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TRIBOLOGICAL COATINGS SELECTION AND DEVELOPMENT

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The strategy and methodology for selecting of optimal surface treatment for a given tribological application are the main objectives of study. The scheme of development of operation technology of surface treatment and coating deposition is proposed.

Розглянуто стратегію та методологію вибору оптимальної поверхні обробки для деталей вузлів тертя. Запропоновано схему розробки операційної технології поверхневого опрацювання і нанесення покриття.

Рассмотрены стратегия и методология выбора оптимальной поверхностной обработки для деталей узлов трения. Предложена схема разработки операционной технологии поверхностной обработки и нанесения покрытий.

Statement of purpose

The use of surface engineering methods in tribological applications is growing and will continue to grow as evidenced by a literature survey [1–9].

Surface treatment as coatings and films deposition and modification of surface layers can offer certain economic and technical advantages over the use of materials without the surface strengthen treatment.

Their main advantage is that strengthen surface layers allow the base material of tribological system (TrS) parts to be optimized for strength purposes while the surface layer is optimized for reducing wear and increasing corrosion resistance, promoting film lubrication, enhancing lubricant effectiveness, modification surface function, etc.

Furthermore, replacing the surface layer by coating deposition during repair may be more cost effective than new TrS part manufacture.

But the principal disadvantage in using coatings concerns the possibility of separation from the base material of TrS part during use.

While the discussions to follow emphasize the considerations important in the selection of tribological surface treatment, it should be noted that other alternatives might exist for any particular problem.

This could involve, for example, use of a more effective lubricant, or a redesign of the tribological system elements, use of more effective methods of lubrication, development of new or use of improved materials, etc.

Classification of surface engineering methods

Many technological methods and processes of surface engineering are available for the modification of surface characteristics. Tribological surface treatment methods are used for different purposes:

– replace surfaces by coatings and films deposition;

– surface modification (surface alloying and/or microstructure is altered);

– combination of methods for coating deposition and surface modification.

A wide variety of surface modification methods are available for tribological purposes.

The main categories are:

– modification of surface layers in process of shaping processing;

– heat (volume) treatment;

– surface heat treatment;

– treatment by surface plastic deformation;

– surface thermomechanical treatment;

– surface alloying;

– chemical and thermochemical treatment, including microarc oxidization;

– ion implantation;

– formation of surface layer composite structure by introduction of hardening phase particles;

– others and hybrid methods.

Resurfacing essentially replaces surface layer of base material (or previously deposited coating) with another having presumably more desirable friction and wear properties. Usually the new surface is harder than the surface replaced but not always. A wide variety of coating compositions is available. Each of these compositions can be applied by a variety of processes. The main categories of coating deposition processes are:

– electroplating;

– electrophorus;

– electroless plating;

– welding;

– thermal spraying;

– Physical Vapor Deposition;

– Chemical Vapor Deposition;

– immersion on melt;

– electro-spark alloying;

– electro-magnetic alloying;

– bonding of powder layers;

– solid phase plating (bonding of plates);

– painting;

– continuous deposition of films in process of friction (rotaprint, from environment, etc.).

Some of these application processes are very simple and inexpensive such as painting. Others are very complex either requiring vacuum processing or requiring a series of treatments and pretreatment. Some of them can be applied in the field while others can only be applied at particular facilities. There is no shortage of tribological coatings and surface layers to try for almost any need. The primary problem that exists is knowing what surface treatment to select for any given application. A related problem is that surface treatment developers often do not know where their coatings should be used or what coating or kind of surface modification to develop to meet a particular need.

There is a need for a strategy or methodology for selecting a surface layer composition and structure and methods of their obtaining for a given tribological application. In this paper such a strategy is proposed and elements of that strategy are discussed.

Solid surface characteristics

The difficulties of selection of surface treatment methods are connected with very large number of parametric variables of solid surface quality, which could be described by next ensemble of characteristics

$$K \supseteq G_{ex} \cup G_{in} \cup S_c \cup S_s \cup Ph_c \cup Ph_s \cup Ch_c \cup$$
$$\cup Ch_s \cup Df_c \cup Df_s \cup St_c \cup$$
$$\cup St_s \cup Pmp_c \cup Pmp_s \cup Ptp_c \cup Ptp_s \cup ....,$$

where G_{ex} is ensemble of characteristics, which are characterized the geometry parameters of external surface of strengthened layer and in its turn could be characterized by ensemble $G_{ex} \supseteq G_{exw} \cup G_{exm}$,

G_{exw} and G_{exm} are ensembles of parameters of waviness and roughness of surface correspondingly;

G_{in} is ensemble of parameters, which are characterized the geometry parameters of internal surface of strengthened layer (or coating) and in its turn could be characterized by ensemble $G_{ix} \supseteq G_{ixw} \cup G_{ixm}$;

S_c and S_s are ensembles of parameters, which are characterized the geometry configuration inaccuracy of surface of strengthened layer (or coating) and its interface with main material correspondingly;

Ph_c and Ph_s are ensembles of parameters, which are characterized;

Ch_c and Ch_s are chemical composition;

St_c and St_s are ensembles of parameters, which are characterized the structure;

Df_c and Df_s are ensembles of parameters, which are characterized the deformation;

Pmp_c and Pmp_s are ensembles of parameters, which are characterized the physico-mechanical properties;

Ptp_c and Ptp_s are ensembles of parameters, which are characterized the thermophysical properties;

indices c and s are for strengthened layer (or coating) and structure of near-surface layer of main material and/or transition zone respectively.

For search of optimal solution of particular tribological problem it is necessary to manifest the ensemble of parameters, which characterized the assembly and friction surface working conditions

$$TrS \supseteq E \cup C_e \cup L_e \cup F \cup M_e \cup W_e ,$$

where E is ensemble of characteristics of TrS work pieces;

L_e is ensemble of characteristics of linking between work pieces;

F is ensemble of kind of friction and its main characteristics;

M_e is ensemble of mutual shifting of TrS work pieces;

W_e is ensemble of wear characteristics of TrS.

For dataware of choice of surface treatment method it is necessary to elaborate the ensemble of parametric variables of solid surface quality, which influenced on wear-resistance at different kinds of wear and recommended for control of wear-resistance

$$QPSS_i \supseteq G_{exi} \cup G_{ini} \cup S_{ci} \cup S_{si} \cup Ph_{ci} \cup Ph_{si} \cup$$
$$\cup Ch_{ci} \cup Ch_{si} \cup Df_{ci} \cup Df_{si} \cup St_{ci} \cup$$
$$\cup St_{si} \cup Pmp_{ci} \cup Pmp_{si} \cup Ptp_{ci} \cup Ptp_{si} \cup ....,$$

where index mark “i” is given for certain kind of wear.

Furthermore, it is necessary to elaborate the ensemble of parametric variables of solid surface quality, which possible to control at each method of surface treatment and to determine the limits of these control.

$$QPSS_j \supseteq G_{exj} \cup G_{inj} \cup S_{cj} \cup S_{sj} \cup Ph_{cj} \cup Ph_{sj} \cup$$
$$\cup Ch_{cj} \cup Ch_{sj} \cup Df_{cj} \cup Df_{sj} \cup St_{cj} \cup$$
$$\cup St_{sj} \cup Pmp_{cj} \cup Pmp_{sj} \cup Ptp_{cj} \cup Ptp_{sj} \cup ....,$$

where index mark “j” is given for certain kind of surface treatment.

Methodology for surfase engineering methods selection

Coating deposition and surface modification have rapidly evolved in recent decades from simple and traditional methods to extremely sophisticated technologies.

These developments are part of an effort to eliminate the limitations imposed by oil-based lubrication and the process of an effort to eliminate the limitations imposed by oil-based lubrication and in the process are changing the general perception of the limits of wearing contacts [6].

Knowledge of the mechanisms behind these improvements in lubrication and wear resistance is, in most cases, very limited. The methods employed in most studies on surface coatings and modification are empirical and there is relatively little information available on which surface technology is the most suitable for a particular application. Prior to selecting the coating material and technological method it is necessary to determie the prime objective which could or be to reduce friction or suppress wear or both. During the selection of the most effective surface material and process to supress wear in a particular situation, the prevailing wear mechanism must first be recognized and assessed.

In the last years, a lot of research is being carried out in field of tribological coatings and surface treatment, and although they are being increasingly used in practice, little is still known about their properties and their tribological behaviour, especially for new advanced surface technology. Different types of coatings of the same composition have different mechanical and tribological properties, depending mainly on the type of deposition process and substrate material. Furthermore, due to the specific test methods and conditions for given applications or research facilities of an organization, it is seldom possible to compare the results obtained by different researches.

Selection of a coating-material and coating-process combination for a specific substrate can be complex. There are a great number of possible combinations, not all of which lead to satisfactory solutions [1; 6–9].

To overcome these problems, the strategy and methodology for selection of optimal tribological coatings and surface treatment for a given application are proposed.

The selection of types of surface strengthen treatment include following stages as shown on fig. 1:

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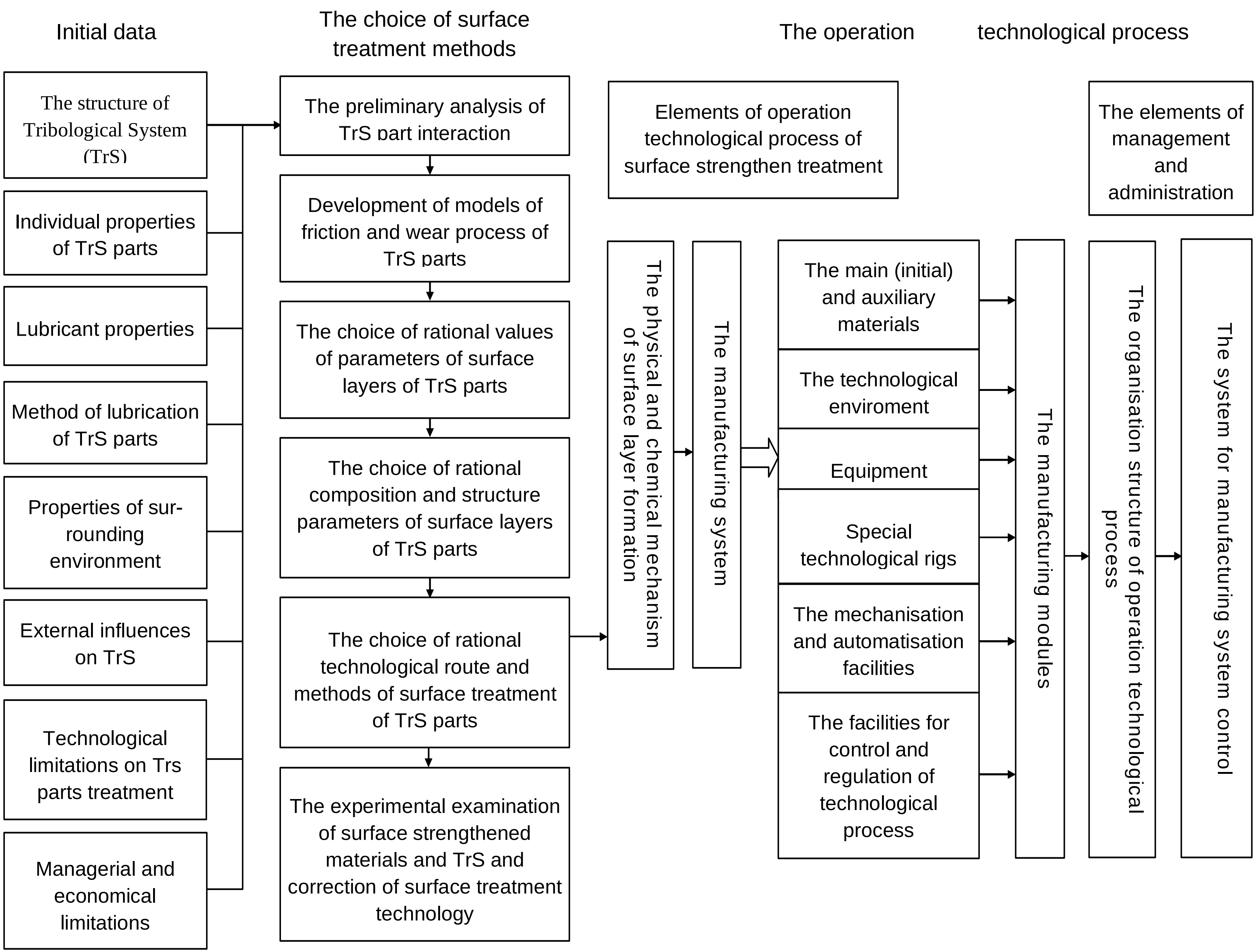

Fig. 1. Scheme of development of operation technology of surface strengthen treatment

1) study of initial data including: composition and internal relations of TrS (parts; relations between them; lubricant; surrounding environment); individual properties of TrS parts including geometry parameters of parts and friction surfaces (macro- and micro-geometry) and properties of main material; lubricant properties (volume and surface properties, chemical and physical, etc.); aggregate properties of lubricant and TrS parts (adsorption properties, moistness, etc.); lubrication manner influencing at first on techniques and lubrication type; properties of surrounding environment (chemical composition, corrode influence, humidity, temperature, pressure, etc.); external influences on TrS (kinetic – sliding (rolling) velocity V, hydrodynamic velocity; dynamic – mechanical force, pressure P, electric field parameters; thermal – temperature ϑ_0, thermal flow, thermal gradient); technological limitations on TrS parts treatment (shape and sizes of parts and surfaces, materials, variability of properties, technological heredity, etc.); managerial and economical limitations (required productivity, presence of equipment, materials, energy sources and others, sanitary, hygienic and ecological demands, permissible expenses, etc.);

2) determination of TrS parts interaction at static and dynamic conditions (adhesion, adsorption, chemosorption, oxidation, corrosion, diffusion, elastic strain, plastic deformation, microcutting, scratching, structure and phase transformation, etc.);

3) development of scheme of TrS action, including preliminary determination of TrS characteristics for describing of input values X transformation in output values Y

$$\{X\} = \{P, V, \vartheta_o\} \Rightarrow \{Y\} = \{F_t, Z, P_t\},$$

where F_t is friction resistance,

Z is wear and seizure,

P_t is accompany processes;

4) development of models of friction and wear process of TrS parts (physical, mathematical, imitative, analogue);

5) determination of rational values of parameters of surface layers properties by using models of friction and wear (by obtaining of permissible values of Y);

6) selection of rational composition and structure of surface layer of TrS parts (it must take into account existing analogues and also structure – properties correlation's);

7) determination of direction of surface strengthen treatment of friction surface of TrS parts: or surface layers modification, or coating deposition or their combination;

8) determination of list of possible physic-chemical methods of surface strengthen treatment;

9) preliminary selection of optimal methods of surface strengthen treatment by using elected criterions of optimisation and maintenance of demanded technique-economical limitations;

10) experimental test of surface strengthen treatment in laboratory or empirical-industrial conditions;

11) preliminary projection of operation methods of surface treatment – equipment, special technological rigs, technological variables, technological environment, the facilities of mechanisation, robotisation and automatisation, methods of management and control, technico-economical comparison of operation variants;

12) clarification of relationships between operation technology of surface strengthen treatment and manufacturing procedure of TrS parts production; correction of structure for both processes for purpose of their optimisation;

13) final selection of surface strengthen treatment methods, development of measures for reliability of maintenance of demanded characteristics of technological process; development of project of processing system of surface treatment.

The selection of optimal methods of surface strengthen treatment usually realizing by using of technical criterions as securing of TrS tribotechnical characteristics accordance to demanded one (fig. 2).

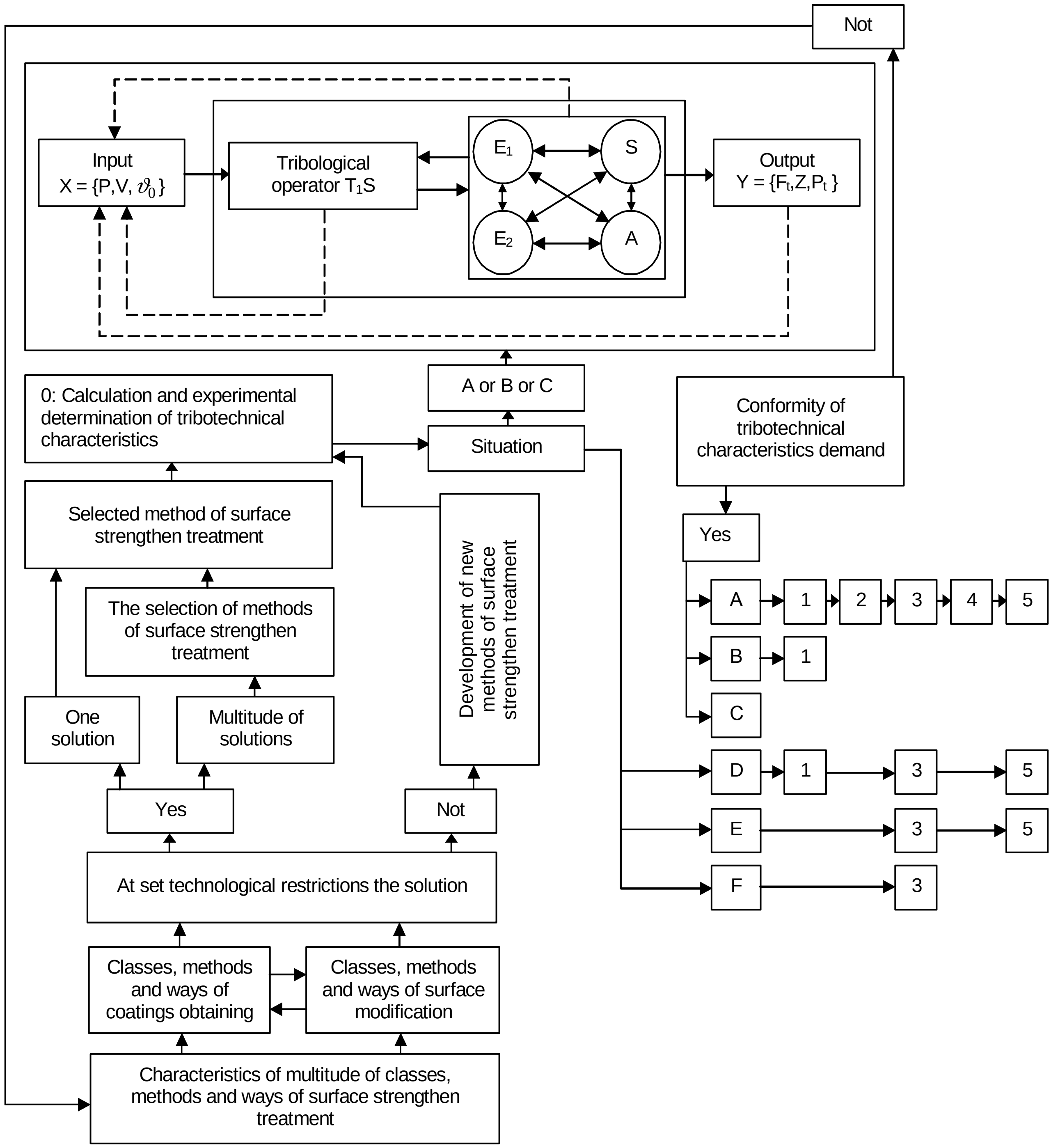

Fig. 2. Scheme of selection of optimal methods of surface strengthens treatment:
A – development of tribological system not having analogues;
B – selection of new friction pair for instead out-of-date one;
C – selection of friction pair for weak-loaded typical tribological system;
D – improvement of typical tribological system;
E – replacement of friction pair by new serial one;
F – determination of inter-repair cycle.
0 – calculation and experimental determination of tribotechnical characteristics;
1 – research test at determined parameter;
2 – boundary research test (at extremes conditions);
3 – model research test;
4 – defined nature test;
5 – exploit test

In case of presence some equivalent surface treatment variants on tribotechnical characteristics for the final selection is used economical criterions. The system of selection of optimal surface strengthen treatment are including the scheme of TrS action and database of multitude of surface strengthen treatment classes and methods characteristics. Preliminary by using technological limitations, other initial data and data base one could select a recommended groups of parameters of surface layers quality which promoted the wear resistance increasing. The next would be the selection of respective methods of surface strengthens treatment, which allowed the control of desirable parameters of surface layer quality. Then by use of early developed model of friction and wear for the this TrS is making more detailed valuation of selected decision including calculation and experimental determination of tribotechnical characteristics and following test of TrS. The use of different methods of surface strengthen treatment is opening the vast possibilities of control of friction surfaces contact interaction independently from composition and structure of main materials of TrS parts.

Depending on kind of aggregate of contacting surface layers of friction pairs it is possible to divide them on three classes:

– contact of two one-phase surface layers;

– contact of one-phase layer and composite structure surface layer;

– contact of two composite structure surface layers.

Only in case of contact of one-phase surface layers the common number of possible variants of contacts is very high and could be evaluated by next equation

$$K_{sum} = 2(n^2 + m^2 + q^2) - 3(n + m + q) + \\ +6 + 2(nm + nq + mq)$$

where n is a number of simple substances,

m is a number of two- and many-component solid solutions,

q is a number of two- and many-component chemical compounds.

Those multiplicity of possible variants of contact in case of only one-phase surface layers is allowed by choice of composition of surface layers materials and their structure to control the quality of physical contact of friction pairs, in particular the size of real contact area, inclination to forming of desirable secondary structures in process of friction, properties of third (intermediate) substance, fatigue wear resistance, etc.

In reality the factual variety of possible contacts of one-phase layers is considerably more inasmuch as the friction processes depends not only from chemical composition of contacted surface layers, but also from their structure and energetic parameters, including size, shape and character of mutual orientation of grains; structure and strength of intercrystalline boundaries; the level of strain hardening; type of crystal lattice; mechanical properties; surface properties, etc.

The creation on one or both friction surfaces of layers with composite structure lead to essential increasing of possible variants of friction surfaces contacts and to appearance of some new physic-chemical phenomena in process of friction. The peculiarities of contact interaction of such friction pairs at first connected with simultaneous presence of contact aggregate between friction surfaces. But the description of friction zone in contact of such surface layers is demanding the use of complex of special parameters.

Conclusion

The approach to the development and selection of surface strengthen treatment for tribological purposes have to involve methods of system analyses. The tribological system work-pierces and friction surfaces functions must be accurately defined in functional, technological, economical, ecological and other respects. The proposed strategy has the potential for simplifying selection and design of coatings and/or surface layers and reduction of development time for new tribological systems and/or improvement of existing ones.

But the subsequent laboratory tests at several levels must be also completed. Development of computer modeling methods for selection of surface engineering processes and experts systems for developing of surface engineering technology for particular application is necessary. The system approach could be also useful for development of new tribological coatings and surface modification methods. However a lot has still to be done for development of methodology of selection of optimal methods of surface engineering and their improvement.

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