Special features of raising of operational data of machine components based on functionally oriented coatings

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Abstract. The paper examines different rational approaches to raise operational data of machine components based on functionally oriented coatings. A structural model has been developed and principles of implementation of the functionally oriented coatings are given. The paper classifies the coatings and gives examples of technological support of the implementation of the functionally oriented coatings.

1. Introduction

Provision of features of machine components based on application of special coatings is one of the promising ways to raise their quality [1, 2, 3, and 4]. The existing coating types allow to solve many problems related to the machine component quality raise, namely: provide protection of the component surface layer from corrosive attacks, oxidation processes, salt and erosion damages, acid and alkaline affects; reduce damageability of the main material; improve the component heat resistance and its parameters; reduce radiation affect made on the main material; solve design and esthetic problems and the entire complex of other issues.

Different materials and their combinations, substance compositions and structures are used to make coatings for the machine components. Metal, intermetallic, composite and com-position and complex and combined coatings are used. The machine component surface coatings can be single-and-multilayer.

Many different methods are used to make machine component coatings. The most promising methods of coating making are chemical deposition (HT-CVD), physical deposition (PVD), the electrolytic method, gas-thermal sputtering, electric-spark alloying and welding.

Application of different types of the coatings allows raising the machine component operational data and solves the entire complex of functional tasks. However, the type of service of the components with the coatings is often connected with complex types of the coating damages, namely:

− the coating uneven wear;
− the coating sector corrosive and erosion and other attacks;
− influence of uneven specific contact load on the coating surface;
− complex impact of different operational functions on the coating (operational function structure different data) and other operational features.

The goal of the paper is to research the raise of the machine component quality based on creation of specific features of every component surface and the feature structure of the entire component under the influence of many uneven operational functions at the expense of the application of the functionally oriented coatings (FOC) and provision of their features [5, 6].
To reach the goal the paper solves the following tasks: analyzes the features of break-ages of the unit functional components under the operation; develops the general approach and principles of the FOC implementation; develops the FOC classification; offers technological provision and researches specific features of implementation of the component functionally oriented characteristics.

2. The general approach and principles of implementation of the functionally oriented coatings of the machine components

Many operational functions influence the component under its operation. Each surface is affected by uneven loads and every zone of influence of the specific load has certain topological parameters with the operating functions having the certain structure. To provide the component functionally oriented characteristics under the conditions the correspondence among the operational functions F, technological influence TI and product characteristics C is to be defined (Figure 1).

There are the certain links [5] among the operational functions F, the technological influence TI and the product characteristics C, namely: similarity, correspondence identity, analogy, equivalence, and adequacy.

Figure 1. shows the model of interconnection of the system objects: the operational functions F, the technological influence TI and the unit characteristic C. The implementation technological scheme FOC is implemented on the interconnection basis [5]. It should be mentioned that the structure of the interconnections among the model components has the closed form that allows defining the parameters of the technological influence and the unit features depending on the characteristics of operational function impact on the unit functional components. All the parameters are defined on the basis of the group of the special principles of element and technological influence orientation [5]:

1. Functional correspondence of the features of the action of the elementary function at each functional component of the unit to the characteristics of implementation of the technological influence and the parameters of provision of the necessary features in the functional component.
2. Topological correspondence of the geometrical parameters of the unit functional component, in which the elementary function acts under the operation, to the geometrical parameters of the zone of the technological influence on the unit and the geometrical parameters of the feature zone.
3. Quantitative correspondence of the multitude of the operational components in which many different elementary functions act under the operation to the multitude of implementation of different technological influence and the multitude of the components providing the necessary features in the unit functional components.
4. Adequate dependence of the spatial features of action of the elementary function under the operation, technological influence and operational characteristics in the space of every unit functional component.
5. Adequate dependence of the temporal features of action of the elementary function under the operation, temporal and spatial features of implementation of the technological influence and temporal operational characteristics in every functional component of the unit at every level of the technology depth.
6. Structural correspondence of the multitude of the elementary functions, implementation of the multitude of the technological influence and multitude of characteristics in the unit functional...
elements out of the condition of provision of the given, required and limit features of the entire unit.

7. Adequate structural and functional correspondence of every functional component to the given, required or maximum potential of the general characteristics of the entire unit in the space and time.

8. Adequate structural and functional correspondence of characteristics in the neighbourhood of every functional component to the given, required or maximum potential of the general characteristics of the entire unit in the space and time.

It is to be mentioned that the process of the given principles of technological impact and unit characteristics implementation can be made on the basis of an iteration approach [5]. The iteration approach allows fulfilling of the FOC synthesis through the implementation of the given principles with taking into account of successive processes and multiple repeated recurrent processes made at the expense of feedback couplings.

The FOC can have the following characteristics (Figure 2):

1. Changeable characteristics (evenly and unevenly changeable, functionally changeable, gradient and others) (Figure 2, a) within every surface of a product and/or unit structure surface.

2. Step-function characteristics (in one direction, two directions, wide, middle, small steps and others) (Figure 2, b) within every surface of a product and/or unit structure surface.

3. Zonal characteristics (zone traditional sizes, macro-zonal, micro-zonal, with change-able characteristics according to the zones and others) (Figure 2, c) within every surface of a product and/or unit structure surface.

4. Spotted characteristics (big, average, small size spots with different or similar characteristics and others) (Figure 2, d) within every surface of a product and/or unit structure surface.

5. Special characteristics within every surface of a product and/or unit structure surface.

The machine component FOC provide fulfillment of the following characteristics of operation under the influence of the changeable parameters of the function on the surface and unequal structural components of the multitude of functions on the unit:

1. Complete adaptation of the unit under manufacturing to the characteristics of its operation in the machine or the technological scheme.

2. Maximum operational potential of the unit or multiple of it in the machine (the multiplicity degree is defined by a designer).

3. The stated wear of every coating on the unit surface at the given period of its operation.

4. Coordinated simultaneous complete wear of all types of coatings on the unit surface at the given period of its operation.

5. Qualitatively new set of the product characteristics under operation and other features.
3. Classification of the functionally oriented coatings

It can be noted that the coatings used for mechanical engineering products can have different physical and mechanical characteristics (FMC) the parameters of which are formed within the limits peculiar for traditional and super-strong coatings. The coatings can have changeable thickness on the product surface which is defined depending on the operational function action. At the same time the coatings made of the materials with different FMC can be used for the unit different surfaces. Besides, the coatings on the unit surfaces can be single-layer and multilayer (Figure 3).

![Diagram of FOC classification](image)

**Figure 3.** Classification of the FOC for machine components.

It is to be mentioned that the thickness of the single-layer and multilayer coatings (unit fibers of the multilayer coating) can be different in general and it depends on the functional purpose of the coating and the method(s) of its depositing.

The FOC can be used for different machine components. In this case they can be classified as the scheme shown in Figure 3. Here the FOC are grouped as follows: the single-layer coatings, the multilayer coatings and the combined coatings.

The single-layer coatings can have the changeable FMC with the changeable thickness and have the following characteristics: functionally dependent, zonal, gradient, and changeable on the axis x, changeable on the axis y, changeable on the axis z and others.

To provide the coating simultaneous complete wear if there is uneven wear on the unit functional components in some number of cases, the single-layer coatings with the changeable thickness with the following parameters can be used: functionally dependent thickness, evenly dependent thickness, changeable on the axis x, changeable on the axis y, other characteristics.

To raise the unit resource the multilayer coatings which can have the following characteristics can be used: zonal changeable number of layers, zonal structured FMC, functionally structured FMC,
modular FMC, step FMC, similar FMC and/or thickness in all layers, changeable FMC and/or thickness in all layers, and other characteristics.

In a number of cases it is reasonable to use the combined coatings for the units. They have the following characteristics: combined FMC of the single-layer and multilayer coatings, functionally zonal FMC, gradient and modular FMC, functionally step FMC and other characteristics.

Figure 4 shows some unit FOC: Figure 4, a – the single-layer coating of constant thickness and characteristics; Figure 4, b – the single-layer coating of constant thickness and changeable characteristics; Figure 4, c – the single-layer coating of variably changeable thickness and constant characteristics; Figure 4, d – the single-layer coating of constantly changeable thickness and constant characteristics; Figure 4, e – the zonal multilayer coating with the layers of similar thickness; Figure 4, f – the zonal multilayer coating with the layers of different thickness.

The given mathematical structural and functional symbol models of the single-layer and multilayer coatings and the alternatives of the functionally oriented coatings allow making synthesis of the unit given or required characteristics. It should be mentioned that the synthesis of the unit necessary characteristics can be done on the basis of the morphological approach with the application of morphological matrixes and methods of morphological synthesis of the coating alternatives. This approach allows generating of new solutions as to non-traditional characteristics of the coatings.

4. Technological support and features of implementation of the unit functionally oriented characteristics

To implement the FOC technological support, namely technological plants that make coatings on the basis of the group of special principles of orientation of technological impacts and the unit feature provision, is necessary.

To implement some methods of the FOC spraying special plants were constructed at Donetsk National Technical University:

1. The plant for vacuum ion and plasma spraying of the FOC made on the basis of the modernized system HHB 6.6-H1.
2. The experimental detonation plant DEPLA-5.
3. The spark plant to form the FOC. It is aimed at implementing of spark alloying of the surface layer of the unit with different functionally oriented characteristics of the sprayed layer.

Figure 4. Some alternatives of the unit FOC:

a – the single-layer coating of the constant thickness and characteristics; b – the single-layer coating of the constant thickness and changeable characteristics; c – the single-layer coating with the variably changeable thickness and constant characteristics; d – the single-layer coating of the constantly changeable thickness and constant characteristics; e – the zonal multilayer coating with the layers of similar thickness; f – the zonal multilayer coating with the layers of different thickness.
Figure 5 shows the plant for vacuum ion and plasma spraying of the FOC based on the modernized system ННВ 6.6-11. It allows making coatings for different machine components. Let us look into the process of making the FOC for the gas-and turbine engine compressor blade with the application of the method of vacuum ion and plasma spraying. Figure 6 shows the single-layer coating destruction scheme and consequent forming of the multilayer FOC at 6 stages – one at each. The single layer destruction scheme shows forming of the entire zone of the surface complete destruction which starts with the zone 1-a1-b-1I which is spread to the zone 2-1-a1-b-1I-2I-a2, then to the zone 3-2-1-a1-b-11-2I-3I-a3 and so on up to the zone 5-4-3-2-1-a1-b-11-2I-3I-4I-5I-an. Under the destruction of the corresponding zone of the single layer coating the wear of the blade main material takes place here. According to the characteristics of the surface destruction under the blade operation formation of the multilayer coating with topological orientation of every layer on the surface of the blade fluted land is offered. It is to be done in accordance with the special principle of the surface orientation described by the expression (2). In this case the FOC is formed with the application of the special shielding matrices. The FOC is technologically formed as a result of consequent spraying of the single-layer coating at every operation stage with taking into account the topological orientation of every layer surface (Figure 6). First coating № 1 with its topological orientation on the surface according to the wear scheme is sprayed, then coating № 2 and the next layers. The coating is sprayed on the entire surface of the blade fluted land at the end of the stage. In this case every coating characteristic can be defined in accordance with the first principle.

The multilayer coatings formed in accordance with the first and the second principles are characterized by one-time complete destruction at the given period of operation of the ГТД compressor blades. It allows avoiding of destruction of the blade fluted land main material for a long period of time and at the same time raising technical and economic indices of their restoration.

![Figure 5. The plant to spray functionally oriented vacuum ion and plasma coatings.](image)

![Figure 6. Schemes of destruction of the single-layer coating and forming of the multilayer FOC.](image)
Figure 7 shows the experimental detonation plant DEPLA-5 used for the FOC spraying. The formation of the functionally oriented characteristics of the coatings takes place at the expense of several dispensers for different types of powder material installed into the plant, specified individual modes of the plant unit cycle and application of different technological methods of the powder material spraying.

The plant body is filled with a mixture of gases able to detonate within the plant operation unit cycle. The corresponding dispensers send a portion of the powder material at the specified time. The powder material composition is changed in accordance with the characteristics of the FOC structure formation and then the igniter (firing light) is actuated. The gas burning occurring in the plant body is transformed into the detonation. The detonation wave is a complex of a shock wave and a gas chemical reaction zone. The detonation wave moves along the plant body at a supersonic speed.

The detonation products in the plant body carry the powder material mixture particles along, heat them and carry them to the component machined surface where the coating is formed. The powder material welding, collision and evaporation take place in the two-phase flow that is formed in the plant body. The detonation processes are repeated in a cycle when the coatings are sprayed and according to frequency of the plant operation, for example 15 shots per second.

Figure 8 shows: a – the scheme of the spark plant to form the FOC, b- the zone and elements to form the coatings, c- the scheme of the FOC with changeable characteristics.

The offered plant (Figure 8, a) operates similar to a 3D-printer that produces the characteristic specified “design”. It makes the spark alloying of the component surface layer with functionally oriented characteristics. Figure 8 shows: 1 – a cylindrical component (cathode); 2 – a tool block system; 3, 4, 5, 6 – tool blocks; 7, 8, 9, 10 – exchangeable alloying tools (electrodes-anodes) made of different materials – molybdenum, tungsten, vanadium and chromium; 12 – a reel (solenoid); 13 – a spring (resilient member); 14 an electrode position regulator that provides the specified amplitude of its vertical alternate motion; 15 – the guides in the tool block system; 16 – electric arc among the electrodes during the spark alloying; 17 – a unit zone (spot) of the alloying metal in the surface formed coating (with the diameter of r); 18 – a unit surface layer made of alloying metals with the multitude zones of their inclusions.

It is to be noted that with the help of the plant (Figure 8, a) the mechanism of formation of the coating alloying layer formation is made as a result of both carrying and interaction of the electrode material and heat impact of electrical spark. The specified characteristics of the coating surface layer can be implemented at the expense of both the anode separate materials and a combination of the material mixture of four anodes.

The operation of the offered plant (Figure 8, a) is based on several schemes. Figure 9 shows the alternatives of the tool tracing schemes as to the component (rimier). It shows the following: Figure 9, a – the motion B1 is periodical, the motion Π is alternate; Figure 9, b – the motion B2 is swinging, the motion Π is alternate; Figure 9 c – the motion B3 is constant and swinging, the motion Π is alternate.
5. Conclusion

The paper under discussion shows the research in improvement of the machine components quality based on special characteristics of every component surface and the entire component characteristic structure under the operation of the multitude of uneven operational functions at the expense of the FOC. The research allowed the following:

1. Analysis of the features of destruction of the unit functional components under the operation. It was stated that in a number of cases the machine components were under the influence of the varying operational functions that led to the resource reduction.

Figure 8. The FOC spark spraying: a – the plant scheme, b- the FOC spraying zone and components, c- the FOC scheme with changeable characteristics.
2. The development of the general approach to the FOC spraying on the machine component surfaces. It is based on the group of special principles of the FOC making.

3. The FOC classification to sort different alternatives of the component coatings and characteristics.

4. Development of the special technological support to spray the FOC on the machine components.

5. The research in characteristics of the implementation of the functionally oriented characteristics of the components based on the FOC. It was stated that the FOC provided the qualitatively new set of the machine components. It is to be noted that to spray the FOC a lot of methods could be applied and a complex of different facilities could be used. It depends on the design features of the certain component and the material it is made of, the FOC necessary parameters, the technological approach as to the coating spraying and a number of other conditions.

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Figure 9. Alternatives of the tracing schemes of the tool as to the component: a – the motion $B_1$ is periodical, the motion $\Pi$ is alternate; b – the motion $B_2$ is swinging, the motion $\Pi$ is alternate; c – the motion $B_3$ is constant and swinging, the motion $\Pi$ is alternate.