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Губін В. В., Альохін В. І., Пензев П. С., Акімов О. В. Аналіз якості відливки картера вхідного безступінчатої гідрооб'ємно-механічної коробки передач трактора з використанням інженерного моделювання

У статті розглянуто моделювання технологічного процесу виготовлення відливки деталі «Картер вхідний». Представлені результати моделювання затвердіння відливки. У результеті проведеного моделювання виявлені місця концентрації ливарних дефектів, виконано оцінку очікуваної кількості браку лиття.

***Ключові слова:** відливка, моделювання, ливарний дефект, 3D-модель відливки.*

Gubin V., Alekhin V., Penzev P., Akimov O. Analysis of quality casting carter input continuously variable hydrostatic-mechanical gearbox tractor with engineering simulation

The article deals with modeling of technological process of manufacturing parts casting process "Carter input." The results of the solidification simulation. The re-modeling conducted revealed zultete place concentration of casting defects, the estimate of the expected number of casting marriage.

***Keywords**: casting, modeling, casting defect, 3D-model casting.*

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Резензент: д.т.н., проф. Тарельник В.Б.

THE COST-EFFECTIVE MANUFACTURING TECHNOLOGY FOR PRODUCTION OF THE QUALITY SLIDE BEARINGS ELEMENTS

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The present paper represents the process of synthesis to obtain rational variant of bearing manufacturing technology with regard to constraints arising from its implementation. Model of the bearing layer-by-layer structure is represented by a graph. Quality requirements for the surface layers of slide bearing elements are formalized. Method for predefined selection of the variant of technological process for slide bearing manufacturing with minimal production cost is presented.

***Keywords:** slide bearing, quality, manufacturing technology, optimization, costs of manufacture, synthesis.*

Introduction

The decision concerning the problem on how to increase the machines service life depends directly upon improving wear-resisting property and reliability of their friction units.

Slide bearings (SB) are indeed those friction units that ensure reliability of modern high-speed turbocompressors, turbo-refrigerating machines, multipliers and pumps. According to statistical data, up to 32% of failures of gas blowers in gas transportation system takes place due to SB malfunction.

A surface layer of machine parts is the most loaded zone wherever these parts work, especially in view of a wide variety of operating conditions. Therefore the real service life of machine depends upon the load-carrying capacity of surfaces of the parts; at that load-carrying capacity is determined by quality of the surface layer. Quality of the surface layer, in its turn, depends upon the technology used for its formation, thus analysis of application methods of antifriction coatings onto SB friction surfaces is relevant and urgent.

Analysis of recentresearches and publications.

Reliability of SB depends, with other factors being equal,significantly upon its manufacturing quality, as well as upon properly carried out installation and repair works, upon meeting all requirements of design and technological documentation.

There are a lot of works dealing with problems of quality improvement of machine parts using technological methods [1,2]. Quality of surface of machine parts is conditioned by geometrical characteristics as well as physical and mechanical properties of the surface layer. The main geometrical characteristics of the quality of surface layer are surface roughness, waviness and deviation from the proper geometrical shape. Structure of the surface layer, microhardness, presence and sign of residual stresses are the main physical and mechanical characteristics of quality.

As a rule, surface of the steel insert is tinplated before it is lined with babbitt. At that forces of molecular attraction operate on the actual contact areas of surfaces and these forces appear at distances, which are dozens of times larger than interatomic distances in crystal lattices, and used to increase as temperature gets higher. In this case there is no transition layer for providing firm metallic bond, thus this fact negatively affects the quality of babbitting, heat conductivity and efficiency of bearing in general.

Home and foreign practice of use of integral shoes made of bronze, with working surface, lined with babbitt, evidenced that it is difficult to achieve high-quality tin plating of the whole surface, when babbitt is mechanically fastened to the shoe with "dovetail". Therefore probability that babbitt may peel off in some places gets higher. Appearing of an air space deteriorates heat removal from oil film and can result in increase of temperature in the shoe [3].

A variety of methods for obtaining a more secure adhesion of sprayed metal are suggested in [4]. For example, electroplating with copper is used. Another way to improve the adhesion strength is plating (metallization) in protective environment. Though replacement of air with inert or reducing gas does not completely eliminate formation of oxides, but at that adhesion of the coating to the base gets better, tensile strength and ductility of the sprayed metal increases. In order to get better adhesion, the surface that has to be metalized is roughened to reduce fatigue resistance of the part.

Analysis of manufacturing technologies of SB inserts, study of their operation conditions and reasons of their failures gives us an opportunity to suggest applying an intermediate layer of copper onto the steel base before tinplating. This will ensure improved adhesion of the steel base to babbitt and more intensive removal of heat from friction zone [5].

There are a lot of different methods for application of soft metal coatings onto steel articles [6-8]: electroplating, metal spraying and others. Comparison of their advantages and disadvantages allowed us to select the EEA method as the most promising one, which provides strong adhesion of the plated metal to base and the abovementioned reason serves as the determining factor for choosing exactly this technology. Furthermore, such a disadvantage of the EEA method as increasing of surface roughness will prove to be an advantage being applied to this technology [9].

Thus, applying the EEA method to form the intermediate layer of copper that on the one side has strong adhesion to the steel base and on the opposite side to tin layer (formation of substituttional solid solutions) and babbit layer, will provide a better adhesion of the steel base to babbitt, as well as more intensive removal of heat from the friction zone [10,11].

Requirements for manufacturing technology of slide bearings

Considering the requirements for the manufacturing technology of SB, it is necessary to define mathematical model of its layer-by-layer structure, which is shown in Fig. 1 as a graph.

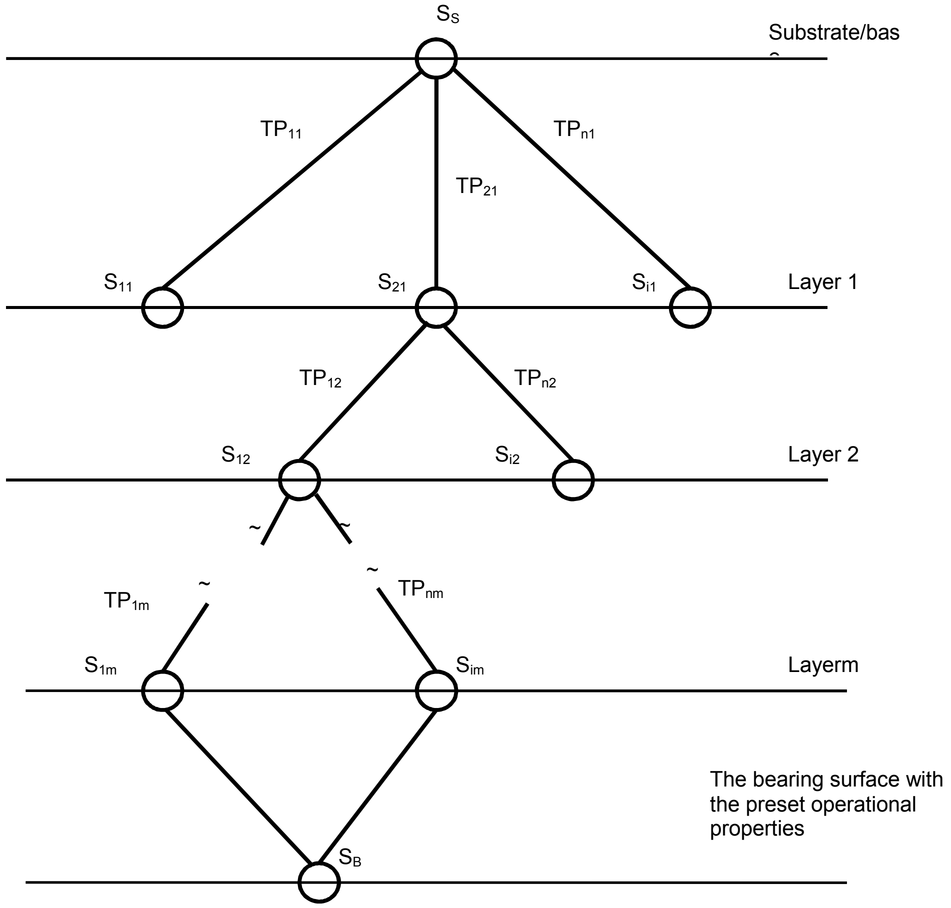

Fig. 1. Graph of the layer-by-layer structure of slide bearing at the stage of its manufacturing.

The following symbols are used in the figure: S_S - surface of the substrate/base; S_B - surface of SB with preset technological properties; TP - technological process for obtaining the bearing layer; m - quantity of the bearing layers; n - quantity of technological processes, that allows obtaining the m^{th} layer of the bearing; i - quantity of variants of surfaces that can be obtained on the m^{th} layer of the bearing.

This graph is built taking into account the sequence of formation of SB layers. The 1^{st} layer is applied onto the S_S surface of the substrate/base using the n^{th} technological process, taking into consideration requirements for quality of the surface and available technological equipment necessary to implement these requirements. As a result we obtain the S_{i1} surface. Taking into consideration technological parameters of S_{i1} surface, the m^{th} layer is applied using the n^{th} technological process. Thus we obtain S_{im} surface with the required preset technological properties. After the last technological process is carried out, we obtain S_B surface of the bearing with required performance characteristics.

The represented graph of the SB layer-by-layer structure at the manufacturing stage formally describes the entire process of formation of the bearing surface layers with the required technological properties.

Quality requirements for surface layers of elements of slide bearings can be logically subdivided into four groups:

– those that are set to running-in coating of bearings;

– those that are set to antifriction layer of bearings;

– those that are set to quality of transition layers;

– those that are set to quality of substrate/base.

If the purpose of running-in coating is to ensure retention of technological properties of antifriction layer when SB is brought out to operation mode, the main requirements for the quality of such coatings are the following: uniformity of application, evenness of distribution and layer thickness.

According to mathematical model of the layer-by-layer structure of bearing (Fig. 1), requirements for the quality of running-in coating can be represented as:

$$k_{S_{m+1}} = f(\tau, \omega) ,$$

where $k_{S_{m+1}}$ is a quality function of the running-in coating of the bearing;

τ - parameter of the coating uniformity;

ω - parameter of the layer distribution evenness.

The antifriction layer should face a lot of requirements, the most important of which are the following:

– mutual compatibility of materials of bearing and of opposing member;

– possibility to achieve high accuracy and proper finishing;

– stability and low value of friction coefficient;

– high antiscuff properties;

– high heat resistance, corrosion stability and erosion resistance, non-bondability, high resistance to vibration;

– technological effectiveness, availability and low cost, high dimensional and structural stability;

– correlation of longitudinal expansion coefficients of bearing couple, conformability, fireproofness, absence of electrostatic attraction on the friction surfaces.

The main formalized parameters of antifriction layer quality are the following:

– specific pressure, P, kN/cm2;

– circumferential speed, V, m/s;

– intensity of work (complex index) P*V, (kN*m) / (cm^2 *s);

– operational temperature, C°.

These parameters are regulated by the standards applied to the material that is used for babbitting. For example, GOST 1320-74 standard is applied for antifriction coating made of B83 babbitt.

In its turn, if circumferential speed depends upon operational conditions of the bearing, then specific pressure and operational temperature appear to be, in addition, the functions of geometrical parameters of the SB contact surface, i.e. they depend upon form error and positional relationship of the bearing elements. In general, quality function for antifriction coating of bearing is represented as:

$$k_{S_m} = f(\chi, p, v, c),$$

where χ is a parameter that depends upon operating abilities of material;

p - parameter that depends upon the specific pressure onto the layer surface;

v - parameter that depends upon the circumferential speed;

c - parameter that depends upon the temperature.

Since availability of transition layers improve adhesion of the antifriction layer with the substrate/base, the following physical and mechanical properties and quality requirements are fundamental for such layers:

– surface roughness, Ra, µm;

– layer thickness, h, µm;

– uniformity of coating.

These characteristics of the transition layers are functions of the technological parameters of an application method. For example, discharge energy (Wp, J) is such a parameter for the EEA method of treatment.

By analogy with the above-said, the quality function of the transition layer of the bearing is represented as:

$$k_{S_\xi} = f(\varepsilon, \eta, \tau), \text{ where } \xi \in [1, (m-1)],$$

where ε is a parameter that depends upon the surface roughness;

η - parameter that depends upon the thickness of the layer;

τ - parameter of the coating uniformity.

The SB substrate/base should meet requirements for roughness, geometric characteristics (form error and position of the contact surface), as well as requirements for physical and chemical properties of the material.

The quality function of the bearing substrate/base is represented as:

$$k_{S_s} = f(\varepsilon, \varphi, \rho),$$

where ε is a parameter that depends upon the surface roughness;

φ - parameter that depends upon the geometric characteristics;

ρ - parameter that depends upon the physical and chemical properties of the material.

Thus, requirement for quality of the SB surface layer is constituted by a set of requirements for the quality of its elements:

$$k_{S_B} = k_{S_s} \cup \left[\bigcup_{\xi=1}^{m-1} k_{S_\xi} \right] \cup k_{S_m} \cup k_{S_{m+1}}.$$

At that the dominant requirements for the proper form of surface of the bearing substrate/base are the requirements for geometrical parameters that specialize errors of form and errors of position of bearing elements in the article; and the dominant requirements for the quality of antifriction coatings are maximum intensity of work and temperature.

Technology for manufacturing of SB is selected based on the complex index, here this index is the production cost and manufacturing technology is selected based on it. So, the lowest manufacturing cost is the main selection criterion.

Constraints in implementation of manufacturing technology of the slide bearings for high-speed machines

At the stage when the rational variant of manufacturing technology for SB is synthesized, it is necessary to take into account constraints in implementation of this technology. Let us consider the principle of formation of these constraints.

Synthesis of the rational variant (Fig. 2) consists of several stages.

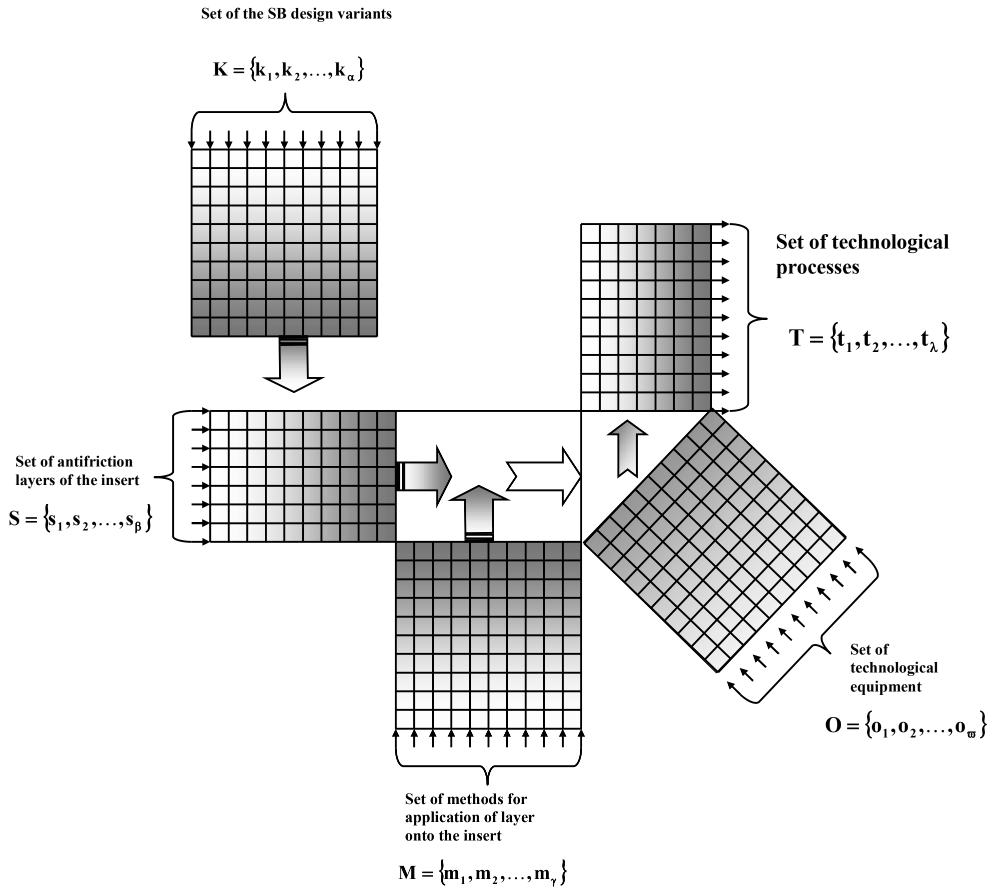

Fig. 2. Scheme of synthesis of rational variant for manufacture technology of slide bearings.

A variety of variants is selected out of a set of the existing designs

$$K = \bigcap_{\eta \in L} k_\eta , \quad \text{where } L = \{1,2,\ldots,\alpha\}.$$

At the next stage we consider a set of existing combinations of antifriction coatings with corresponding composition of transition layers, which are present in SB. A variety of variants is generated out of this set.

$$S = \bigcap_{\rho \in N} s_\rho , \quad \text{where } N = \{1,2,\ldots,\beta\}.$$

Next, a variety of methods for application of layers onto the bearing insert is generated for each variant of layers combination.

$$M = \bigcap_{\theta \in \Psi} m_\theta , \quad \text{where } \Psi = \{1,2,\ldots,\gamma\}.$$

The next stage is to find implementation for these methods by means of technological equipment, taking into account a variety of variants of the existing equipment

$$O = \bigcap_{\tau \in \Phi} o_\tau , \quad \text{where } \Phi = \{1,2,\ldots,\varpi\}.$$

At that there are following constraints in implementation of the manufacturing technology:

1. Kinematic capabilities of technological equipment should ensure the preset mechanical trajectory of the tools during application of layers with 100% uniformity.

2. Weight and dimensions of a workpiece should not exceed the equipment performance capabilities specified in the technical datasheet.

3. Geometric accuracy required to implement this manufacturing operation should not exceed the design accuracy of the technological equipment.

4. First of all the equipment that has minimum cost and provides all the necessary technological parameters for bearing production is used.

5. The suggested solution is the most cost-effective for mass production.

The following set of technological processes comes out in result of the searches:

$$T = \bigcap_{\xi \in I} t_\xi , \quad \text{where } I = \{1,2,\ldots \lambda\}.$$

Formation of a variety of technological processes takes place if:

$$T = K \cup S \cup M \cup O .$$

Hence possibility of realization of the technological problem can be described with the following expression:

$$\exists_{\xi \in I} t_\xi = \left[\bigcap_{\eta \in L} k_\eta\right] \cup \left[\bigcap_{\rho \in N} p_\rho\right] \cup \left[\bigcap_{\theta \in M} m_\theta\right] \cup \left[\bigcap_{\tau \in \Phi} o_\tau\right]$$

Since technological cost of the article manufacturing is used as the criterium for selection of the proper manufacturing technology variant, the variant that results in the minimum cost is considered to be the most rational variant of technological solution:

$$t^{opt} = \bigcap_{\xi \in I} t_{\xi} \Rightarrow C^{\min} \quad .$$

In actual practice of companies a lot of technologies are limited by quantity of the available methods for the application of coatings and means of the technological equipment that can be used for realization of these technologies.

System of predefined selection of manufacturing technology of slide bearings for high-speed turbocompressor units

The developed model of predefined selection of variant of technology to manufacture and repair of slide bearing at the lowest production cost is shown in Fig. 3. According to this model, layer 1 is applied onto the substrate/base using the n1st technological process. At this, a number of constraints is imposed on the technological process and a number of requirements is set for the surface layer. There can be a few technological processes, which can be used to obtain layer 1. Therefore, to a first approximation we choose the technological process that has the lowest production cost. Further layers 2 … m are applied sequentially onto the layer 1. In doing so it is necessary to meet the quality requirements for surface layers of slide bearing and to consider the imposed constraints on the technological processes that are used to obtain these layers. Finally running-in coating is applied onto the layer *m* using the technological process TP_{nrc}. As a result the surface of slide bearing with the preset performance characteristics is obtained. Technological cost of manufacture or repair of slide bearing is calculated and the current variant of technological process is taken as the basic one. After doing so we go back to the beginning of planning the technological process and choose technological process for obtaining layer 1. Layer 1 has higher production cost than the layers obtained using the basic process, since constraints on the technological processes and quality requirements for the surface layer are taken into consideration.

Production cost of the technological process for slide bearing manufacturing and repairing is calculated. The current cost is compared with the cost of the basic process. If the current production cost is lower, then it is taken as the basic one. In such a way all possible variants of technological processes for slide bearing manufacturing are evaluated. The variant of the process, which will turn out to be the basic one after evaluation of all possible processes, will be the most rational variant of the process for slide bearing manufacturing under the given production conditions.

The entire sequence of processes for obtaining the bearing surface with the preset technological properties is taken into consideration.

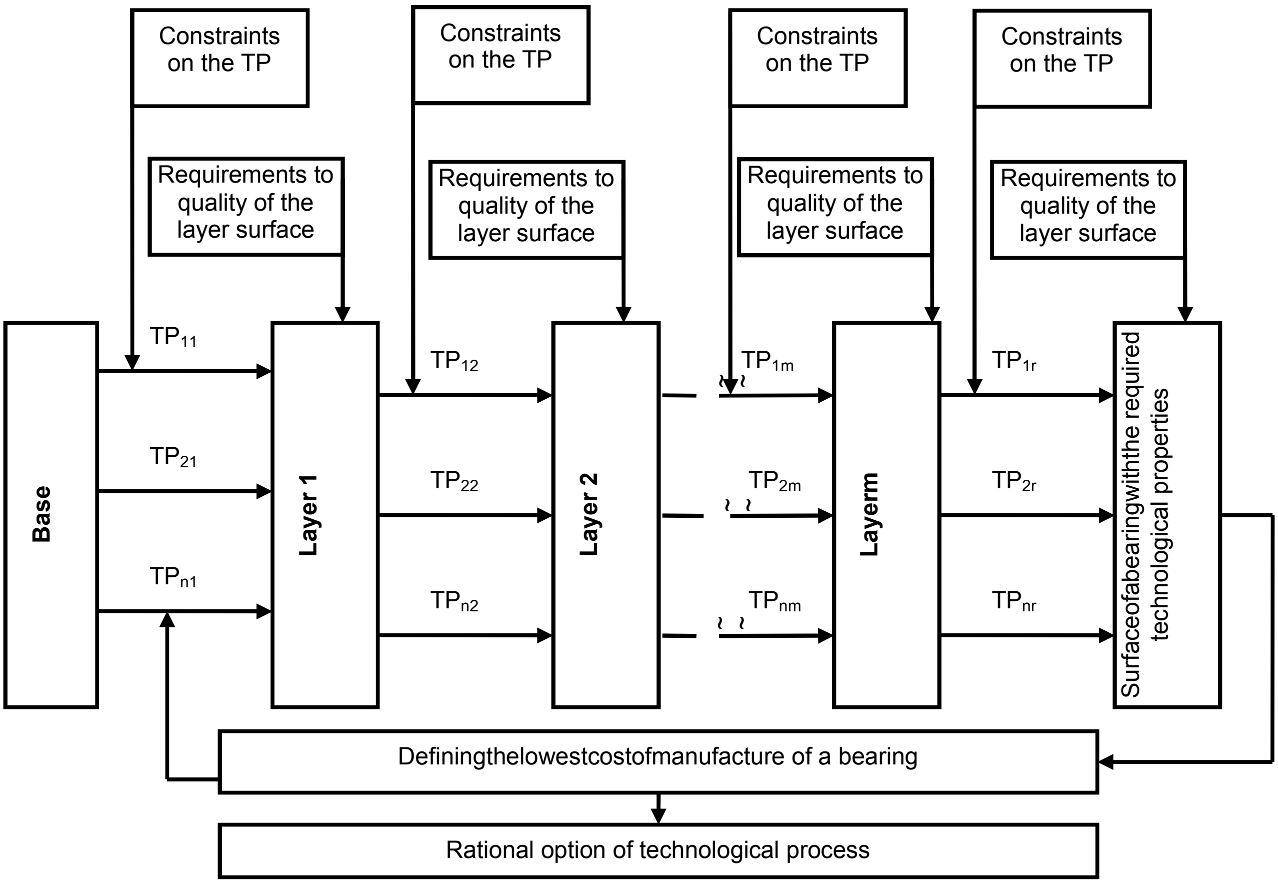

Fig. 3. Model of directed selection of an option of the technological process for manufacture of a slide bearing at the lowest manufacturing cost

Let us consider in detail the sequence of steps on how to define the rational process for formation of the slide bearing layers with the preset technological properties.

The following method is used for the predefined selection of the technological process**:**

Step 1. Matrix of ($m \times n$) size of corresponding antifrictional layers (A) is formed at the level of SB design with consideration for the substrate/base (BA) material of bearing. (Fig. 4).

Step 2. In accordance with materials of **BA** and **A** the matrix of ($m \times n \times \eta$) size is formed. The present matrix represents variants of combinations for transition layers (CTL) (Fig. 5) for all m sections of **BA**.

Step 3. In each combination a set of layers (S) of the slide bearing (Fig. 6) for all m sections of **A** is defined.

Thus a four-dimensional array of data is formed, which is used as initial information for further calculations.

Later each combination of layers of the slide bearing is considered separately.

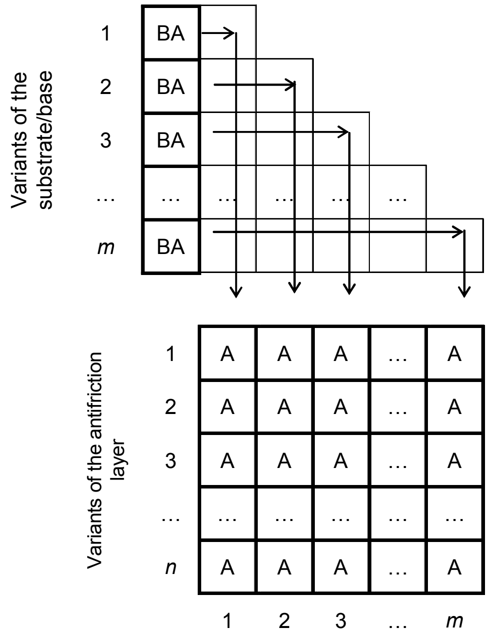

Fig. 4. Procedure of formation of ($m \times n$) matrix of antifriction layers.

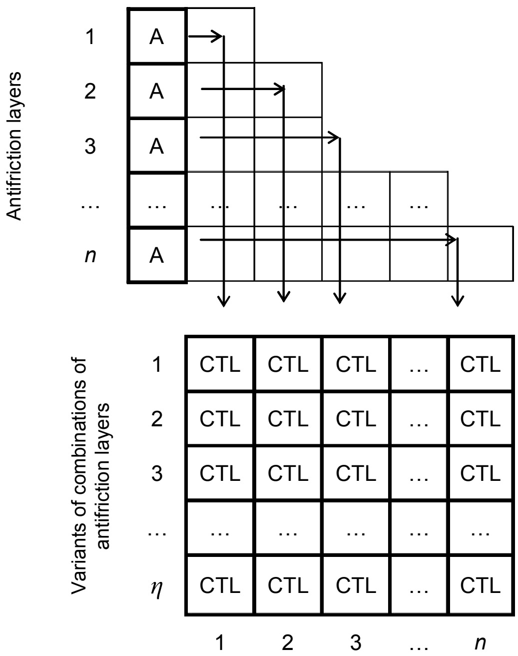

Fig. 5. Procedure of formation of ($m \times n \times \eta$) matrix of combinations for transitional layers for the first section of BA.

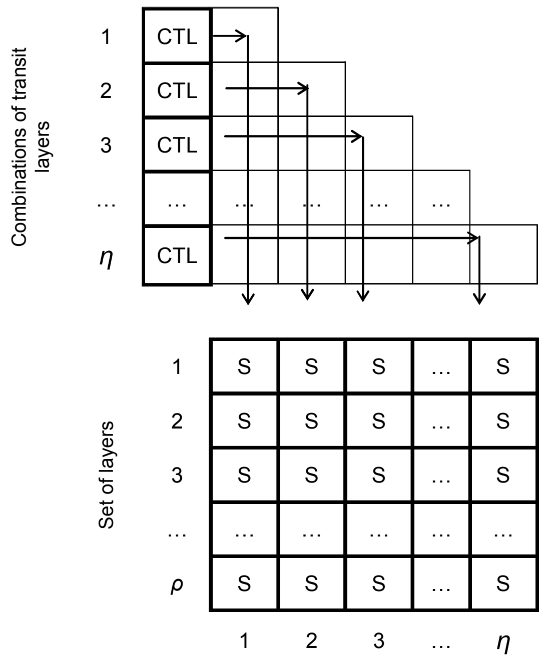

Fig. 6. Procedure of formation of ($m \times n \times \eta \times \rho$) matrix of a set of layers for the first section of **A**.

Step 4. In compliance with each layer we form matrix of methods for their application (Fig. 7) for all η sections of **CTL**.

Step 5. At this step we select the equipment (means of technological equipment - **MTE**) which allows us to implement specific methods for applying layers of the slide bearing (Fig. 8) for all ρ sections of *S*.

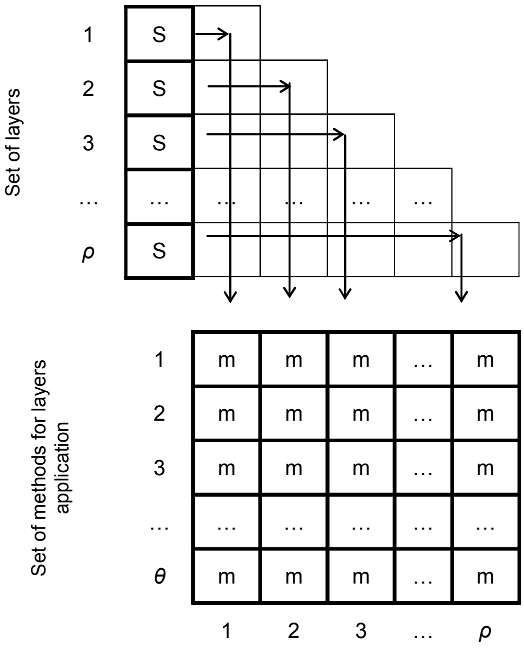

Fig. 7. Procedure of formation of matrix of **m** methods for application of **S** layers for the first **CTL** section.

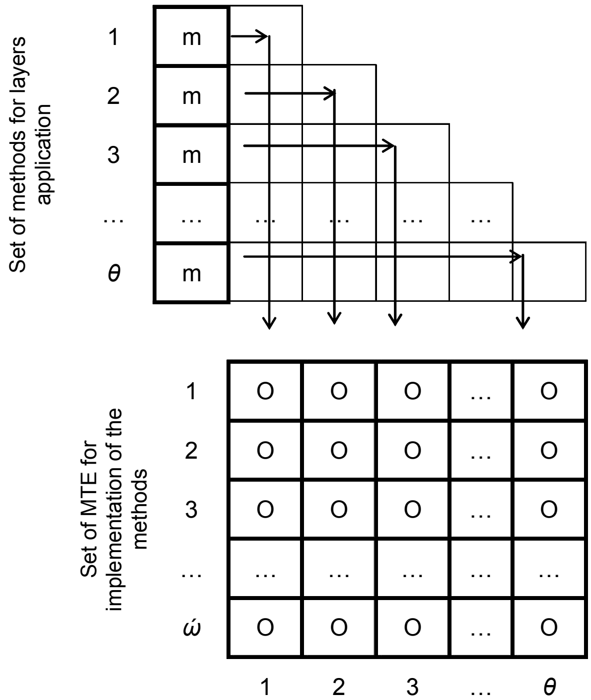

Fig. 8. Formation of the **MTE** matrix for implementation of methods for applying layers for the first section of **S**.

Step 6. Depending on the possible technological modes we form matrix that includes variants of the production operations for application of the specific layer of the SB, considering the imposed constraints on implementation of the technological process and the requirements for the quality of the surface layer (Fig. 9) for all θ sections of the **m** methods.

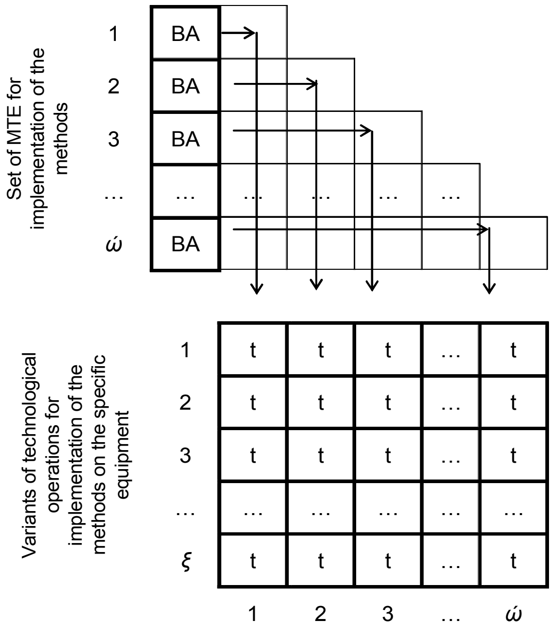

Fig. 9. Formation of matrix of variants of production operations that implement methods of applying layers for the first section of **m** methods.

In the end of the selection we get a set of production operations, in which $t_{mn\eta\rho\theta\acute{\omega}\xi}$ is the ξ^{th} variant of the technological operation that is carried out on the $\acute{\omega}^{th}$ equipment that allows to realize the θ^{th} method for applying the ρ^{th} layer of the slide bearing out of the η^{th} variant of combination of transition layers for improving adhesion of the n^{th} variant of the antifriction layer using the m^{th} variant of substrate/base of the slide bearing.

Predefined selection of the technology is carried out in several stages. First, at the level of production operations, the variant of technological process for applying the bearing layers with the lowest production cost is synthesized (Fig. 10).

The present TP is taken as the basic process for further optimization. Then the next combination of the transition layers is considered for the same material of the substrate/base of the bearing and the antifriction layer. The TP with the lowest technological cost is selected out of all available variants of CTL, at that the requirements for the quality of the surface layer and constraints on implementation are to be taken into consideration. This TP is referred to as the basic one in the current section. A similar synthesis takes place for other available "substrate/base - antifriction layer" sections.

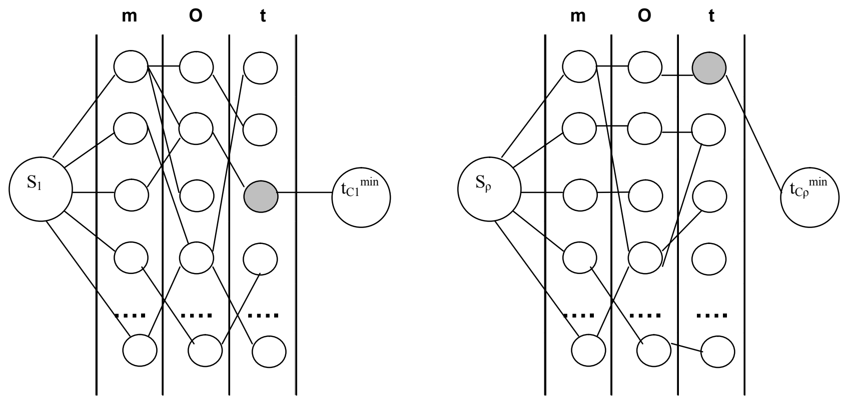

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Fig. 10. Scheme of synthesis of the technological process with the lowest cost of production operations.

Conclusions

Thus, applying the method of “minimum sections” as the optimization method we’ll obtain a cost-effective manufacturing technology for the slide bearing production as a result of the predefined selection of technology that ensures the preset quality of friction pairs.

The developed mathematical model of the layer-by-layer structure and the systematized requirements for the quality of the slide bearing layers make it possible to optimize the technology, which is used to improve the quality of the "bearing insert - shaft journal" friction pair surface on the high-speed turbocompressor units.

The developed method of synthesis of technological processes variants takes into consideration the constraints on manufacturing technologies of slide bearings for high-speed machines, thus this method makes it possible to form surfaces of the friction pairs with the preset performance characteristics.

The developed system for predefined selection of the bearing manufacturing technology makes it possible to ensure the preset quality of elements of the slide bearing using the most cost-efficient methods.

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Кундера Ч., Антошевский Б., Тарельник В.Б., Коноплянченко Е.В. Марцинковский В.С. Экономичные технологии изготовления элементов подшипников скольжения заданного качества

Рассмотрен процесс синтеза рационального варианта технологии изготовления подшипника с учетом ограничений, возникающих при ее реализации. Представлена графом модель послойной структуры подшипника. Формализованы требования к качеству поверхностных слоев элементов подшипника скольжения. Приведена методика направленного выбора варианта технологического процесса изготовления подшипника скольжения с минимальной технологической себестоимостью.

Ключевые слова: *подшипник скольжения, качество, технология изготовления, оптимизация, себестоимость, синтез.*

Кундера Ч., Антошевський Б., Тарельник В.Б., Коноплянченко Є.В. Марцинковский В.С. Економічні технології виготовлення елементів підшипників ковзання заданої якості

Розглянуто процес синтезу раціонального варіанта технології виготовлення підшипника з урахуванням обмежень, що виникають при її реалізації. Представлена графом модель пошарової структури підшипника. Формалізовані вимоги до якості поверхневих шарів елементів підшипника ковзання. Наведено методику спрямованого вибору варіанта технологічного процесу виготовлення підшипника ковзання з мінімальною технологічної собівартістю.

Ключові слова: *підшипник ковзання, якість, технологія виготовлення, оптимізація, собівартість, синтез.*

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АНАЛІЗ СТРУКТУРНОГО СТАНУ ПОВЕРХНЕВОГО ШАРУ ПРИ ЕЛЕКТРОЕРОЗІЙНОМУ ЛЕГУВАННІ ТВЕРДИМИ ЗНОСОСТІЙКИМИ МАТЕРІАЛАМИ

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Представлені результати досліджень впливу режимів і матеріалів легуючих електродів на структуру і твердість поверхневих шарів зразків із сталі, нікелевого сплаву і берилієвої бронзи. Сформульовані рекомендації, які дозволять підвищити надійність і довговічність відповідальних деталей при виготовленні і ремонті машин.

Ключові слова: *якість поверхні, мікротвердість, шорсткість, товщина шару, електроерозійне легування, зміцнення, легування*

Постановка проблеми в загальному вигляді

Більшість відповідальних деталей компресорів, насосів, газоперекачуючих апаратів і іншого промислового устаткування працюють при високих швидкостях, навантаженнях і температурах, а також в умовах абразивного, корозійного і інших видів дії робочих середовищ. Завдання підвищення довговічності і надійності цих деталей вирішуються, як правило, шляхом застосування високоміцних нержавіючих сталей і сплавів, що спричиняє велику витрату, як дорогих матеріалів, так і металорізального і штампового інструменту. Постійна нестача інструменту і дефіцитних матеріалів веде до зниження ефективності виробництва, утрудняє забезпечення необхідної якості продукції і, зрештою, ускладнює функціонування підприємства в умовах ринкових відносин.

Бурхливий розвиток техніки вимагає підвищення режимів роботи машин і механізмів(зростання швидкостей, тисків і т. д.), що диктує необхідність створення нових композиційних матеріалів типу «основа-покриття», які поєднують захисні властивості покриттів з механічною міцністю основи. Застосування покриттів обумовлюється ще і тим, що руйнування деталі розпочинається з поверхні.

Аналіз останніх досліджень і публікацій

Одним з найбільш ефективних методів нанесення захисних покриттів на металеві поверхні є електроерозійне легування(ЕЕЛ). Метод ЕЕЛ був розроблений Б. Р. Лазаренко і Н. И. Лазаренко і його суть викладене в ряду робот [1-4].

Вдосконалення технології отримання покриттів на металевих поверхнях методомЕЕЛ багато в чому пов'язано з глибшим вивченням впливу фазового складу і структури електродних матеріалів на інтенсивність перенесення матеріалу і властивості покриттів. Іскровий розряд від-