COMPUTER PROCESSING OF SOME SURFACE IMAGES OF TECHNICAL OBJECTS AFTER INFLUENCE OF THE HIGH TEMPERATURE CONDITIONS

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Abstract: Computer processing of the image of surface of operating gas turbine blades was proposed in order to make the method of the evaluation of the condition of these blades more objective. The dependences and connections between the degree of blade material overheating and the colour of analyzed surfaces were shown on the basis of images registered in visible range of electromagnetic wave (digital image – Charge Coupled Device matrix). The proposal of methodology to assign the overheated areas on the blade's surface in order to assess the range (of degradation) of thermal usage of the blade and to forecast it's working resources, might be useful to monitor the situation in the operating conditions. Moreover in the article the problematic of acquisition of the form digital images dates was presented by showing physical basis of analysis of reflected signal from metallic surface are showed in aspect of recording by photoelectric light sensor (matrix CCD).

1. NATURE OF THE UNDERTAKEN DIAGNOSTIC PROBLEM

During the operating process of technical objects such as: airplane, traction, as well as marine of propulsion, all kinds of failures of their turbine sets take place. Most common defects are material overheating, as well as thermal fatigue of jet and rotor blades. These kinds of defects lead to faulty engine operation, and sometimes in case of airplane engines to tragic accidents. Elimination of this kind of defects is always carried out as a major engine repair, which results in high costs (Błachnio, 2005; Dudziński 1987; Poznańska, 2000).

At present, the evaluation of the condition of turbine blades is carried out based on the registered image of the diagnosed element's surface and compared to the standard images of operational and nonoperational analogical blades surfaces. Such condition evaluation criteria are very subjective, because they depend on the knowledge as well as the vision of the diagnostician. Verification of diagnostician's decision is carried out through destructive method. Tested element undergoes microstructure analysis on metallographic section. Errors in the subjective evaluation by the diagnostician can lead to mistaking an overheated blade for a suitable one, or a not-overheated one for unsuitable. Up until now, a non-destructive method of evaluation of the degree of overheating of blade's material based on objective criteria hasn't been developed.

Objectivity, sensitivity and reliability increasing of evaluation condition of the tested technical element will be possible thanks to disclosure of dependences and connections between the colour change of the analyzed surfaces and the change of material microstructure owing to influence of working factor of high temperature (Błachnio and Bogdan, 2008; Bogdan and Błachnio, 2006).

On the grounds of problem analysis the following hypothesis is assumed: in visible band of electromagnetic wave the digital images processing of surfaces gas-turbine can be used for the evaluation of the condition of microstructure after effecting of working factor of high temperature.

The task of the conducted researches is aimed to demonstration of the relationship between the parameters change of surface image of gas-turbine blade and changes of the material microstructure. The data presented in form of the digital images is recorded by optical system with light-sensitive detector (photodetector) – matrix CCD (digital camera).

2. PHYSICAL BASIS OF METHOD ANALYSIS IN VISIBLE LIGHT

Blade surface is recognized by light-sensitive detector (matrix CCD with optical system) thanks to the light reflected – reemitted from blade surface (light source secondary). It makes possible the indirect method of tested object recognition through processing and analysis of the data presented in form digital images (Rafałowski, 2004; Sanecki, 2006; Manaybe and Inkokuchi, 1996). A small part of incident luminous flux is captured at metallic surface. Majority of light (90% – 95%) emitters from surface in form of visible light with the same length like incident light. Rest of energy (5-10%) is scattered in heat form (in agreement with principle of conservation of energy) (Sanecki, 2006):

$$I_o = I_r + I_p + I_e \qquad (1)$$

where:

I_o – intensity light incidence, I_r – intensity light reflection, I_p – intensity light transmission, I_e – intensity light dispersion

Property of metallic surface are characterized by numerical coefficients. When we apply these characteristics to the wave length of used radiation the properties are presented by spectrum coefficients. Most interesting light incidence coefficient is presented like ratio of luminous flux Φ_ρ reflected by illuminated surface to Φ luminous flux incidence.

$$\rho = \frac{\Phi_\rho}{\Phi} \qquad (2)$$

Every kind of surface reflection that occurs in practice can be considered as a combination of regular and diffusion reflection.

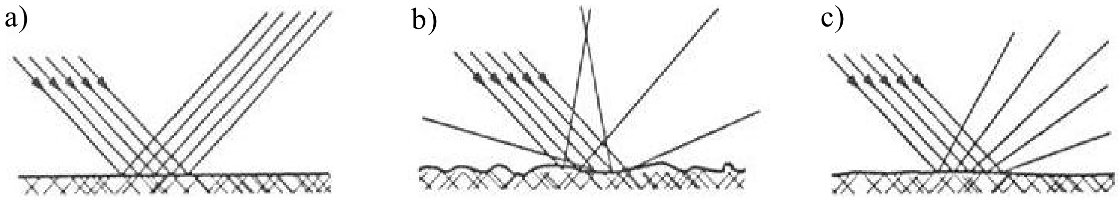

Fig. 1. Method of light reflection from different surfaces: a) polished surface, b) matted surface c) smoothed surface (Sanecki, 2006)

Depending on the structure of metallic surfaces, light reflected from them can farther propagate in the form of:

- directional reflected light (from polished surface);
- transmitted light (from matted surface);
- directional transmitted light (from smoothed surface no mirror surface).

Defined in physical sense the intensity of shinning (brightness) of metallic surface that is the source of reflected light, is described by introduction of luminance term. This term is understood as light radiation of shining surface (own, reflected, passed light) that depends on its area, value of radiated luminous flux and its light distribution in various directions.

Polish standards define luminance at a given time and direction as a ratio of quantity of the light that is at given direction, being generated from infinitesimal element of the surface which surround the given point to this element projection on orthogonal plain (Rafałowski, 2004; Sanecki, 2006):

$$L = \frac{E}{S \cdot \cos\alpha} \qquad (3)$$

Formula (3) results that the luminance of shining surface attains maximum in perpendicular direction and it decreases when the observation deviation changes.

Chemical constitution of matter which covers surface of metallic objects defined the suppression individual of wave length in radiation spectrum of shinning object and mix of selectively light reflected from its surface defines its colour (specified metals can have colour owing to selectively of light reflecting – gold, copper). To characterize the spectral properties of testing surface it is possible to use the graph ratio of spectral luminance coefficient to wave length (curve of reflection ability).

3. PROBLEM OF IMAGINING BY THE MATRIX

Matrix CCD is sensitive light detector (photodetector). Simplifying in a measure, we can say that it is built out of pixels and every pixel is an elementary part of whole registered image (single point). Task of pixels (elements of processing and accumulation) is photons capturing (measure of light intensity). In order to capture photons the pixels realize photoelectric effect, i.e. electrons freeing under influence of photons energy reaching to the centre (scheme of this conversion as well as forming losses illustrated in Fig. 2). Next, the assembled signal reaches amplifier through the electrodes assembled at the end of every rank of pixels. With the rise in gain the level of noises is also increasing. It is presented if form of graininess as well as perturbations of colour of processing images.

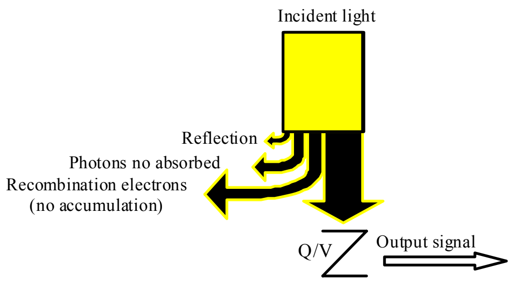

Fig. 2. Block diagram of losses in process of conversion from optical signal into CCD electric signal (Rafałowski, 2004)

Matrix CCD itself doesn't differentiate (can't differentiate) colours. It only counts photons incident (the light radiations incident on particular pixels). In front of detector the colour filter is placed, it consist of 3 primary (basic) colour: red, green and blue (this scheme of basic colour is called RGB – from first letters of English name). This is the most often applied colours system of filter which is called as Bayer's (filter) scheme.

The image acquisition process using CCD matrix and quality of imaging quantification are influenced by the following factors and parameters:

- too low sensitivity of CCD matrix – big noised (graininess);

- image defect – less onerous error mainly results from lens construction – the defect of image dimensions is among this kind of errors;
- vignetting – lightly (delicate) raising shade of images edges;
- chromatic aberration – delicate broadering of thin lines colour – the lines remind then a rainbows miniature;
- noise level – (visible on photographs as irregular bright and dark light spots which appear while photographing of uniform colour surfaces);
- accuracy of colours and brightness mapping – that is technique of reading-out of deep red and black colours as well as fragments of very high brightness by the matrix.

4. INVESTIGATIONS OF JET TURBINE BLADES

Fifteen blades of blades ring of turbine jet were examined. The recording was carried out using digital camera. On special measuring position, for the purpose of avoidance of errors at images recording, following conditions are stipulated, i.e. angle of light incidence is 45º, light dispersion is achieved by application of special diaphragms, the recorded light is in range of visible light, angle of image detection is 90º, images are of the same picture resolution. Preliminary classification according to evaluation used before was accepted. Generally, fifteen photos for each state were carried out. The examined region of interest along the edge of attack was selected (format: JPEG, size: 250x750 pixels, depth of colour: 24 bits – true colour).

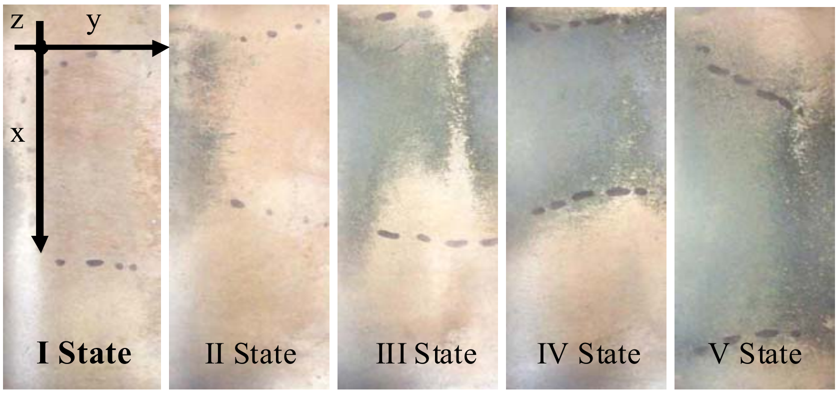

Fig. 3. Accepted classification the degree of overheating blades (according to evaluation used before) - acquisition of the digital camera

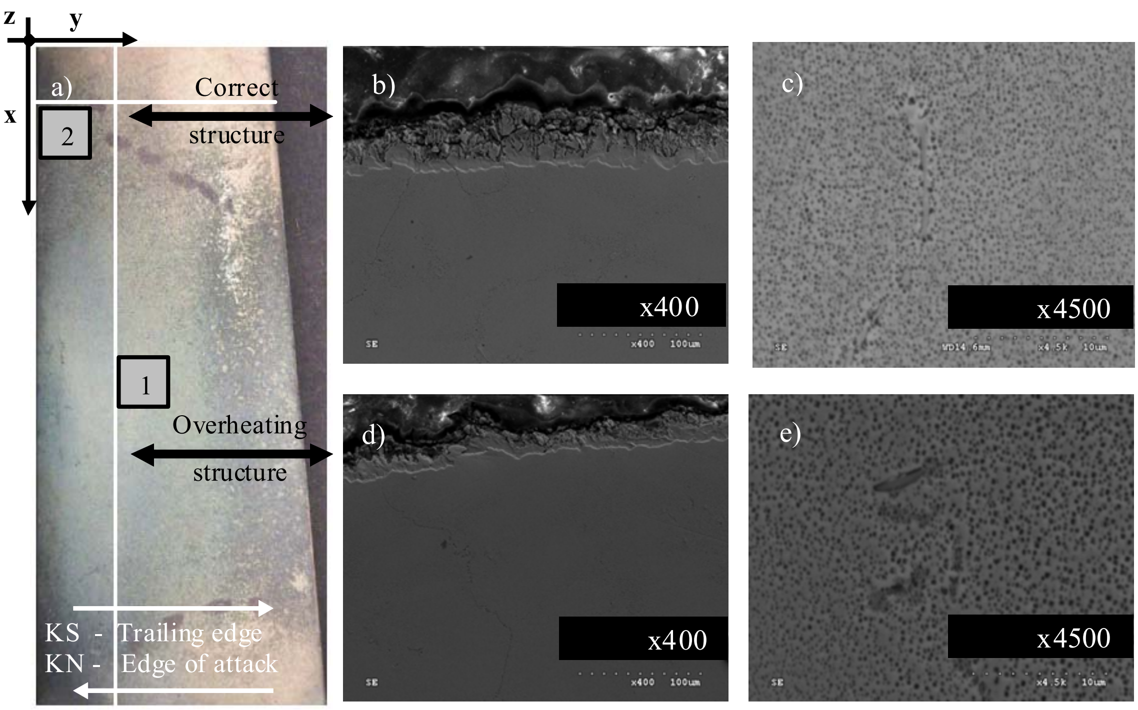

Fig. 4. Metallographic researches of blade of ring made from ŻS6 K alloy: a) cutting lines (number 1, 2) of turbine blades; b, c) example of non overheating structure of surface layer and subsurface layer; d, e) example of overheating structure of surface layer and subsurface layer

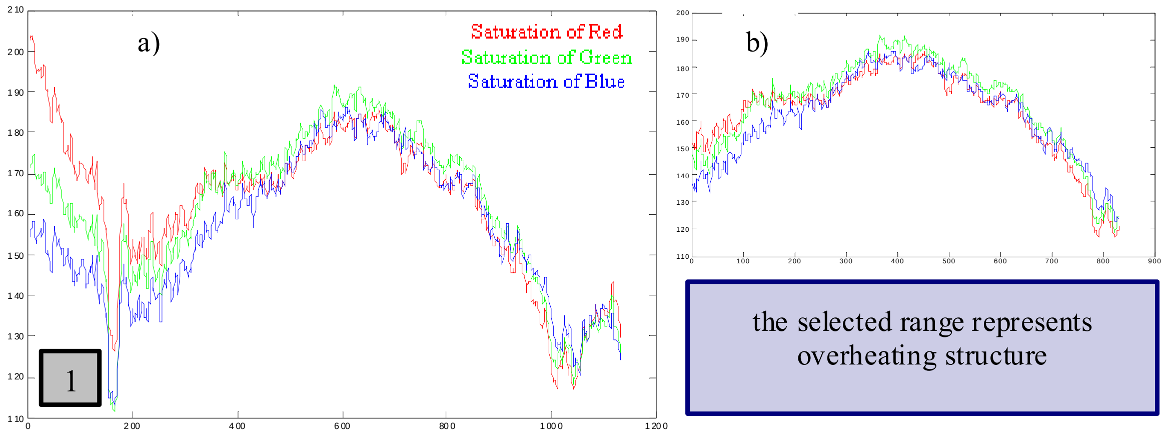

Fig. 5. Average RGB colour profiles: a) along line number 1 – parallel to edge of attack (KN), b) selected range of overheated structure

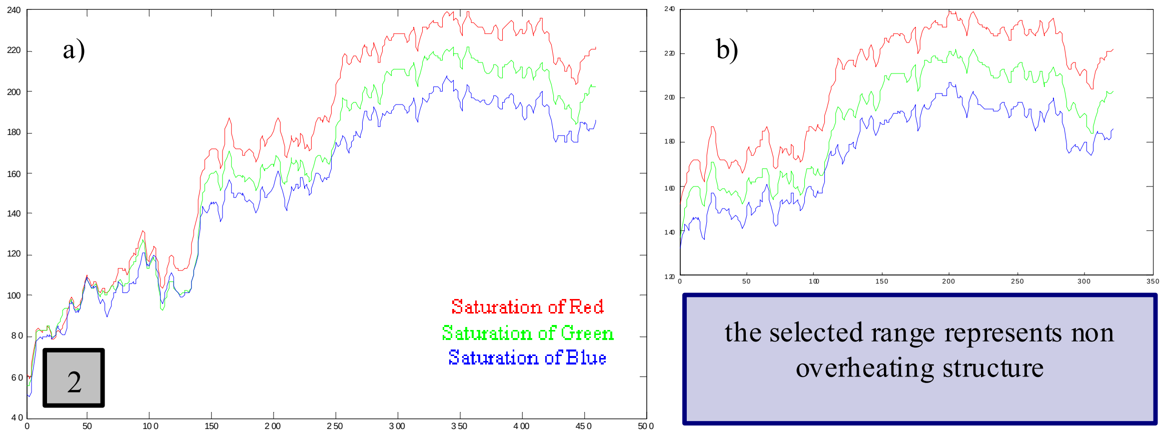

Fig. 6. Average RGB colour profiles: a) along line number 2 – perpendicular to edge of attack (KN), b) selected range of non overheated structure

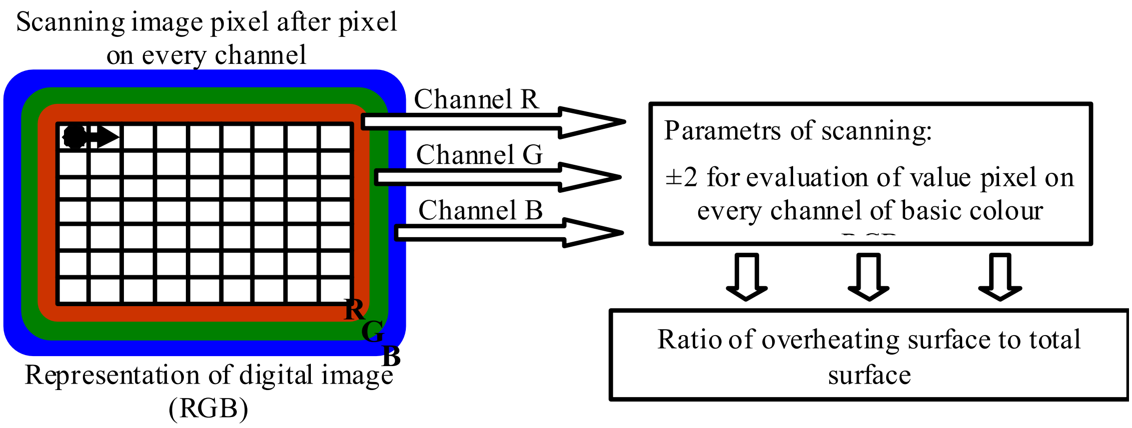

Fig. 7. Scheme of scanning images of surface blades

Blades have been working at the range of temperatures from 990K to 1123K (overheated occurred as a result of exceeding of the working temperature limit). The fifth state according to classification used before is defined as overheating blade. For the purpose of this evaluation verification the metallographic examinations were carried out along 2 cutting lines (Fig. 4).

Changes of thickness of surface layer (aluminium) and changes of quantity of precipitates and spacing of strengthening γ' phase (materials were examined with a scanning electron microscope – computer analysis of metallographic images) were defined. Changes of these both parameters have decisive effect on thermal property (heat-resisting and high-temperature creep resisting) of tested alloy (Błachnio and Bogdan, 2008; Błachnio, 2008). It makes possible presenting of graph of average colour profile which presents both the overheating structure (selected range of along line number 1 – Fig. 5 a, b) and non overheated structure (selected range of along line number 2 – Fig. 6 a, b).

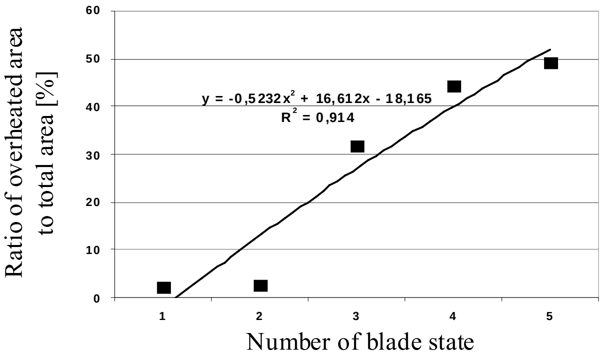

Fig. 8. Effect of scanning of surface images

On the basis of two ranges of average colour profiles (Fig. 5b, Fig. 6b) every surface element (pixel after pixel) of states (I-V) of turbine blade was tested. It was made from point of view of occurrence of colour points (RGB) which describe the overheating and non overheating structures (with tolerance ± 2 of value for each pixel from selected range) (see Fig. 7). The condition fulfillment means that pixel belongs to the range of graph 5b and the unit should be set in resulting matrix. Furthermore, in case of the range of non-overheated structure, the unit was set for pixels which out of the range of graph 6b. The final result for every state was obtained as a logical sum of two matrix. Both matrixes represent the points recognized as overheating points and the values of second matrix, as it was described above, were obtained as a result of negation of colourful points which represent the non overheating structure (= point overheating).

The points (image pixels) recognized as overheated were summed for every state and this sum was related to the total number of pixels. As a result of ratio of overheated area to total selected area (Fig. 8) is obtained.

5. FINAL CONCLUSION AND SUMMARY

As a result of scanning of blades of image surfaces for the states I - V ratio of overheating surface to total surface (expressed in percents) was obtained. The above presented graph shows that the blade from state 3 should be recognised as to be overheated. The above investigation process may contribute to the increase of credibility (growth of objectivism) of evaluation of the blade condition. Automated image acquisition along with the programme for the surfaces image recognition would also lead to rationalization and more precise diagnostics of this technical object. Moreover, the use of sight-glass devices (videscoops) for image acquisition may be applied to the investigation of the changes during the monitoring of the blade condition and damage development, i.e. technical state of examined elements during operating process (periodic researches) without the need of engine disassembly.

To get know the influence of working factor on the state of blade surface it is necessary to describe the environment of the blade turbines, i.e. the working time of the engine that includes the starting and acceleration time, while the most destructive heat loads of the engine are thermal shocks which mainly (affect) have an impact on structural elements of so-called hot part of engine, caused by the large gas temperature changes, characteristics of environment. That is, the rotation speed increase (accretion) during engine starting, distribution of temperature behind turbine, distribution of real average temperature in front of turbine (Wiatrek, 1982). The important factor which has an influence on colour of tested surfaces is the composition of fuel and correct working of injector.

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