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ELECTRIC-SPARK ALLOYING TECHNOLOGY FOR IMPROVING THE WORKING LIFE OF STEAM TURBINE ROTOR BLADES AND EQUIPMENT FOR ITS IMPLEMENTATION[1]

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Work is devoted to studying development of technology for forming erosion-resistant coatings for steam turbine rotor blades by electric-spark alloying. Comparative analysis is provided for current methods of steam turbine rotor blade strengthening and repair. It is shown that electric-spark coating formation on leading edges is important, and development of forming technology is connected with a search for new materials. New engineering solutions are found for coating formation from cobalt stellites, the properties of cobalt stellite and cermet hard alloy VK8 electric-spark coatings are studied, and the effect of operating unit parameters on coating formation is demonstrated. New vibrator structures are created for forming electric-spark coatings making it possible to expand the range of electrode vibration to 260 Hz, and specimens are prepared for testing with coating formation.

Keywords: electric-spark alloying; electric-spark coatings; coating erosion resistance; steam turbine blades; blade trailing edge; leading edge; thermal power station; electromechanical vibrator; single pulse energy.

Rotor blade (RB) erosion of the last stages of steam turbines is a serious problem of steam turbine manufacture.

Various methods for protecting the leading and trailing edges of RB last stages from erosive breakdown have their own advantages and disadvantages. They are summarized in Table 1.

A promising method for protection from erosion is formation of a protective-strengthening coating based on use of electric-spark alloying (ESA) technology [1 – 3]. This method is most economic and is promising for application of new materials, and development of equipment and a production process. It is based on physical phenomena of electric erosion and unipolar transfer of anode (tool) material to a cathode (component) with occurrence of pulse discharges in a gas medium (Fig. 1). During protective-strengthening coating formation on a blade surface the blade being treated is the cathode, and a consumable electrode-tool is the anode.

Between the surface being treated (alloyed) and alloying electrode there are electric current pulses with energy of 0.5 – 50 J lasting $1 \times 10^{-3} - 1 \times 10^{-5}$ sec, developing local material temperature in the space between the electrode from 4000 to 12,000 K [4]. Due to a relatively low (normally up to 100 Hz) sequence frequency of discharges, the short time of pulse occurrence and high component (blade) substrate thermal conductivity, it is not heated and has a temperature not above 200°C.

Research procedure. Specimen preparation for performing studies was accomplished from workpieces that in turn were prepared by cutting from different parts of rotor blades made of corrosion-resistant steel 12Kh13Sh dismantled from the LPR of a PT-65/75-130 Leningrad Metal Works turbine. Use of the blade material (steel 20Kh13Sh) was due

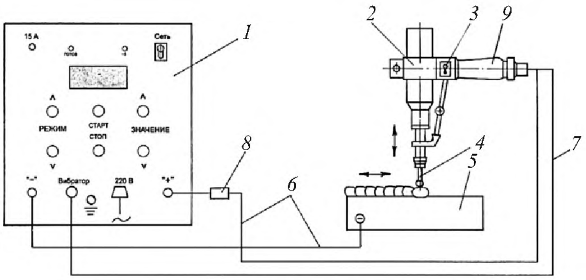

Fig. 1. Equipment for ESA: *1*, source control panel; *2*, vibrator; *3*, switch; *4*, electrode; *5*, component; *6*, welded cable; *7*, electric motor supply lead; *8*, series resistor; *9*, handle.

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to the fact blades of this material are given oil quenching for martensite followed by high-temperature tempering at 650 – 700°C, experimental specimens had standard (plant) heat treatment, and steel 20Kh13Sh microstructure corresponded to the as-delivered blade structure. Specimens were used for study with dimensions of 20 × 20 × 8 mm and with roughness R_a 0.8 μm.

A study of the microstructure and coating thickness was accomplished in prepared transverse microsections using a DMI 5000M (Leica, Germany) optical inverted microscope.

X-ray microanalysis of elements content within a coating and base was determined by means of a Tescan Vega scanning electron microscope with an OXFORD Instruments X-Max attachment with an accelerating voltage up to 30 kV.

Specimen surface roughness determination before and after coating formation was determined by means of a contour instrument model 220 in a profilometric regime.

Coating formation on specimens was accomplished in Spark-1000 (development of the Belorussian National Technical University) and GBF-3 (JSC VTI development) units. Their characteristics are given below:

	Spark-1000	GBF-3
Power requirement, kW	1.0	0.5
Supply voltage, V	220	60 – 90*
Overall dimensions, mm		
length	500	500
width	250	480
height	250	120
Weight, kg	20.5	15

* From rectified current welding circuit.

Coating formation was accomplished with electrodes (diameter 5 mm, length 50 mm) of cermet hard alloy VK60M, cast stellite grade V3K, and stellite-6.

TABLE 1. Results of Evaluating the ESA Method Compared with Other Well-Known Methods for Strengthening Worn Elements of a Steam Turbine Flow Section

Protection formation method	Resistance			Strengthened objects	MUF	Ecology	Applicability to repair work	Note
	erosion	abrasive	corrosion					
Soldering plates 2 mm thick of stellite V3K with PSr-45 solder on steel 15Kh11MF-Sh	High, 1.0 — adopted as standard	High	Mean	Only last stage RB leading edge	High	Clean	Used	Expensive PSr-45 solder is used. For second repair 50 – 90% of plate peeled off
HFC hardening of steel 15Kh11MF-Sh 0.2 mm thick	Low, 0.25 – 0.3	Low	Low	Only last stage RB leading edge	High	Clean	Not used	Considerable defectiveness of HFC hardened layer
GTM application of V3K stellite powder:								
gas flame — 3 mm	Low, 0.01	Low	Mean	RB and GV leading and trailing edges	Low	Ecological protection necessary	Used	GTB with low adhesive and cohesive properties, high porosity. Expedient to use only with subsequent flashing off
plasma — 0.3 mm	Low, 0.01	Low	Mean	RB and GV leading and trailing edges	Mean	Ecological protection necessary	Used	
detonation — 0.2 mm	Low, 0.01	Low	Mean	Only last stage RB leading edge	Mean	Ecological protection necessary	Used	
Laser surfacing	Mean	High	High	Only last stage RB leading edge	Mean	Ecological protection necessary	Used	
Ion-plasma coating with alternating layers of Ti and TiN up to 60 μm	High	Low	High	RB and GV leading and trailing edges (blade covered entirely)	High	Clean	Not used	Production process increases component cots by factor of two. Low process productivity
ESA coating — 180 – 250 μm (JSC "Turboatom" technology) T15K6	Mean, 0.6	High	Mean	Only last stage RB leading edge	High	Clean	Used	Quite simple technology. Cost of work for coating formation is less than 10% of component cost
ESA coating 250 – 300 μm VK60M (VK6, VK8); 300 – 350 μm stellite V3K (OJSC "VTI" technology)	High 0.95 – 0.98	High	Mean	RB and GV leading and trailing edges	High	Clean	Used	Possibility of using technology directly in repair of HPR, MPR, and LPR blades in set-ups with rotor locations: on repair area trestles; in bearing supports with an open cylinder cover; without removing the cylinder cover through turbine condenser (only for rotor blades of turbine last stages with power more than 50 MW)

Note. MUF is material utilization factor; GTM is gasothermal method of coating formation.

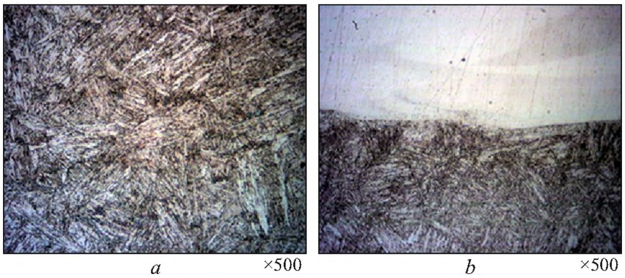

Fig. 2. Specimen microstructure (steel 12Kh13-III) before (*a*) and after (*b*) stellite coating application (etchant 4% alcoholic HNO_3 solution).

Coating wear resistance was studied in a MSTs-2 friction machine using a "roller – block" friction pair with coating on the roller.

Research results. ESA-coatings prepared using a V3K electrode are continuous and uniform; only an insignificant number of pores was observed in individual areas. Metallographic studies established that the base material microstructure (highly tempered martensite) does not change during ESA (Fig. 2). This provides the possibility of forming a coating on turbine blades made of metal and cermet materials without a thermal effect, and without the risk of obtaining a quenched microstructure or fatigue crack generation.

Coating thickness on average with single-pulse energy of 30 – 32 J is 200 μm (Fig. 3*a*). Coatings are well bonded with the base, and there are no extraneous inclusions and pores at the coating interface — basic metal boundary. A magnified microstructure is shown in Fig. 3 for a typical coating area without etching. Magnification made it possible to observe within a microstructure dispersed phases of dark color with a size from 0.05 to 0.25 μm. Probably this phase is iron that saturates coating material almost uniformly and is distributed within its volume.

X-ray microanalysis at nine points of a coating and base (Fig. 4) made it possible to reveal chemical element distribution within a coating. The distance between points was about 30 μm.

Element distribution is typical for the base and coating. It is caused by occurrence of electrode and substrate electroerosion processes and metallurgical movement up to 180 μm (points 1 – 6); the change in iron, cobalt, and chromium concentration is most marked in the area of points 6 – 8 (60 μm — transition zone).

Energy parameters affect coating properties as follows:

— an increase in Spark-1000 unit generating pulse duration from 100 to 250 μsec with the electrodes used (stellite grade V3K and stellite-6) increasing coating thickness by not less than 35%;

— an increase in pulse generation frequency from 500 to 6000 Hz using the same stellite electrodes leads to an increase in surface roughness from 5.68 to 25.7 μm;

— an increase in pulse duration from 60 to 120 μsec with the same electrodes leads to an increase in surface roughness of a coating formed from 3.67 to 11.7 μm;

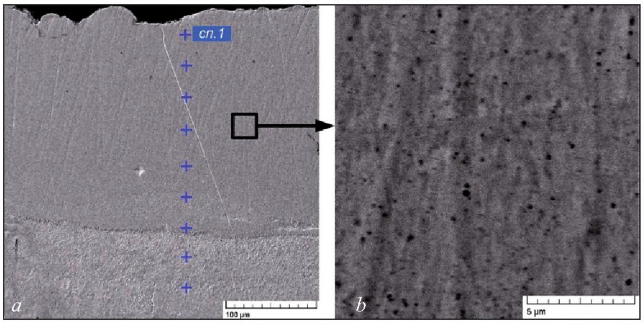

Fig. 3. Microstructure of ESA coating with a stellite V3K electrode unetched at different magnifications of electron microscope (+*cn.1* is first point of coating chemical composition obtain by x-ray microanalysis method, and subsequent points are designated "+").

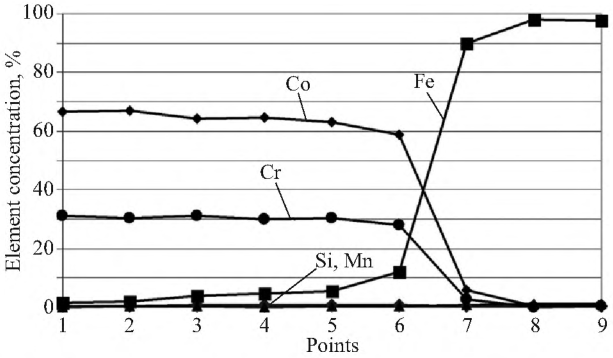

Fig. 4. Element concentration distribution curves in ESA coating at depth of 270 μm.

— an increase in pulse duration using an electrode of sintered hard alloy VK8 led to scatter of roughness and microhardness. It may be explained by the nonuniform distribution of carbide through the coating cross section, distorting measured results;

— all coatings prepared using VK8 electrodes have almost identical thickness and roughness outside a dependence on change in pulse frequency; with an increase in pulse frequency the number and size of porous inclusions increases;

— coatings formed with a pulse frequency of the order of 3200 Hz have the best wear resistance;

— during friction and wear testing there is no clear separation and breakdown of a coating;

— there is no coating porosity at the base-coating interface for all coatings.

The process of ESA-coating formation from stellites (stellite V3K and stellite-6) and from sintered stellite hard alloy VK8 is not the same. Base alloy VK8 is tungsten carbide, melting at a higher temperature compared with stellites, whose base is cobalt. During a single discharge (10^{-3} – 10^{-1} sec) the amount of VK8 material transferred from anode to cathode is less than for stellite materials. The liquid phase crystallization time for alloy VK8 is much less than the liquid phase for stellite alloys. As a result of this with a pulse frequency of 100 Hz the next portion of a VK8 coating is carried to the crystallizing mass of the layer of this

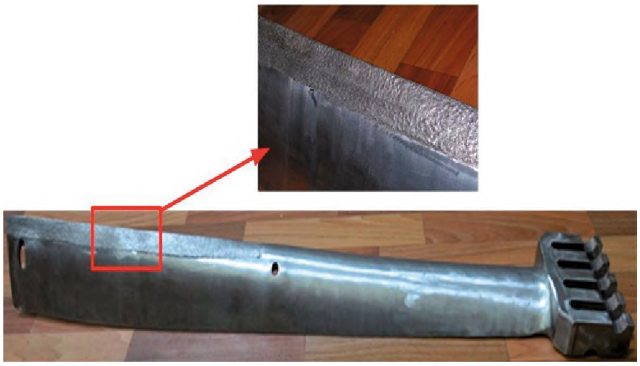

Fig. 5. External appearance of last steam turbine stage rotor blade with an ESA stellite coating on leading edge.

coating. Microwelding of the electrode and substrate does not occur ("electrode sticking effect"). With application of stellite alloys each new coating portion falls on layer being in a semiliquid condition with a greater amount of liquid phase not managing to crystallize. As a result of this there is microwelding of material transferred with each pulse to a layer already present on a substrate in a semiliquid condition. The GBF-3 unit, for which the vibration frequency is 15 – 25 Hz, depending on single pulse energy, provides stellite coating formation up to 500 μm without an "electrode sticking effect."

Taking account of this stellite materials are currently more promising for creating effective erosion-resistant coatings on the leading edge of a blade of the last steam turbine stage. Technology and equipment for electric-spark coating formation are actively being developed.

In order to prevent "coalescence" a process has been developed using an underlayer 0.2 mm thick, consisting of powder reagents based on titanium carbide by which a stellite coating was formed with increased electrode frequency [5 – 7]. Coating formation productivity increased by 30%; an "electrode sticking effect" was not observed.

In order to prevent "coalescence" an electromechanical vibrator (applicator) has also been developed, accomplishing vibrations of an electrode by cams, driven from a direct current electric motor, which may be installed both outside and within the vibrator housing.

Vibration is accomplished with a frequency up to 260 Hz. The increased frequency reduces coating roughness and lowers the effect of electrode "coalescence" with a base.

An RB made of steel 15Kh11MF-Sh is shown in Fig. 5 with an electric-spark coating of stellite V3K on the leading edge, formed on a substrate from reagents using a Spark-1000 unit, fitted with an electromechanical vibrator providing a vibration frequency of 260 Hz. Coating layer thickness is 320 μm.

CONCLUSIONS

1. Electric-spark formation of protective coatings is an effective and economic method for reducing blade erosion of the last stages of a steam turbine and restoring the operating capacity of blades subject to erosion.

2. It is distinguished by the local nature of coating formation, absence of a thermal effect on the component being treated, a high material utilization factor, the possibility of applying a coating without deblading a turbine, or even without uncovering the cylinder. Studies and existing experience show that:

— with use of electrodes of sintered cermet hard alloy VK8 and stellites (grade V3K and stellite-6) an increase in generated pulse duration from 100 to 250 μsec increases coating thickness by not less than 25% with absence of porosity at the base-coating interface and good coating adhesive strength with the base;

— in order to form coating by the electrospark alloying method it is preferred to use cobalt stellite V3K as electrode material;

— the microstructure of a V3K coating formed on steel 12Kh13-Sh does not contain defects in the form of microcracks, cavities, and is uniform through the coating thickness;

— it is possible to avoid an "electrode sticking effect" using an underlayer of reagents applied to a surface before coating formation and by increasing electrode vibration frequency.

3. Equipment consisting of a vibrator and pulsed sources has been created, which makes it possible to vary parameters over a wide range and create high quality coatings: source with pulse frequency from 500 to 12,000 Hz and duration from 20 to 250 μsec. Vibrators have been developed with an electrode vibration frequency up to 260 Hz.

4. Coatings have been prepared made of stellite up to 300 μm thick, providing good coating life in an erosive atmosphere of moist wet steam.

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