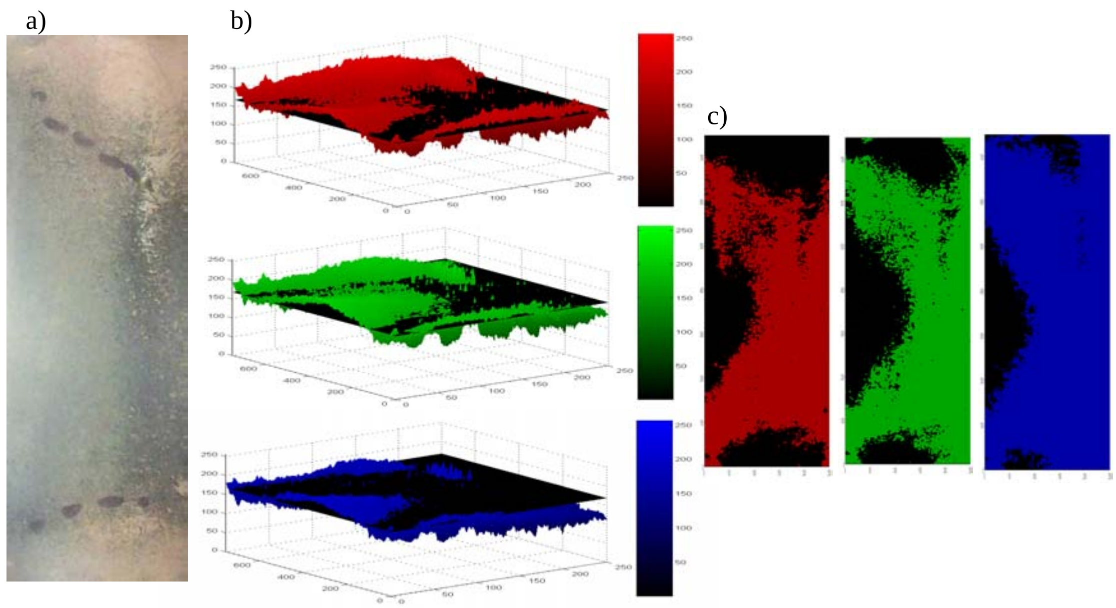

Fig. 10. Vane in state V: a) surface image; b) 3D distribution of basic RGB colours; c) vane surface viewed from below – the result of introduction of criterion plane

As the technical condition of vanes deteriorates, the overheated area increases (the set of image pixels) – figs. 9c, 10c. The introduction of the plane (criterion of overheating of vane material) to 3D graphs of distribution of RGB colours for images of surface of examined turbine element allows determination of overheated area/total area ratio (fig. 11). The same relation was determined for images recorded with two videoscopes (fig. 12).

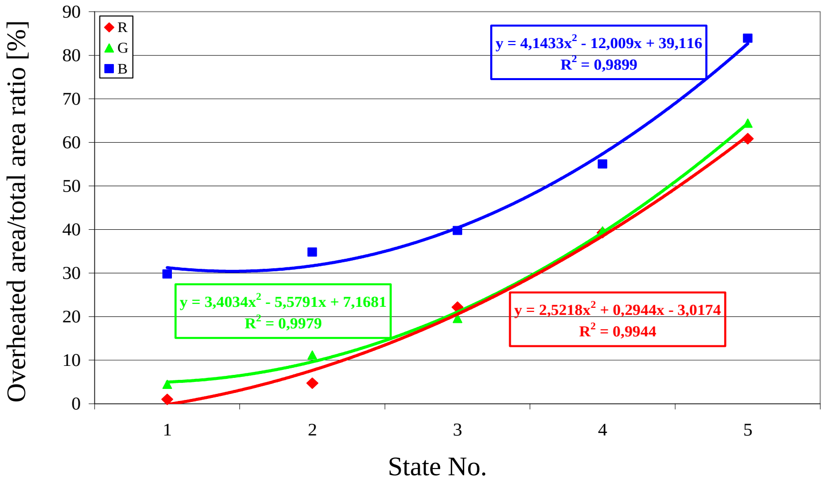

Fig. 11. Overheated area/total area ratio – images recorded with digital camera

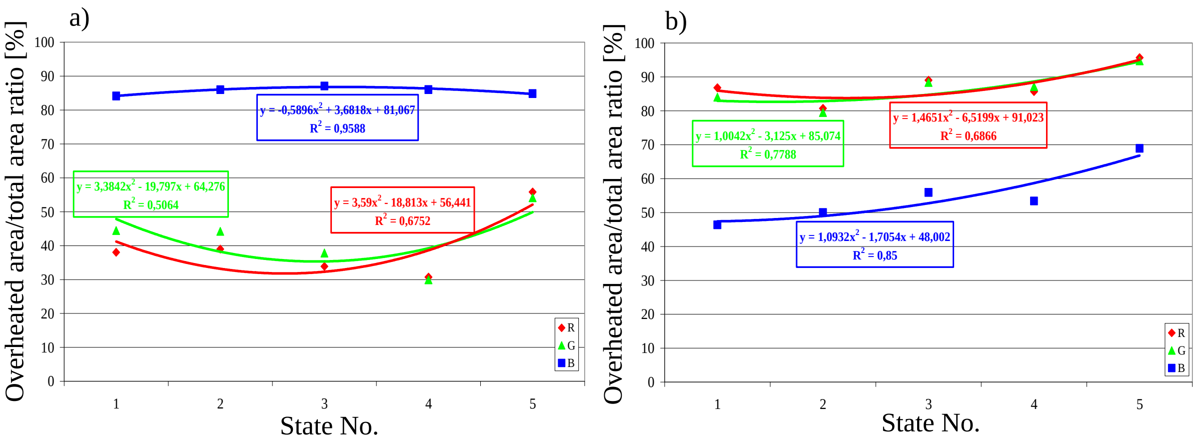

Fig. 12. Overheated area/total area ratio: a) images recorded with a Japanese videoscope; b) images recorded with an American videoscope

Summary

The above graphs prove that very good results were obtained for images of vane surface recorded in laboratory conditions with digital camera. The obtained graphs (fig. 8. 11) prove that changes of colour of vane surface reflect technical condition of examined turbine elements. Thus, application of described method improves credibility (objectivity) of assessment of vane condition in comparison with hitherto applied method. Percentage variations for individual states result from applied light and method of illumination of examined vanes. In laboratory conditions was used dispersed white light, and for videoscopes – concentrated light of another colour. Different is also the ability of colour recording by light-sensitive CCD matrixes installed in detection appliances. However, it is worth to note that application of endoscopes (i.e. videoscopes) for image acquisition can be useful for monitoring of vane condition (propagation of defects – technical condition of examined element) during periodical inspections without disassembling the turbine.

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This scientific work was financed as a research project from the means designated for science in 2008-2010