International Journal of INNOVATIVE AND INFORMATION MANUFACTURING TECHNOLOGIES
IIMT
Donetsk National Technical University & International Union of Machine-Builders
International Journal of Innovative and Information Manufacturing Technologies, SHEI "Donetsk National Technical University"; 58, Artyoma Street, 83001 Donetsk, Tel.: +38 062 305 01 04, Fax: +38 062 301 08 05, E-mail: ij.iimt@gmail.com, Skype: ij.iimt, http://iimt.donntu.edu.ua

TECHNOLOGICAL FEATURES OF GTE COMPRESSORS BLADES RESTORATION BY USING THE FUNCTION-ORIENTED COATING

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Submitted 15.05.2015 accepted 25.05.2015

Abstract. In article it is analyzed features of using the GTE compressors blades and there are data about technological features of their restoration by using the function-oriented coating. In work the parameters of corrosion and erosive coating destruction during operation compressors blades are considered. The universal structure of restorations manufacturing process titanic alloyed blade with ion-plasma coatings restoration is developed. This technological process is structured by the main stages. To increase resistance and for uniformity erosive destruction of coating during using of them, there is offered an application of function-oriented coating.
Keywords: gas-turbine engine, blades, technology of restoration, vacuum ion-plasma coatings, function-oriented coatings.

1. Introduction

Blades of the gas-turbine engines (GTE) compressor are basic elements of modern aviation engines which define a resource and reliability of their operation in the combined action of gas corrosion processes (high-temperature oxidation, different types of salt corrosion), the erosive phenomena, and phase and structural changes of material properties. It is caused by action of aggressive gas environment at high temperature, humidity, liquid particles, a dust, sand and other particles in an air stream. This leads to emergence of a chemical and abrasive erosion of blades elements and their failure.

Also it is necessary to notice that elements of compressors blades during operation tests tensile and bending stress from centrifugal forces, bending and torsional stress from a gas stream, variable tension from vibrating loadings, with largely change frequency and amplitude, and also thermal tension from thermal loadings. Wherein recurrence of sign-variable tension destroys of blades because of arising micro cracks, and phase and structural changes of materials properties [1, 2, 3].

Besides, the compressors blades (especially 1st step compressors blades) the first perceives an action of large foreign body which have got to engines tract [4, 5]. That leads to considerable local impulsive tension and to decrease of their work-life.

Hereby, the work-life and reliability of GTE is defined by blades properties to resist to complex action of gas corrosion and the erosive phenomena, phase and structural changes in material properties, thermal processes, considerable variable tension (of various types) from vibration actions, cyclic and impulsive loadings.

In modern engines, compressor blades (fig. 1) make from special titanic alloys. They have a complex spatial of blades feather, with the thin input and output edges. The compressors blades is one of the most labor-intensive and high-value part of GTE. It is caused by complex technologies and expensive materials to their manufacturing, and a large number of them in one engine [5]. The whole complex of various finishing and strengthening processing is applied to increase lifetime and reliability of GTE compressor blades. For example, for decrease of corrosion and erosive effect during operation of GTE TV3-117 model, the vacuum ion-plasma coating is put on compressors blades. The coating allows to considerably raise of their lifetime [5].

Fig. 1. The general view of GTE compressor blades TV3-117 model

The executed researches of compressors blade coating destruction features show that during operation GTE the coating is destroys irregularly by elements and blades surfaces (fig. 2). It caused by a spatial form of blades elements and kinematics of its motion, gas streams motion features in a power stroke of the engine and also particles of a dust and liquid actions. Coating destruction on a blades usually begins on a 1st blade input edge, in a zone of crossing the input and peripheral edges. Then, the destruction of a coating extends from this zone on an input edge down to the lock of blade and from peripheral edge to output edge 2. Then, from these zones the coating starts to collapse on surfaces of a blades trough 3, and then a coating remains only in a blades trough zone 4. On fig. 2 the destruction scheme of nitride-titanium coating on a of blades feather surface from a trough side, depending on duration of use, is presented (shaped lines show borders of final fracture of a coating which change in time): 1- destructions of an input feathers edge, 2 - destructions of an output feathers edge, 3 - a surface without coating, 4 - a surface with coating. The carried-out researches are executed on nitride-titanium coated compressors blades with a thickness of coating 5-6 microns, by a vacuum ion-plasma coating method using the VT 1-0 titanium cathodes. Here it should be noted that coating on a feather surface has certain destructions regularities in use of GTE blades. It may be noticed that coating on a feathers surface from back side is less subject to destruction.

Thus, the researchers have allowed to establish that in use of GTE the compressor blades coating collapse irregularly. Even after long-term use the part of a coating remains on blade feather surfaces (fig. 2). And in blades use there is an intensive destruction of blades feather main material, in places of final destruction of coating. Whereas in zones with undamajed coating the main feathers material is not exposed to destructions. These uneven corrosion and erosive destructions processes lead to loss of blades maintainability.

To improve the compressors blades maintainability level, there are any steps to follow at operating blades and coating:

1. At uniform coating thickness on surfaces and elements of blades feather, it is necessary to provide long-term operation only before the first signs of final coating fracture in areas of high fracture coatings.
2. For providing full operational capacity of blades feather coating, in the uneven coating destruction conditions by various blades areas, it is necessary to provide a variable thickness of the coating. It size should be defined depending on the degree of destruction of coating in this blades area at its operation. In this case, the coating thickness can be continuously varying or discontinuous varying - according to features of change the destruction size of coating in this point or in this blades feathers area (fig. 2) at its operation.
3. For providing full operational capacity of blades feather coating, in uneven destruction conditions of coating on various blade areas, it is necessary to provide a variable coating properties by erosive firmness. It value should be defined depending on the degree of destruction of coating in this blades area at its operation. In this case erosive coating firmness can be continuously varying or discontinuous varying - according to features of change the destruction size of coating in this point or in this blades feathers area at its operation. Here it is possible to note that in case of providing the various thickness or properties of coatings, the full destruction of coating on all blade feather surfaces and elements at the same time is provided at the same time. Therefore by the time of blades repair all coating collapses at the same time and it is not necessary to remove it from surfaces or to remove it requires a minimum cost. The purpose of this work is development of blades compressors GTE restoration manufacturing process based on the function-oriented coatings application which provide increase of blades resistance under difficult operation conditions.

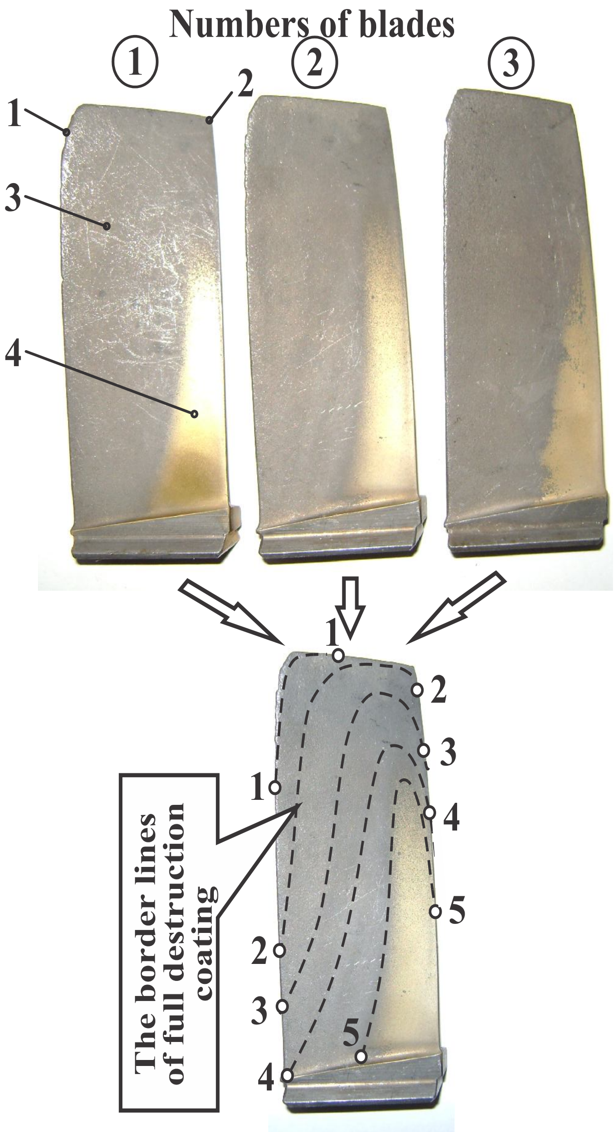

Fig. 2. Scheme of nitride titanium coating destruction on the blades feather surface from trough side, depending on duration of usage: 1 – the destruction of input feather edges; 2 - the destruction of output feather edges; 3 – the uncoated surface; 4- the coated surface

To achieve the purpose it following tasks are defined:

1. To analyze the corrosion and erosive destructions features of ion-plasma coated blades compressors GTE.

2. To develop the universal structure of blades compressors GTE restoration manufacturing process with ion-plasma coating.
3. To offer the scheme of formation a multilayered function-oriented coating on blades compressors GTE. To develop the structure of a multilayered coating on blades feather working elements scheme of creation.
4. To develop recommendations about formation the structure of blades compressors GTE restoration manufacturing process. These tasks are solved in this work.

2. Universal structure of blades compressors GTE restoration manufacturing process.

It is possible to note that in blades compressors GTE can be used without coating and with the titanium nitride vacuum ion-plasma coating. At GTE operation the following cases of ion-plasma coatings wear on compressors blades are possible: o- the coating has no zones of full wear and destructions, u- the coating has zones of full wear and destructions on blades feathers edges, - the coating has zones of full wear and destructions on blades feathers edges and surfaces. It is possible to note that in the last case of coating destructions, the intensive corrosion and erosive destruction process of blades material body which lead to loss of compressors blades maintainability in general. Therefore in this case it is necessary a careful inspection and fault detection of blades considering their maintainability(fig. 3) Depending to the vacuum ion-plasma coating destructions features on blades feather surfaces the structure of blade GTE compressor restoration manufacturing process is made. Therefore the structure of this manufacturing process is multivariate, it is built taking into account the presence or absence of the old coatings, the degradation of coatings and a new vacuum ion plasma coating characteristics. Also it should be noted that the structure of manufacturing process can include the nitriding of blades which is an effective way of additional increase resistance of them.

On fig. 3 the universal structure of restoration manufacturing process of titanic alloyed blades GTE TV3-117 with ion-plasma coating is presented. Here it is shown: *V*- input of manufacturing process; *W*-output of manufacturing process; v_{11} - input of the 11th operation; w_{10}- output of the 10th operation. The blades restoration manufacturing process universal structure (fig. 3) contains the following steps:

1. Inspection and fault detection of blades. At this step the maintainability of blades is defined.
2. Pre-cleaning of blades from corrosion and scale. It can be made:
2.1. By means of easy blowing by fine powder of electrocorundum, the black or green carborundum based on pneumatic abrasive processing.
2.2. By means of ultrasonic cleaning.
3. Final cleaning and polishing a small nick, dents, corrosion and erosive damages.
4. Sorting blades according to coating existence
4.1. Blades without coating. If blades are without coating, they go to geometry control of them.
4.2. Blades with vacuum ion-plasma coatings.
5. Sorting blades according to wear and destruction coating degree.
5.1. The coating has no zones of a wear-out and destructions.
5.2. The coating has zones of a wear-out and destructions on blade feathers edges.
5.3. The coating has zones of a wear-out and destructions on edges and surfaces of a blades feather.

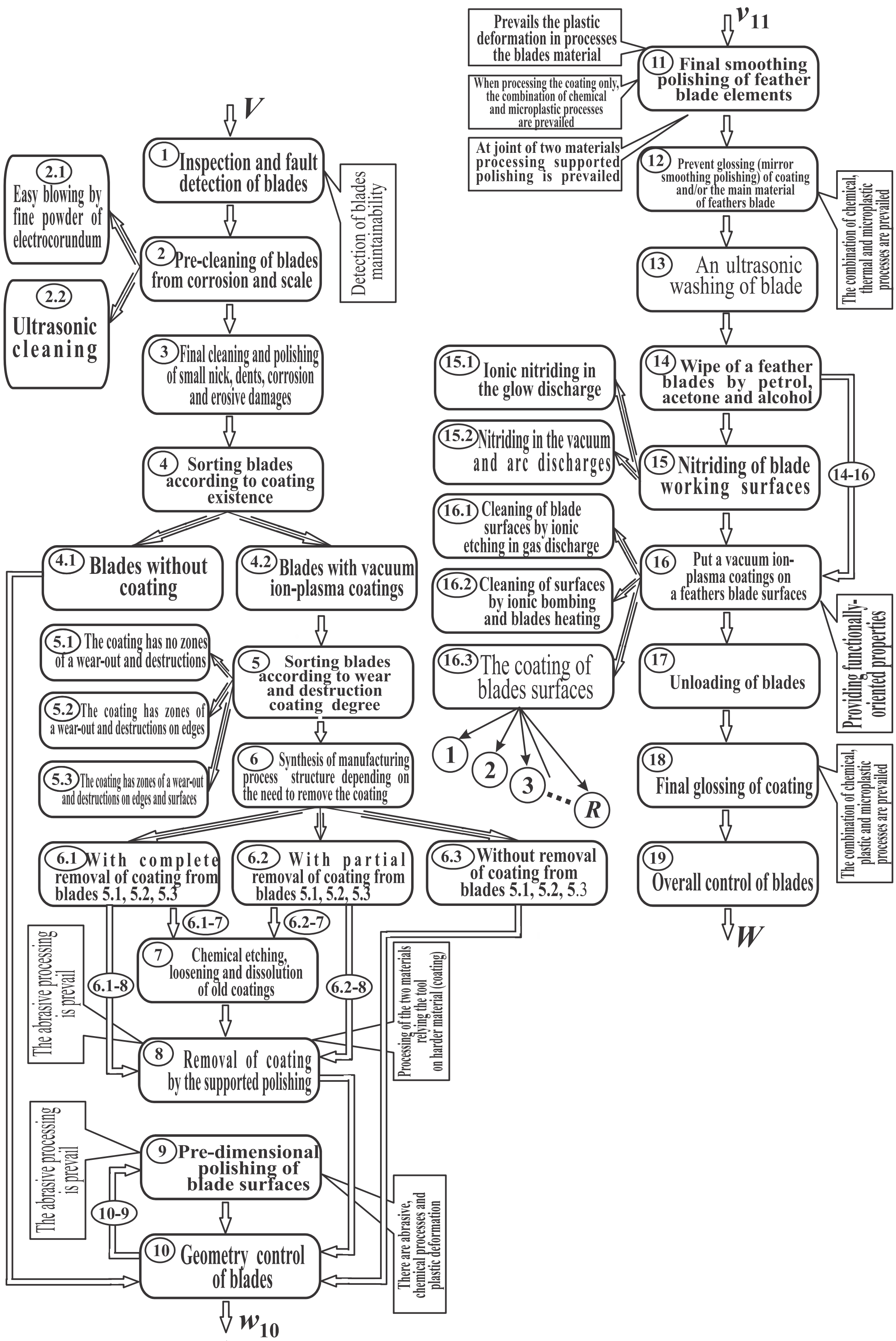

Fig. 3 The universal block diagram of titanium alloyed GTE TV3-117 blades with the ion-plasma coatings manufacturing process: V- input of manufacturing process; W - output of manufacturing process; V_{11} – input of 11-th operation; W_{10} – output of 10-th operation

6. Synthesis of manufacturing process structure. Here the structure is defined depending on the need to remove the coating:
6.1. With complete removal of coating from blades by points 5.1, 5.2, 5.3. There are two options of removing the coatings.
6.2. With partial removal of coating from blades by points 5.1, 5.2, 5.3. . There are two options of removing the coatings.
6.3. Without removal of coating from blades by points 5.1, 5.2, 5.3. If blades are without a coating, they go to geometry control of them.
7. Chemical etching, loosening and dissolution of old coatings.
8. Removal of coating is doing by the supported polishing.

In this case the polishing has some features, caused by simultaneous processing of two dissimilar properties materials, namely: extra hard titanium nitride coating, microhardness H_μ=21…25 GPa and more softer titanic alloy VT 8M, micro hardness H_μ = 1,2 … 1,5 GPa. At simultaneous processing of two various hardened materials, their processing should be done with a tool support (a polishing circle) on more hard material (with a coating). It is caused by that when processing a coating there is necessary polishing circle effort in 2-3 times bigger, compared to require for titanic alloy polishing. At the moment of complete removal of coating there is probably forcing through titanium alloy, because the contact pressure polishing wheel on titanium alloy should be much smaller. Therefore blades feather processed surface receives a considerable tuberous (a tuberous waviness). At supported polishing the abrasive cutting should prevail. On the whole polishing is characterized by abrasive, chemical, plastic strain and thermal processes.
9. Pre-dimensional polishing of blade surfaces. On this step the recovery of blade geometry, which was disturbed during using or processing of surfaces is performed. The abrasive processing in this case should prevail. This operation is performed after geometry control of blades. Parameters of a roughness R_a = 0,4 … 0,16 microns.
10. Geometry control of blades.
11. Final smoothing polishing of blades feather elements. For vacuum ion-plasma coating, the blades feather elements and surfaces are should be prepared for coating and have a surface roughness R_a = 0,100 … 0,063 microns. On this step the three cases of processing are possible. When processing is the main blade material only (titanic alloy VT 8M), plastic deformation of a material is prevailed. When processing the coating only (titanium nitride), the combination of chemical and microplastic processes are prevailed. At joint of two materials processing (the basic and a coating) supported polishing is prevailed.
12. Prevent glossing (mirror smoothing polishing) of coating and/or the main material of blades feathers. On this step the combination of chemical, thermal and microplastic processes are prevailed. Roughness parameters on this operation are R_a = 0,050 … 0,032 microns.
13. An ultrasonic washing of blades. On a blades feather surface are present pollution and oxides, which must be removed and cleared from surfaces. The process is carried out by ultrasonic processing in special baths. The source of ultrasonic vibrations is the installation UZG3-4 and the magnetostriction converter PMS 2,5-18. As processing liquid in a bath is used the solution of following composition: the technical trisodium phosphate - 30-40 g/l; the technical soda ash 20-30 g/l; a surfactant OP-7 or OP-10 - 3,5 g/l. Solutions temperature is 50-60ºC. Thereafter it is a washing of blades under the flowing water
14. Wipe of a blades feather by petrol, acetone and alcohol. At first the blade is purged by Galosh petrol (BR-1) of GOST 443-76, after that by ether and then their purging in the ethyl rectificative alcohol.
15. Nitriding of blade working surfaces. Nitriding is necessary for blade material hardening, and to provide the desired structural and phase properties of a blade material after operation of them. In this case the blade compressor nitriding is reasonable to do by next methods:
15.1. Ionic nitriding in the glow discharge.
15.2. Nitriding in the vacuum and arc discharges. These processes are realised in vacuum ion-plasma installations, for example NNV 6.6-I1. Use of these installations allows to apply vacuum ion-plasma coating just after nitriding. The nitriding step in this manufacturing process is not necessarily and may be missed.
16. Put a vacuum ion-plasma coatings on a blades feathers surfaces. The coating process is realized in vacuum ion-plasma installations, for example NNV 6.6-I1. There are main stages of coating process:
16.1. Cleaning of blade surfaces by ionic etching in gas discharge.
16.2. Cleaning of surfaces by ionic bombing and blades heating.
16.3. The coating of blades surfaces. The coating process can be multivariant, the numbers of various variants can be 1, 2, 3, …, *R*. It can be single-layered coatings and multi-layered coatings, single-element (*TiN, TiC* type*)* and multielement (type (*Ti, Al*) *N*, (*Ti, Zr*) *N*) coatings, multicomponent coating (*TiCN, ZrCN* type), and composite coatings ((*Ti, Al*) *CN*, (*Ti, Zr*) *CN* type). Besides, for increase of coating resistance to corrosion and erosive processes at blades operation, the function-oriented coating [6] is recommended.
17. Unloading of blades.
18. Final glossing (mirror smoothing polishing) of coating. On this step the combination of chemical, plastic and micro plastic processes are prevailed. Roughness parameters on this operation are R_a = 0,040 … 0,020 microns.
19. Overall control of blades. The presented structure of GTE compressors blades restoration manufacturing process is universal. On the basis of this structure the select of concrete processes variant of blade restoration

with a new vacuum ion-plasma coatings for various cases of existence on blades the old coatings is carried out. The universal structure of manufacturing process of coating includes the possibility of their coating with the function-oriented properties [6] which provides limiting operational potential of use the GTY blades. However an additional researches are necessary for realization of function-oriented coating on blades, will be presented further in this work.

3. Features of providing function-oriented properties to coatings of compressor blades

On fig. 4 is the scheme of old coating destruction and successive multilayered function-oriented coating formation in 6 stages - one for each. On the old coating destruction scheme is shown the beginning final fracture coating zone of 1-a_1-b-1^I, which consistently extends to a zone 2-1-a_1-b-1^I-2^I-a_2, then to a zone 3-2-1-a_1-b-1^I-2^I-3^I-a_3 and so on to a zone 5-4-3-2-1-a_1-b-1^I-2^I-3^I-4^I-5^I-a_n. According to these features of blade coating destruction, in work it is offered to successive formation a multilayered coating with topological each coat layer orientation on blades feather surfaces, according to a special orientation principle, offered in this work [6]:

$$\left.\begin{aligned} &\varphi_{21}: G(F) \rightarrow G(TB);\\ &\varphi_{22}: G(TB) \rightarrow G(C);\\ &\varphi_{23}: G(C) \rightarrow G(F), \end{aligned}\right\} \qquad (1)$$

where φ_{21} - the geometrical parameters mapping (transformation) a zone of product operational functions $G(F)$ to geometrical parameters of technological impacts zone implementation $G(TB)$;

φ_{22} -the geometrical parameters of technological impacts zone mapping (transformation) $G(TB)$ to geometrical parameters of a providing properties zone $G(C)$;

φ_{23} - geometrical parameters of a providing properties zone mapping (transformation) $G(C)$ to geometrical parameters a zone of operational functions $G(F)$ of a product.

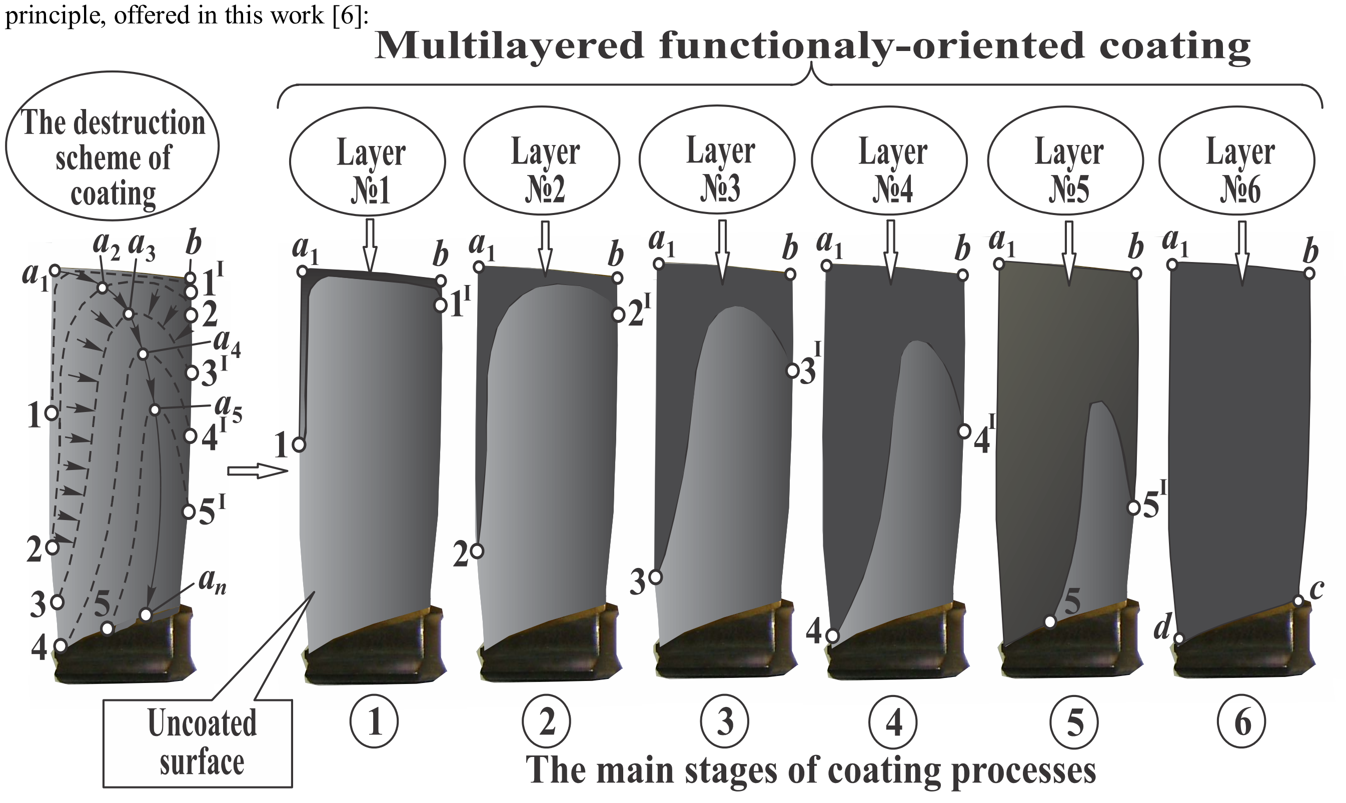

Fig.4. The scheme of multilayered functionally-oriented coatings formation

Thus, the multilayered coating (fig. 5) is formed by successive put of single-layered coatings at each stage according to equation 1 of each coating layer topological orientation (fig. 4). Here, the topological oriented to surfaces coating No. 1 is put according to the wear scheme, then coating layer No. 2, coating layer No. 3 and so on. At the end a coating is put on all blades feather surfaces. In this case, the properties of each coating can be defined according to equation:

$$\left.\begin{aligned} &\varphi_{11}: F \rightarrow TB;\\ &\varphi_{12}: TB \rightarrow C;\\ &\varphi_{13}: C \rightarrow F, \end{aligned}\right\} \qquad (2)$$

where φ_{11} - mapping (transformation) of operational product function F in technological impact TB;

φ_{12} - mapping (transformation) of technological impact TB in product properties F;

φ_{13} - mapping (transformation) of properties C in technological impact TB.

The created according to equations (1) and (2) multilayered coatings have properties of destruction within the prescribed GTE compressors blade operation period . It allows to exclude destruction of the blade main material at extended period of time and at the same time to raise technical and economic indicators of their restoration.

4. The analysis of manufacturing processes structural options. The main recommendations.

Analyzing the universal structure of compressors blade restoration manufacturing process (fig. 3), made from titanic alloys with ion-plasma coatings, it is possible to note the following.

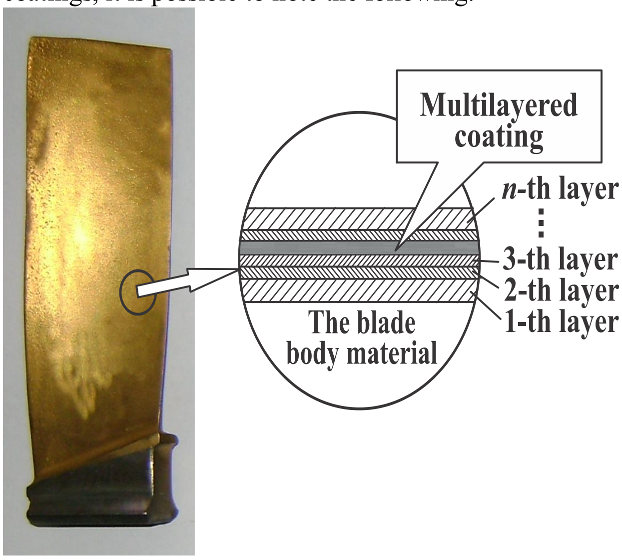

Fig. 5. Scheme of constructing a multi-layered coating structure on the blades feather working elements

1. Development of blade restoration manufacturing process and formation structure of it, is defined by blades initial properties and operation features of them.
2. The developed manufacturing process universal structure is based on the next stages:
- removing of corrosion and erosive destructions and scale on a blades feathers, formed at GTE operation;
- full or partial removal of old coatings,
- recovery of blades feather geometry, preparation and providing the required quality parameters of surfaces for a new coating put;
- put the coatings on a blades feather with providing of required operational properties;
- final providing the required quality parameters of surfaces and elements of a blades feathers.
3. The operation of blades feathers elements finishing has any features associated with processing of two dissimilar materials, with the considerable difference in properties.
4. The blades feather ion-plasma coatings can be realized by the following options:
- depending on applied material: single-element and multielement, multicomponent and composite;
- depending on number of layers: single-layered and multilayered; l- depending on a type of coatings: traditional and function-oriented coatings; v- the function-oriented coatings can have the follow properties: functionally dependent, functionally independent, special properties, other properties.
5. The thickness value, geometrical parameters, topography, structure and properties of surfaces coating and blade elements, should be based on the condition of its final simultaneous corrosion and erosive fracture in any point of blades feathers or depending to operational functions action.
6. On the whole a function-oriented properties of blades coatings should be formed depending on blade operation features as well as corrosion and erosive destructions of a coating in each point of feather.

5. Conclusions

Thereby, investigations have allowed to realize the following:
1. In work it is analyzed corrosion and erosive destructions features of GTE blades with ion-plasma coatings. It was found that these destructions of coatings have a certain regularities. For increase the corrosion and erosive fracture resistance of blades, is offered to put function-oriented coatings.
2. The universal structure of blades compressors GTE restoration manufacturing process is developed for increase the restoration efficiency of them. The developed manufacturing process is structured on 5 main stages, each of them has a certain technological features. It is established that for ensuring high adhesive durability (to 250 MPa) of formed new coatings layers cohesion with non-removed coatings on feather surfaces, and with a blades feather material (substrate), it is necessary to do prevent glossing (mirror smoothing polishing) of coatings and/or the blades feathers main material with a roughness parameters R_a = 0,050 … 0,032 microns.
3. In work the scheme of multilayered function-oriented coating formation on a GTE compressor blades is offered. The scheme of structure multilayered coating creation on blades feather working elements is developed.
4. In presented work it is analyzed structural options of coatings, which providing increase of blades compressor GTE maintainability level, and there are recommendations to formation the structure of blades compressors GTE restoration manufacturing process.

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