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High-current pulsed electron beams for modification of the surface layer of parts of the flow part of a modern gas turbine engine

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Abstract. In this paper, a generalizing analysis of the results of studies and tests concerning the modification of the surface layer of highly loaded parts of modern aircraft engines is carried out. It is shown that a high-current pulsed electron beam is a reliable tool for improving the operational properties of the working blades of a gas turbine engine, and the data obtained allow us to consider the possibility of using HPEB irradiation in repair technology, as well as for leveling production defects. In addition, the necessity of using irradiation with simultaneous exposure of a high-current pulsed electron beam on all surfaces of the sample is shown, which allows obtaining a high level of operational properties.
Keywords: high-current pulsed electron beams, surface modification, gas turbine engine repair, structure study, roughness.

1. Introduction

The most important operational characteristics of the blades of a gas turbine engine are: fatigue strength, quantitatively described by the endurance limit; heat resistance; resistance to erosion and salt corrosion under thermal cycling conditions, etc. It is these operational characteristics that most often determine the service life of the entire product. The reasons for the destruction of metal parts under cyclic loading and the corrosive effect of the surrounding gas environment at elevated temperatures are various factors related both to the test conditions and material properties (structural factors) and to the manufacturing technology of these parts (technological factors). Moreover, the values of the endurance limit on the established test base and the thickness of the gas-saturated layer formed during the tests are determined by the state of the surface layers of the operated parts, namely: the presence of macro- and micro-defects, surface roughness, heterogeneity of chemical and phase composition of compositions, heterogeneity of the distribution of linear and point defects, the concentration of these defects, increased degree of hardening etc. Since with any kind of corrosion of erosive and fatigue loading, the maximum loads develop directly on the surface, it is in the near-surface layers that fatigue cracks originate and the initial stage of their growth occurs by various mechanisms [1–3]. This implies one of the basic principles of the development of new technological processes aimed at increasing fatigue strength, heat resistance, erosion and corrosion resistance of any part – surface modification, leading to the formation of coatings unique in properties, residual compressive stresses and increasing the uniformity of the physico-chemical state of the material in the surface layer. Since pulsed electron beam processing makes it possible to radically change the chemical and phase compositions, as well as the structure of the material in surface layers with a thickness of several tens and hundreds of nanometers to 10–100 microns, it is natural to assume that this type of processing, implemented at the atomic level, is one of the most promising methods for improving the performance of parts of a wide range [3, 4].

In this article, based on the accumulated experience in the development of technological processes for the modification and repair of surface layers of parts of the flow part of a gas turbine engine using high-current pulsed electron beams (HPEB), ways to optimize the technological processes of repairing turbine blades are considered.

2. Experimental setup

Turbine blades of the 1st stage of various modifications of the RD-33 engine after operation were selected as objects of research.

The material of the blades is a heat-resistant nickel alloy ZhS 32-mono, an ion-plasma condensed multicomponent coating is applied to the outer surface VSDP9+VSDP18.

The blades came out of service with a damaged coating and are subject to repair in accordance with the regulatory documentation. Based on the previously obtained results of the study, irradiation modes were established [1–3].

Irradiation of the above blades was carried out in accordance with the following mode (in 4 positions):

• energy density $W = 45–50$ J/cm^2;

• number of pulses = 10 pulses.

The irradiation was carried out sequentially on the four sides of the blade.

As part of the study, the microstructure of the outer coating was studied, the size of the coating and the modified layer were investigated using metallographic analysis [4].

3. Results and discussion

To carry out a comparative analysis of the condition of the outer coating (during irradiation), a microsection was made in the cross section of the blade pen at a distance of ~ 15–20 mm from the end of the pen before irradiation.

After irradiation (at an energy density of $W = 45–50$ J/cm^2 and the number of pulses = 10; (in 4 positions), microsection were also made, and sample preparation of the surface for examination was carried out on the surface of the initial site (see Fig.1).

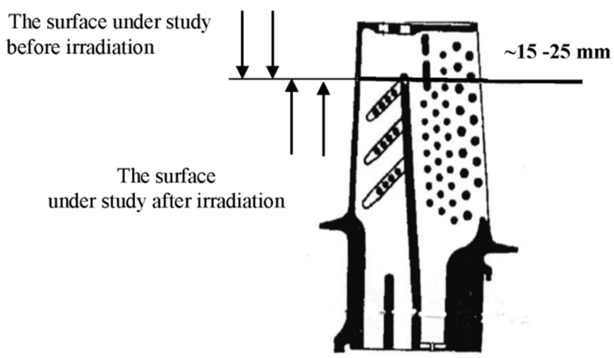


Fig.1. The scheme of cutting the blade in the manufacture of microsection.

The study of the microstructure, measurement of the outer coating before and after irradiation, as well as the modified layer were carried out according to Fig.2: on the entrance edge of the blade, output edge and on the rest of the surface.

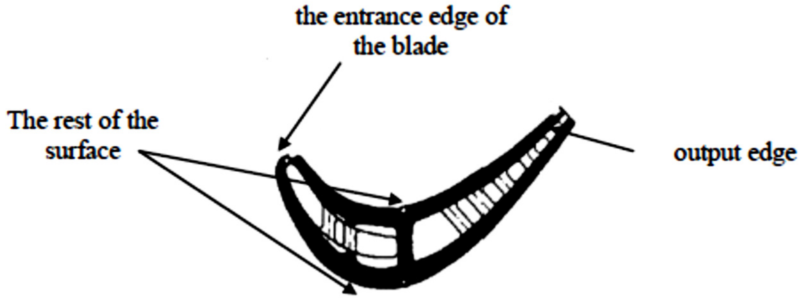


Fig.2. Controlled surfaces of the blades during the study before and after irradiation.

The results of measurements of the size of the outer coating before and after irradiation, as well as the depth of the modified layer are shown in Table 1.

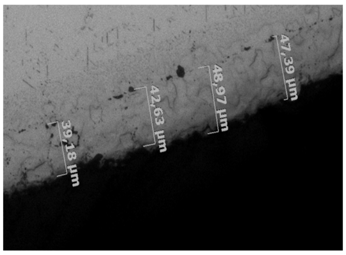
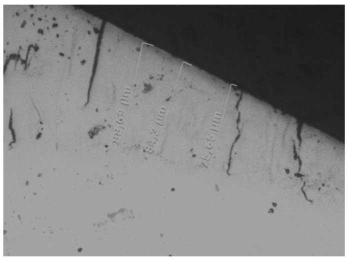
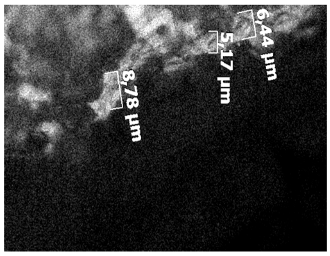
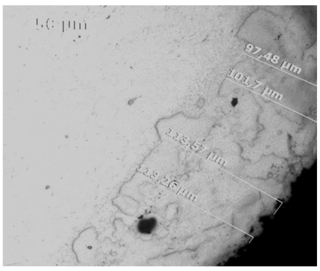
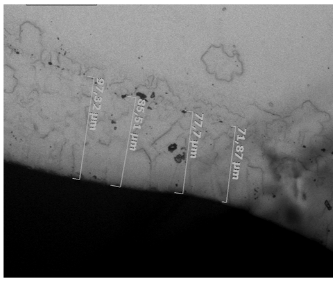
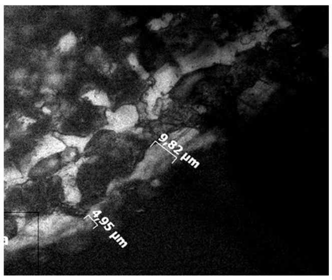
Table 1. Results of measurements of the value of the outer coating before and after irradiation

Irradiation mode	Blade Number	Viewing location	The size of the coating, microns		Presence and depth of the modified layer
			Before irradiation	After irradiation	
Energy density W = 45–50 J/cm^2; number of pulses 10 pulses (in 4 positions)	1	The entrance edge of the blade	85	60	6
		Output edge	53	56	3
		The rest of the surface	54	43	3
	2	The entrance edge of the blade	98	77	6
		Output edge	75	70	4
		The rest of the surface	78	39	4

According to the results shown in the table, the coating removal process occurs under the specified irradiation mode, and this process occurs more intensively on the input edge and the rest of the surface: the difference between the coating values before and after irradiation is up to ~ 12–25 microns on the input edge and ~ 11–30 microns on the rest of the surface. At the output edge, this parameter corresponds to ~ 3–5 microns.

The state of the microstructure of the outer coating before and after irradiation at the entrance edge, as well as the modified layer are presented in Table 2.

Table 2. Microstructure of the outer coating before and after irradiation at the entrance edge

Shoulder blade number	Before irradiation	After irradiation	
		Without etching	After etching
1			
2			

As can be seen from the photofixation of the results of the study of the microstructure of the outer coating after irradiation, the surface of the blade pen becomes less rough at all the points studied, there is no operational plaque.

After irradiation, cracks are observed along the entire perimeter of the microsection. When studying the nature of the cracks, it was found that some of them are wide open. However, all cracks spread inside the coating: the development of some cracks ends at the "coating – substrate" boundary, the trajectory of others changes when approaching the surface of the base material, and cracks develop inside the remaining coating parallel to the surface of the blade, when approaching the diffusion zone of the base material coverage.

Also, when examining the microstructure after irradiation, a modified layer in the form of a lighter zone on the surface of the blades is clearly visible on the surface. At the input edge, this zone is ~ 6–8 microns, at the output edge and the rest of the surface – up to ~ 3–4 microns (Table 1 and Fig.2).

4. Conclusion

In the process of irradiation of the blades of the I stage according to the mode: energy density $W = 45–50$ J/cm^2; number of pulses = 10 (in 4 positions), the process of removing the outer coating occurs.

On the input edge and the rest of the surface, this process occurs more intensively: up to ~ 12–25 microns (input edge), ~ 11–30 microns (remaining surface), ~ 3–5 microns (output edge).

After irradiation, the surface of the blade pen becomes less rough at all the studied points, there is no operational plaque.

After irradiation, cracks are observed along the entire perimeter of the microsoft within the remaining coating.

After irradiation, there is a modified layer on the surface and is ~ 6–8 microns – on the input edge, up to ~ 3–4 microns on the output edge and the rest of the surface.

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