Developing a system and criteria for directed choice of technology to provide required quality of surfaces of flexible coupling parts for rotor machines

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Abstract. The paper discusses the process of normal friction and wear as a result of fretting corrosion, as well as measures to reduce its level. There are considered the issues of reliability and accuracy of the connection of “shaft - sleeve with key” type, which is of particular danger. The disadvantages of the considered connections are shown, namely the relative complexity of the disassembly-assembly processes; high level of stress concentration; the tendency to corrosion at contact. There has been proposed a physically based mathematical model of the wear process for the strengthened surfaces of the flexible coupling parts on the friction conditions. By using the friction work value, the model allows determining the wear expressed through the change in the surface roughness. A method has been developed for determining the constant of the wear equation for various materials of friction pairs. Using the energy and economic criteria, the technique of the integral description of the method for achieving the required quality of the surface layers of the elastic coupling parts is given. A mathematical model has been developed to reliably allow predicting the wear amount for the surfaces of the elastic coupling parts whose surface layers are formed in various ways. It is proposed a system for the directed choice of the technologies to produce the surface layers of the flexible coupling parts taking into account all the stages of their life cycles. In doing so, both economic and environmental requirements are also taken into consideration. The use of the system for the direct choice of the technology to ensure the required quality of the flexible coupling parts at the repair stage allows more economically solving the problem of restoring their performance. As practice shows, at this stage, the application of the results of the scientific research gives a significant economic effect.

1. Introduction
In modern centrifugal pump and compressor units as well as other rotary machines for the gas, petrochemical, food and agricultural industries, the problem of connecting the shafts to obtain a single-unit rotary system comes across new aspects. The couplings should not only provide the reliable transmissions of high torques at high rotation frequencies, but also have the stable low unbalance values, damp the vibrations that are transmitted along the shaft from one part of the unit to another,
and have the optimal elastic-mass characteristics. When operating in zones of heavy loads, the couplings should have a high degree of reliability and a long service life. In current economic conditions, an important requirement is that the cost of their maintenance and repair should be reduced.

All of the above requirements are most fully satisfied by flexible couplings (FC) with metal membrane packs. In comparison with the traditional gear or pin couplings, the main advantages of the flexible couplings with metal membrane packs are their compensating capabilities in terms of radial misalignments and distortions of the shafts, as well as soft start, damping of axial and radial forces; the flexible couplings are silent in operation and do not require maintenance in the process of work. The assembly design of a membrane pack is not jammed. The low reactive forces favorably affect the rotor system, the service life of which depends little on the accuracy of centering the shafts. The couplings simultaneously possess torsion stiffness and flexibility in axial and angular directions, compensating for significant shaft decentering, in particular, misalignments.

Despite the advantages listed above, many surfaces of the FC parts are subjected to the fretting process (FP), namely, the destruction which manifests itself in sharply intensified oxidation or seizures. Thus, analyzing the causes and studying the problems of the fretting process (FP), researching the factors which influence the occurrence of this type of wear, investigating the nature of the processes and the surface damages of the parts interacting in the frictional contact and also the methods for preventing the occurrence thereof are an urgent task that needs to be timely solved.

2. Statement of the problem. Analysis of the main achievements and publications

Under the action of cyclic workloads, in the FC (Fig. 1), the periodic displacements of the mating surfaces of the FC contacting parts occur. The presence of the contact pressure between the mating surfaces and the amplitudes of their relative displacements determine the FP manifestation. The wear rate of the parts increases in the course of their operation in aggressive environments. In this case, the damage of the connected surfaces occurs under the fretting corrosion conditions. As a rule, the fretting corrosion conditions appear with insignificant oscillatory relative movements of the connected surfaces.

![Figure 1](image_url)

**Figure 1.** The design of the coupling with flexible metal elements: 1 – half-coupling; 2 - spacer; 3 - pack of flexible metal elements; 4 - sleeve; 5 - washer; 6 - screw; 7 - washer; 8 - sleeve; 9 – nut.

In the process of the flexible coupling operation, on the mating surfaces of the parts which form various friction pairs, there would simultaneously take place the process of fretting corrosion.
The practice shows that in the course of work, a lot of parts of the flexible couplings are more or less subjected to the action of the fretting corrosion process. Those are the surfaces of half-couplings, spacers, bolts, washers, sleeves, flexible elements, etc. (Fig. 2).

According to [1], the various designs of the interfaces of the component parts might be conditionally divided into two groups, either of which has common design features:

- The relative motion of the contacting surfaces is not provided for by the design of the assembly unit;
- The relative motion is provided for structurally.

The relative motion of the contacting surfaces, which is incorporated structurally, concerns only the “flexible element - flexible element” interface. In this case, while being bent, the contacting surfaces of the flexible elements of the pack are moving relative to each other, and the farther the flexible element is from the center of the pack, the longer the path its contacting surfaces go.

It should be noted that for the first group, there is a particular danger for the “half-coupling – shaft” interface, wherein the outer cylindrical surface of the shaft is in contact with the inner cylindrical surface of the half-coupling, and the parts form a preloaded joint [2-5].

The process for assembling the preloaded joints can be carried out in various ways: by pressing the shaft into the hole, by heating the part with a hole, or by cooling the shaft, etc. In this case, the contacting surfaces of the parts are subjected to elastic-plastic strain, and the strain degree is determined by the hardness of a surface layer: the lesser the initial hardness of the surface layer, the greater its plasticity, strain rate and reserves to increase it are.

![Image](image1)

**Figure 2.** Flexible coupling parts subjected to fretting corrosion: a – half-coupling; b - spacer; c - spacer with a pack of flexible elements; d - bolts and sleeves; d - destroyed flexible elements.

In the process of operation, between the contacting cylindrical surfaces, the fretting process (FP) usually takes place in the area of the half-coupling faces. As a result of the fretting corrosion, the FP can lead to loosening of fit, increasing of vibration, disrupting of the joint and appearing an accident condition [6].

In [7], there are discussed the issues of reliability and accuracy of the “shaft-sleeve with key” connection, which are of a particular danger. The wear of the joints begins along the cylindrical
surface of the shaft and the sleeve, as a result of which the gap increases, the runout and shear in the fit occur, the wear and the plastic strain of the key and its grooves start.

As a result of the fretting corrosion appearance, there reduces the fatigue strength of the parts, which fact might cause serious accidents.

For now, a large number of structural and technological methods are known to reduce the influence of the fretting corrosion on the quality of the surfaces of the parts connected with preloaded fit.

Frictional contact in multicomponent threaded joints has been studied in [8–10].

Moisture accumulates between the plates within the operation of couplings with metal membrane packages, and this leads to galvanic element emerging, and mechanical stresses lead to intensification of microelectrochemical corrosion processes, similar to crack propagation [11, 12], which leads to rapid destruction of plates. The works [13–15] studied the stress and temperature state of layered compositions.

[16] shows the disadvantages of the joints under consideration: the relative complexity of the disassembling and assembling processes; high level of the stress concentrations; tendency to the occurrence of the corrosion at contact (the availability of the axial micro displacements of the points of the parts in the region of the joint end faces) and, as a result, the reduced strength of the joints under the variable dynamic loads; the complexity of performing the non-destructive tests for the procedures of fixing the parts. Due to the need to maintain the accuracy of the positions of the mating parts under load, the joints must satisfy the stiffness requirements.

Since under the combined action of the contact pressure (from the fit) and the bend (from the rolling force), the distribution of the total pressures is determined by the coefficient of friction between the mating surfaces of the female and male parts, it is advisable to increase the coefficient of friction by applying a coating to improve the quality of the interface of the parts of the large-sized assembled items.

When fitting, for example, the roll sleeve on the axle of the large-sized rolling roll of the large-sized composed rolling rolls, the friction coefficient on the mounting (fitting) surfaces is taken to be 0.14. It is known that when the preloaded joint is bending, there are being formed the slippage sections contributing to the appearance and manifestation of the fretting corrosion, which fact reduces, for example, the fatigue strength of the composed rolling rolls and provides for the displacement of the roll sleeve [17].

As a rule, most of the known methods for improving the quality of press joints (increasing bearing capacity, improving joint tightness and shaft strength, as well as reducing the fretting corrosion) involve the introduction of certain “interlayers” between the mating surfaces which, as in contact, possess properties that are substantially different from the original ones, namely, transferring the slipping ability to the intermediate (interface) medium. This can be either a coating applied onto one or both contacting surfaces [18, 19], or a hardened or softened surface layer [20], etc.

For other surfaces of the mating parts of the first group, the result of the fretting process is not so hazardous; however, it also significantly affects the reliability and durability of the coupling. Among those, in the interfaces of “flexible element – sleeve”, there is a preloaded joint; in such interfaces as “bolt neck – sleeve” and “sleeve – half-coupling”, the parts are connected in tight fit. The other interfaces are the two surfaces that are tightly pressed against each other. Increasing the gaps in the interfaces is accompanied with increasing the amplitude of the mutual relative displacement of the contacting surfaces, which in turn stimulates strengthening of the fretting corrosion. The greater the amplitude of the relative slippage of the mating surfaces, the greater the damage.

In [21], to reduce the micro displacement of the contacting surfaces, it is proposed to increase the friction force as in contact, which for the case of dry sliding friction according to Amonton’s law is

\[ F_{\text{cs}} = f \cdot P, \]  

(1)

where \( F_{\text{cs}} \) is a sliding friction force; \( f \) is a coefficient of sliding friction; \( P \) is a load being normal to the plane of friction (pressure of bodies against each other).
As can be seen from (1), the friction force depends on the coefficient of sliding friction and the mutual pressure of the bodies.

Having low shear resistance, the coatings of such soft antifriction metals as lead, indium, tin, etc. expose themselves as solid lubricants. In this case, in spite of the fact that the friction force is reduced, the main purpose of such coatings is to transfer the shearing process inside the coating. Increasing the hardness of the surface layers of the mating parts contributes to decreasing the mutual penetration of the materials of the parts into each other and, as a result, to the occurrence of lesser wear, while decreasing the hardness is accompanied with increasing the area of the contacting surfaces, decreasing the specific pressure and also to the occurrence of lesser wear.

Often, in order to organize the better protection against the fretting corrosion process, the surfaces of the parts are subjected to various types of strengthening: by centrifugal reinforcement [22], surfacing with hard and wear-resistant materials [23–32], laser surfacing [33–39], plasma spraying [40–45], application of galvanic coatings [46], formation of combined layered coatings [47, 48], chemical-thermal treatment (CTT) [49–56] and others.

Over recent years, to improve the quality of the surface layers of machine parts, the method of electrospark alloying (ESA), namely, the process of transferring material to the surface of an item by a spark electric discharge [57–60], has become increasingly important. Its specific features that attract technologists are: locality of action, low energy consumption, lack of volumetric heating of the material, strong connection of the applied material with the base, ease of automation, the possibility of combining operations, etc. [61, 62]. Under conditions of applying various electrode materials and the environment, the ESA methods can be used to carry out the processes that are alternative to the chemical-thermal treatment (CTT), but doing significantly more with less [63, 64]. So, applying a graphite electrode and saturating the surface of a part with carbon, it is possible to carry out the carburizing process (CESA), applying an aluminum electrode – the aluminizing one, conducting ESA in a nitrogen environment – the nitriding process, etc. [65, 66]. Moreover, ESA technology is environmentally and technologically safe.

In our previous works, we proposed a number of ways to increase the reliability and tightness of preloaded joints by applying special coatings with the use of the ESA method [67, 68]. In [21], the area of contacting surfaces was proposed to be increased by applying copper, tin, cadmium, silver, or gold onto the surface of the electrolytic layer. The process for cadmium plating of the surfaces of inserts, bolts and other parts to protect them against the fretting corrosion is well known in the aviation and automotive industries. However, with an increase in micro displacements, these coatings themselves undergo the fretting corrosion and quickly wear out.

The author of [69] evaluated a number of electrodeposited coatings of various metals by their ability to reduce fretting fatigue damage on bright-drawn mild steel (HV190) and arranged them in such an order: silver, copper, lead, tin, zinc, nickel, chromium. Silver and copper had sufficient plasticity to withstand overloads without cracking, and also to remain within the contact area without being extruded. In addition, both metals had high thermal conductivity and cathode efficiency. Tin and lead were too soft and, therefore, they squeezed out of the contact zone, while numerous cracks developed in nickel and chrome, and a lot of them penetrated into underlying steel.

According to [70], the coating thicknesses of 75 to 125 microns are recommended for practical application for most parts, although in some cases, the thicknesses of up to 300 microns were proposed.

When a design of an interface for mating parts does not provide for the exclusion of their mutual micro displacement, and the amplitude of the oscillatory motion is large (about 2.5 mm), then the area of the damage due to the fretting corrosion increases and the wear occurs as at unidirectional sliding.

According to [71], an increase in the slippage amplitude causes increased wear, especially, in the range of the amplitudes exceeding 0.10–0.15 mm. With an increase in the number of micro displacement cycles, the degree of the damages caused by the fretting corrosion process increases, and the intensity of destruction is most significant in the initial period of the process. Then the mating surfaces start running in, and the wear process is stabilized [72]. With an increase in the offset
frequency values for the contacting surfaces at the same test base in terms of the number of cycles, the rate of destruction decreases, which is mainly due to the length of time for oxidation of the exposed metal layer. Thus, the analysis of the design features of the flexible couplings, and also a large number of different tribounits (friction units) [73], which are characterized by different mechanisms of interactions of the contacting surfaces of the parts, indicates the absence of a single method for guaranteed protection against fretting corrosion.

The review of the literary sources showed the lack of comprehensive researches to develop environmentally friendly, energy-efficient and energy-saving technologies for producing the surface layers of the flexible coupling parts with required properties. None of the available recommendations in the literature on selecting the most effective method for preventing the occurrence of the fretting corrosion can be considered universal.

The purpose of the present paper is to develop a system and criteria intended for performing the directed choice of the most promising technological methods to provide the quality parameters for the surface layers of parts and their elements by analyzing and synthesizing the existing analogues, industry experience and recommendations in the native and foreign literature, the use of which would provide the flexible coupling maximum operating life.

3. Main study material representation

The system of the directed choice of the technology for providing the required quality of the flexible couplings covers their entire service life cycle (Fig. 3), including preparation of production, production, operation, repair and utilization. At the same time, the quality of the flexible coupling as an assembly unit is determined by the quality of its individual parts, which are formed with the use of the directed choice system of the technologies providing such a quality.

The method of the directed choice of the technology to ensure the required quality of the individual parts consists of the procedures of the choice of the materials of the parts and their components, the technology of their manufacture, the processes for ensuring the quality of their surface layers, the repair technology, etc. All of them are considered through the special methods for direct choice. In doing so, it is necessary to take into account the influence of the chosen methods on each other, which fact will ultimately affect the quality of the final item.

![Flexible coupling service life cycle](image)

**Figure 3.** Using the system intended for directed choice of the technology to ensure the required quality of the surface layers of the parts at various stages of the flexible coupling life cycle.

When performing a research, the need to apply a systematic approach requires an analysis of the appropriate usage of the directed choice of the technologies to ensure the required quality of the surface layers of the flexible coupling parts at all stages of the life cycle.

At present, it has become obvious that the issues of increasing the wear resistance of tribounit (friction unit) parts should be carried out at close cooperation of the design, technological and
tribological solutions. The correct choice of the materials is possible only if the analysis of the design and tribological characteristics of the friction unit and its operation conditions has been carried out.

At the stage of the design preparation of the production, when designing the flexible coupling parts which perform certain functions, it is important to know the methods which can provide the required surface characteristics and, in accordance with this, to specify the surface quality factors (technological rationality of the design). As practice shows, there can be a lot of such methods.

At the stages of the technological preparation of the production, the possession of information on the methods for improving the quality of the surface layers of machine parts allows to plan a rational (effective) technology for obtaining the desired properties.

As a result of the scientific research, it becomes possible to choose the most rational process to obtain the blanks for the parts of the required quality. Perhaps, they would be made of cheaper materials, with reduced processing allowances, etc. The possibility of more rational using the heat treatment of the blanks, reducing the number and the duration of its individual stages is not ruled out.

Taking into consideration the requirements to the surfaces of the parts of the flexible coupling, it becomes possible to choose such machining methods which would be most suitable and economically justified.

There is also need to know the obtained research results when planning and implementing the assembly process. The choice of certain assembly operations, for example, welding, assembling with thermal influence, etc., depends on the quality of the previously obtained surface layer. This leads to the need for a deeper analysis of the assembly process, as at the final stages of the manufacturing process, the necessary item characteristics are finally formed.

When forming a surface layer with specified characteristics, the methods of control and testing of the flexible couplings change.

Having specified the material and the surface quality of the flexible coupling, it is possible to predict the conditions under which the coupling would operate better, and under which it would operate worse, and therefore, using the results obtained, one can control the process of the most effective operation of the flexible coupling.

The use of the system for the direct choice of the technology to ensure the required quality of the flexible coupling parts at the repair stage allows more economically solving the problem of restoring their performance. As practice shows, at this stage, the application of the results of the scientific research gives a significant economic effect.

The results obtained must also be known for the rational utilization of the flexible coupling parts, since their processing largely depends not only on the composition of the materials and their structure, but also on the environmental conditions (acid, poisons, food products, etc.)

In Figure 4, there is represented the set of the methods for achieving the required quality of the contacting surfaces of the individual groups of the flexible coupling parts (shaft - half-coupling interface; pack of flexible elements; fasteners), which make up the practical area of application of the results of the scientific research.

When solving the problems of improving the quality of the surface layers for the flexible coupling parts, it is important to take into account not only the cost but also environmental characteristics of the process (Fig. 5).

The costs of supporting the environmental characteristics of the flexible coupling parts of the appropriate level are included into the total cost. It should be noted that environmental characteristics can be used as an independent optimization criterion while accepting preliminary chosen economically feasible options.
As criteria for the quality indices of the surfaces of parts, depending on the conditions of their operation, the following can be used: critical load, time or number of loading cycles until defects are formed, yield and creep limits, tensile strength, ultimate strains, surface hardness, etc.

These criteria are more acceptable to prevent inadmissible processes of damage of the friction surfaces of the component parts of machines, including frictional seizure, contact fatigue, corrosion-mechanical and abrasive processes.

The authors are considering the process of normal friction and wear as a result of the fretting corrosion as well as the measures to reduce their level. The normal processes determine the operating resources of machines, namely, their durability, productivity and efficiency.

The change in the energy of the friction system due to the stored energy causes significant changes in the properties of a body. In this case, depending on the type of the crystal lattice of a component part material there might be changed the physical and mechanical state of its surfaces.

**Figure 4.** Methods for achieving the required quality of the flexible coupling parts surfaces.

**Figure 5.** The relationship of the flexible coupling manufacturability factors at various stages of its life cycle.
Under external influence, a lot of body properties are associated with changes in their free energy which, in turn, determines the change in the properties and sizes of the body. The amount of the stored energy and the energy intensity are the essential technological characteristics by which it is possible to judge about the achieved changes in the properties or sizes of the body in the course of a specified type of external processing. At performing the practical choice of the technology for processing materials, the specialists are guided not only by the physical and energy criteria, which provide the basis for determining the desired efficiency, but also by engineering and economic ones.

Thus, the energy and economic criteria should be the main ones to evaluate a certain method for achieving the required quality of the surface layer of the flexible coupling parts.

The energy criteria having a decisive influence on the wear resistance formed by various surface layer technologies are considered below.

The advantage of the energy approach lies in the possibility of performing an integrated description with the use of the energy criteria of the influence of the numerous parameters which the friction and wear processes depend on.

Since the large mechanical loads, which arise from the external friction, lead to a sharp change in the physic and mechanical properties of the surface layers and their radical transformation (mechanical energy stimulates chemical reactions), it could be possible to take the wear process activation energy as a wear criterion.

If we assume that under the influence of external elastic stress \( \sigma \), which is applied to the coating, binding energy \( U_0 \) decreases by the value of strain energy \( \gamma \sigma \), then, since the bond breaking is a discrete activation stage during the wear process, difference \( U_0 - \gamma \sigma \) is considered as activation energy \( E_A \) of the wear process.

Under the normal friction, at the stages of running-in and steady-state wear, between weight wear \( (\Delta m) \) and work \( (A_{fr}) \), which is spent on friction and initiates this wear, to a first approximation, there exists an exponentially increasing dependence.

With increasing the amount of work spent on friction, the higher the activation energy of \( E_A \), the greater the wear increase will be.

Considering the specifics of the wear at the fretting corrosion, when the wear products are not removed from the friction zone, but continue to charge the contacting surfaces in the “center” (zone) of friction, it is necessary to pass from weight wear \( (\Delta m) \) to the wear, which is expressed by changing the surface roughness \( (\Delta Ra) \).

Thus, based on the experimental dependence of \( \Delta Ra \) on \( (-A_{fr})^t \) (decreasing exponent), we can conclude that \( \ln\Delta Ra \) is proportional to \( (-A_{fr})^t \) and \( E_A \), i.e. \( \ln \Delta Ra \sim (-A_{fr})^t \), \( E_A \). Passing from the approximate equality to exact one

\[
\Delta Ra = c \cdot e^{\frac{-E_A}{A_{fr}}} \tag{2}
\]

where \( c = \Delta Ra_s \) is a saturation wear, i.e. the maximum allowable wear during the steady-state wear.

Then

\[
\Delta Ra = \Delta Ra_s \cdot e^{\frac{-E_A}{A_{fr}}} \tag{3}
\]

Dependence (3) is called as the wear equation.

Taking in formula (3)

\[
E_A = A_{fr} \tag{4}
\]

We have:
\[
\frac{\Delta Ra}{\Delta Ra_s} = e^{1-1}.
\] (5)

Hence \(E_A\) is a physical value equal to such a work of friction for which \(\Delta Ra = \Delta Ra_s/e\), i.e. \(\Delta Ra\) is \(e\) times smaller than \(\Delta Ra_s\). Let us call it as the wear constant of the ESA surfaces. The dimension of \([E_A]\) is [J]. The amount of the friction work, which is necessary to obtain the wear expressed by a particular value of roughness \((\Delta Ra_s)\), can be determined from equation (2).

Then, respectively:

\[
A_p = \frac{E_A}{\ln \frac{\Delta Ra}{\Delta Ra_s}}.
\] (6)

Using the proposed approach for solving the problem of the directed choice of the technology to improve the quality of the surface layers of the flexible coupling parts, it is possible to solve both the direct problem, namely, to determine the wear expressed by the particular value of the surface roughness, according to the known friction work value, and the inverse problem, namely, while setting the wear expressed by the particular value of the surface roughness, to determine the friction work being necessary for this purpose, and, therefore, also the time taken to complete that work. In addition, knowing the time to achieve a certain amount of the flexible coupling parts wear, we have an opportunity to organize more rational operation of the flexible coupling, timely appointing the repair time and preventing the friction surfaces from catastrophic wear.

Thus, on the basis of the proposed mathematical model, it becomes possible to reliably predict the amount of the wear for the surfaces of the flexible coupling parts, the quality of the surface layers of which is formed in one way or another. Moreover, the constants of the wear equation (activation energy of wear process, \(E_A\) and maximum allowable wear during steady-state wear, \(\Delta Ra_s\)) can serve as a criterion for choosing the most acceptable technology for improving the quality of the surface layers of the items.

Having known the amount of the wear for a certain period of time, as well as the amount of costs to carry out a particular technology, one can select the necessary technology to improve the quality of the surface layers of the flexible coupling parts. The logical diagram of the direct choice of the technologies at achieving the specified quality of the items can be represented by the block diagram of Figure 6.

4. Conclusions

1. The research allowed developing the general provisions for improving the quality of the surface layers of the flexible coupling parts, depending on the requirements of operation.
2. A system for the directed choice of the technologies to produce the surface layer of the flexible coupling parts is proposed, taking into account all stages of their life cycle. In doing so, both economic and environmental requirements are also taken into consideration.
3. To achieve the specified surface quality of the flexible coupling parts, both individual methods and their combinations can be used depending on the flexible coupling type and requirements for it.
4. There is proposed a physically based mathematical model of the wear process for the strengthened surfaces of the flexible coupling parts on the friction conditions. Using the friction work value, the model allows determining the wear expressed through the change in the surface roughness.
5. A method has been developed for determining the wear constant of \(E_A\) for various materials of friction pairs, as well as the constants for the equation of the wear which is expressed through the change in the surface roughness that is, the saturation wear.
Development of surface engineering technology for each variant of the method implementation on specific equipment.

The choice of a lot of methods to ensure a specified quality of the surface layer of the part (it is desirable to take into account cost criteria).

The choice of the objective (optimization criteria when making a decision) and technological limitations that take into account all stages of the item life cycle and environmental requirements (consideration of energy criteria is desirable).

The choice of technological equipment which is capable of implementing each method.

Development of surface engineering technology for each variant of the method implementation on specific equipment.

Comparison of technology options according to accepted optimization criteria and rational choice.

Output of results

Figure 6. Algorithm for the directed choice of the technologies for changing the quality of the surface layers of the flexible coupling parts.

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