Application of high-power pulse electron beams for maintenance and restoration of the properties of a gas turbine engine blades from nickel alloy GhS32 with NiCrAlY+NiAl coating and perforated holes

D A Teryaev1, O A Bytsenko2, V A Shulov1, I G Steshenko2 and K I Tkachenko3

1Moscow Aviation Institute (State Technical University), 4 Volokolamskoye shosse, Moscow, 125993, Russia
2Moscow Machine Building Enterprise MMP named after V.V. Chernysheva, 7 Vishnevaya Str., Moscow, 123362, Russia
3Efremov Institute of Electro-Physical Apparatus, 1 Sovietsky Ave., Metallostroy, St. Petersburg, 189631, Russia

E-mail: shulovva@mail.ru

Abstract. The present paper reviews the experimental results dedicated to the effect of irradiating conditions with intense pulsed electron beams on ablation kinetics of the surface layer of gas turbine engine blades made of GhS32 with NiCrAlY+NiAl resistant coatings. Application of intense pulsed electron beam allows one to ablate per a pulse the surface layers fractured during operation with thickness of 2-4 μm, if the energy density is equal to 50–55 J/cm². It has been shown that intense pulsed electron beam of microsecond duration is a high-effective instrument for modification and repair of turbine blades with perforate holes and resistant NiCrAlY+NiAl coatings without the decrease of fatigue strength.

1. Introduction

The maintenance of turbine blades of gas turbine engines allows increasing the service life of the product by more than 50% while significantly saving expensive materials and resources used to manufacture new blades [1]. At the same time, in recent years has not been carried out sufficiently fundamental research devoted to the development of high-intensity technological processes for repairing machine parts. In [1] it was proposed to use high-current pulsed electron beams to remove carbon deposits, damaged and oxidized surface layers of the GTE compressor blades. The authors of these publications developed technological processes for repairing blades of the 3rd and 7th stages of the high-pressure compressor rotor from the VT9 titanium alloy and EP866sh steels, as well as turbine blades made of the nickel alloy GhS26NK with a SDP-2 coating using a high-current pulsed electron beam formed in the «Geza-1» and «Geza-2» accelerators [2]. However, at the present time aircraft engines use blades made of GhS32 alloy with the heat-resistant coating NiCrAlY + NiAl, obtained by vacuum-plasma technology with subsequent heat treatment and hot isostatic compaction. In addition, modern blades have perforated holes for realization of forced cooling during operation.

In this regard, the purpose of this work is to study the technological fundamentals of repairing precisely such modern parts with the use of a high-current pulsed electron beam, formed in the experimental-industrial «Geza-MMP» accelerator.
2. Materials, equipment and research methods
As objects of research, we used the RD-33 engine turbine blades made of the alloy GhS32VI (Ni; 4.0-Re; 5.6-Cr; 6.2-Al; 1.0-Mo; 9.0-Co; 1.4-Nb; 1.4-N; 7.5-W; 4.0-Ta $<0.18$-C; $<0.1$-O; N; $<0.02$-H; $<0.015$-B, heat treatment: annealing at 1250$^\circ$C in vacuum for 3 hours, cooling at a rate of 50–60 deg/min, stabilizing annealing at 1000$^\circ$C in vacuum for 2 hours) with SDP-2 (base-Ni, 18-22-Cr, 11-13.5-Al, 0.3-0.6-Y) and VSDP18 (Ni; Cr; Al; Ta; Y) deposited with the MAP-1 device using the VIAM technique [3]. The appearance of the blade is shown in figures 1 and 2.

![Figure 1. The appearance of the turbine blade.](image1)

![Figure 2. The appearance of the perforations on surface of the turbine blade.](image2)

A part of the blades before the irradiation was cut by an electroerosion machine and investigated by the following methods: scanning electron spectroscopy, X-ray diffraction analysis and optical metallography in polarized light [4, 5]. In addition, the microhardness ($H_\mu$) and roughness ($R_a$) were measured. The processing of the blades with high-power pulse electron beams was carried out on the «Geza-MMP» accelerator with a rotation of 180 degrees around the vertical axis, i.e., in two positions, from the side of the back and from the side of the face (electron energy: 115-150 keV; pulse duration: 30-60 μs; energy density in the beam: 40-50 J/cm$^2$; cross-sectional area of the beam: 30-80 cm$^2$; inhomogeneity density along the beam cross section: 5%). The blades after irradiation were also cut, and transverse sections were made from the obtained test specimens, as a result of which the specific entrainment of the substance was determined as a function of the energy density and the number of pulses. In addition, the surface of the targets was investigated by SES, X-ray diffraction and OM methods to determine the thickness of the layers removed by one pulse and the recrystallized and modified target regions.

3. Experimental data and discussion
Some results of the study are presented in the table 1, as well as in figures 3 and 4.

From these data, we can observe that the material removal rate from the surface layer of the NiCrAlY + NiAl coating after hot isostatic compaction (HIC) is 2–4 μm per pulse, which is significantly lower than the ablation rate from the surface of the SDP-2 coating (5–10 μm). The latter is associated with the compaction of the material during the HIC, and especially with the blocking of the pores formed at the stage of deposition of the vacuum-plasma coating. In this regard, it is necessary to use accelerators with a higher energy density in the pulse. Another task for the accelerators manufacturers is to search for the possibility of rotating the beam and carrying out the irradiation in a volume without a cathode. It follows from table 1 that an increase in the thickness of the coating occurs at the trailing edge of the blade due to the spraying of the material. The sprayed material precipitates on the tip of the cathode, as well as at the trailing edge of the blade, which leads to its premature failure. Perforated holes on the surface of the blades are retained (figures 5 and 6), which is confirmed by the results of the blade-shedding tests (table 2).
Figure 3. Coatings on the surface of the back of the blade before irradiation.

Figure 4. Coatings on the surface of the back of the blade after irradiation.

Table 1. Results of the study of the ablation kinetics from the surface of the blades.

| № | View location | Coating thickness, μm | Irradiation mode | p/p | Before irradiation | After irradiation |
|---|---------------|-----------------------|------------------|-----|-------------------|-------------------|
| 1 | Leading edge  | 91.5                  | W=50÷55J/cm²,   | 10a525 | 86.59             | 86.59             |
|   | Trailing edge | 71.7                  | pulses number:  |      | 76.56             |                   |
|   | Remaining     | 43.7                  | face–5 pulses   |      | 43.7              | 32.2              |
|   | surface       | 43.7                  | back–10 pulses  |      | 32.2              |                   |
| 2 | Leading edge  | 86.58                 | W=50÷55J/cm²,   | 10a4 | 63.7              |                   |
|   | Trailing edge | 59.3                  | pulses number:  |      | 63.7              |                   |
|   | Remaining     | 49.2                  | face–5 pulses   |      | 49.2              | 37.3              |
|   | surface       | 73.35                 | back–10 pulses  |      | 73.35             | 61.5              |

Figure 5. Perforations appearance after 5 pulses.

Figure 6. Perforations appearance after 10 pulses.
Table 2. Blade-shedding test results for the turbine blades after removal of the coatings.

| Blade number | Blade-shedding before coating removal $Q_7=376^{+32}_{-27}$ gr/sec | Blade-shedding after coating removal $Q_7=376^{+32}_{-27}$ g/sec | Lum-1OV control |
|--------------|--------------------------------------------------|--------------------------------------------------|-----------------|
| 10g503       | 341                                             | 311                                             | Background glow on the platform |
| 10i335       | 339                                             | 312                                             | -               |
| 10c451       | 330                                             | 304                                             | -               |

4. Conclusion

It was shown experimentally that the material removal upon irradiation by a high-current pulsed electron beam from the surface of the NiCrAlY + NiAl coating after the hot isostatic compaction (HIC) is 2–4 μm per pulse, which is much lower than the removal due to ablation from the surface of the SDP-2 coating (5–10 μm). The latter is associated with the compaction of the material at the HIC, and especially with the blocking of the pores formed at the stage of deposition of the vacuum-plasma coating.

For technological reasons, to optimize the turbine blades maintenance process, it is proposed to develop accelerators of higher power and with a separate chamber for spraying the material of the blades surface layers to increase the life of the cathode.

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References

[1] Shulov V A, Novikov A S, Engelko V I 2012 *High-current pulsed electron beams for aircraft engine construction* (Moscow: Artek Publishing House) p 292
[2] Kablov E N 2001 Casted blades of gas turbine engines (alloys, technology, coatings) (Moscow: MISiS) p 632
[3] Yatsenko B, Mueller G, Bluhm H 2001 *Vacuum* 62 211
[4] Perlovich Y A, Isaenkova M G 2008 Three laws of substructure anisotropy of textured metal materials, revealed by X-ray method of generalized pole figures, in Applications of Texture Analysis (New York: Wiley) p 189
[5] Shulov V A, Paikin A G, Teryaev D A, Bytsenko O A, Engel’ko V I, Tkachenko K I 2013 Structural-phase changes in surface layers of elements made of VT6 titanium alloy under irradiation by high-current pulsed electron beam (Road Town: Pleiades Publishing, Ltd.) p 189