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## ANALYSIS AND DESIGN OF HIGHLY EFFICIENT METHODS OF TREATMENT

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**Abstract:** Analysis of the self-organization processes in deposition, thermal treatment, deformation, and cutting of surface layers of items, as well as in combined methods of treatment, i.e. in deposition of coatings and thermal treatment combined with deformation and cutting, shows that a technological complex can work continuously and stably in an automatic mode requiring no external control. This gives reasons for the technological complexes designed as autonomous flexible production modules to be used for combined electromagnetic and thermomechanical treatment of workpieces.

**Key words:** self-organization, processes of deposition, thermal treatment, technological complex

### 1. INTRODUCTION

Development and adoption of new methods of treatment based on combination of different types of energy or effects on the treated material is a promising trend in machine building.

Generally, a system model of technology [1] is represented by a combination of three input flows: substance, energy, information. It may be reasonable to consider the use of energy and information subsystems for these purposes. The first supplies and converts energy necessary to affect an intermediate product in order to change its physical and mechanical properties, to remove or to deposit material. It is specified by the form of treatment. The second controls the flows of energy and substance, providing them in the required quantities to the prescribed place of the working volume so that to ensure the certain form, size and properties of the workpiece surface.

### 2. FORMATION OF A SURFACE LAYER BY METHODS OF TREATMENT

It is expedient to consider the process of treatment as some energy system affecting an intermediate product so that transition from one state to another corresponding to a new quality is provided [2]. This effect is achieved in several stages. At the first stage, the supplied energy is converted to working energy,  $E_w$ , by technological equipment. At the second stage, the working energy is converted to the energy of the effect,  $E_{eff}$ , on the treated object. At the third stage, the energy of the effect leads to the formation of physicochemical mechanisms,  $M_{ph.-ch}$ , of treatment of the intermediate product that are a main element of the method of treatment parameters formation (efficiency, energy consumption, quality of the surface, etc.).

Thus, the process of treatment (PT) represents a chain of energy conversion

$$PT = \{E_w \Rightarrow E_{eff} \Rightarrow M_{ph.-ch}\}. \quad (1)$$

Processes of shaping (Sh) are characterized by the components [2]

$$Sh = \{M_{e.s}, F_{d.e}, K_{sch.t}\} \quad (2)$$

and features of them: point, linear, surface, volumetric sources for  $M_{e.s}$ ; continuous, oscillating, pulse effect for  $F_{d.e}$ ; rectilinear, rotary, two rectilinear, rotary-translational motion or its absence for  $K_{sch.t}$ .

As a result, all methods are first subdivided into three classes: with removal, without removal, and with deposition of the material. Second, subclasses which characterize the types of energy used in treatment of the material are distinguished for each class. Third, there exist differences in the character of the physicomachanical effect and, fourth, in the type of instrumentation used and the kinematics of treatment [1].

On the basis of this classification, there are suggested the generalized models of the method of treatment (MT), which are usually represented [2] by analytical expression of the form

$$MT = \{N_{mt}, RA_{mt}, E_w, E_{eff}, M_{ph.-ch}, K_{sch.t}, F_{d.e}, M_{e.s}, S, G\}, \quad (3)$$

where  $N_{mt}$  is a name of the method of treatment;  $RA_{mt}$  is a range of application of the method of treatment;  $S$  is a scheme of location and fastening of intermediate product;  $G$  is a treating instrument.

Formulas (1) - (3) give a rather complete and clear idea about the structure and composition of the processes of treatment and shaping components. It would be convenient to use them for the new technological procedures and methods of shaping development, yet they are of no effect when any logical operations and transformations are needed. To formalize the conditions

of target-oriented formation of new methods of treatment, each aggregate of like components  $r_i$  is described as some set of technological solutions  $R_i$ . This approach [3] allows each method of treatment  $r_{mt}$  to be represented in the form of a procession

$$PT = \{E_w \Rightarrow E_{eff} \Rightarrow M_{ph.-ch}\}. \quad (4)$$

where  $r_{surf}$  is a treated surface of workpiece;  $r_{mat}$  is the treated material;  $r_t$  is a type of the method of treatment application area;  $r_{effmat}$  is the means to effect the material of intermediate product;  $r_{e,s}$  is a type of energy supplied to the working zone;  $r_{me,s}$  is the means of energy supply to the working zone;  $r_{e,sour}$  is an energy source;  $r_{e,m}$  is an energy mode of treatment;  $r_t$  is the treating tool;  $r_k$  is a type of kinematic scheme of treatment;  $r_{st}$  is a static scheme of treatment.

Each element of procession (4) is a component of the corresponding set of technological solutions, i.e.,  $\{r_i\} = R_i$  or  $r_i \in R_i$ .

The presence of a specific property  $\alpha$  in a technological solution  $r_i$  is expressed by the corresponding predicate

$$E_\alpha(r_i), \quad (5)$$

which confirms that the technological solution  $r_i$  possesses the property  $\alpha$ .

Each property  $\alpha$  can acquire many values  $\theta_\alpha$ . Then the expression

$$E_\alpha(r_i) \wedge \theta_\alpha \quad (6)$$

indicates that the technological solution  $r_i$  possesses the property  $\alpha$  and the value of the latter is  $\theta_\alpha$ .

Predicate (5) allows one to choose a technological solution with a given property, the value of which is determined by formula (6).

In general, a technological solution  $r_i$  is characterized by a number of properties  $\alpha, \delta, \dots, \gamma$ , each of which can acquire different values; this is expressed by the formula

$$\forall r_i \exists \alpha \exists \delta \dots \exists \gamma \{ [E_\alpha(r_i) \wedge \bigwedge_{j=1}^n \theta_{\alpha_j}] \wedge [E_\delta(r_i) \wedge \bigwedge_{k=1}^m \theta_{\delta_k}] \wedge \dots \wedge [E_\gamma(r_i) \wedge \bigwedge_{p=1}^q \theta_{\gamma_p}] \}.$$

Certain relationships can exist between the values of the properties of the solution  $r_i$  and not every combination of them is admissible, i.e., the technological solution  $r_i$  possesses the property  $\alpha$  with the value  $\theta_{\alpha n}$  and the property  $\delta$ , the value of which is determined by the set  $\theta_{\delta p j}$ . This situation is described by the relation

$$\exists \alpha \exists \delta \forall r_i [E_\alpha(r_i) \wedge \theta_{\alpha n} \rightarrow E_\delta(r_i) \wedge \bigwedge_{j=1}^k \theta_{\delta p j}].$$

We assume that if any two components of the method of treatment possess at least one common property, then a relationship of commonality of properties exists between them. This makes it possible to organize the selection of technological solutions by equivalency and preference [3]. Unlike solutions, with the combinations of their properties corresponding to each other, are chosen by the first characteristic:

$$\exists \alpha \forall r_i \forall r_j [E_\alpha(r_i) \wedge E_\alpha(r_j) \wedge (\theta_\alpha^{r_i} = \theta_\alpha^{r_j}) \rightarrow (r_i \approx r_j)] \quad (7)$$

and like solutions possessing the best values of the required properties are chosen by the second characteristic

$$\exists \theta_\alpha \forall r_{i1} \forall r_{i2} [E_\alpha(r_{i1}) \wedge E_\alpha(r_{i2}) \wedge (\theta_\alpha^{r_{i1}} h \theta_\alpha^{r_{i2}}) \rightarrow (r_{i1} \approx r_{i2})]. \quad (8)$$

According to (7), (8), this approach allows one to formalize the search for a technological solution  $r_i$  by the specific value of the determined criterion of selection  $t_q$ :

$$\theta_\alpha^{r_i} h t_q, \quad (9)$$

where  $h$  is a symbol of preference ratio, which can acquire values  $>, \geq, <, \leq$ .

Then a combination of predicates of the type (9) allows one to select the solution  $r_i$  by several criteria of selection  $t_{q1}, t_{q2}, \dots, t_{qn}$ , which correspond to  $n$  different properties of the solution  $r_i$ . In this case the condition of selection of the solution  $r_i$  takes the form

$$\bigwedge_{j=1}^n (\theta_{\alpha_j}^{r_i} h_i t_{qj}) \quad (10)$$

Use of expression (10) in problems of selection of unlike technological solutions possessing different but mutually dependent properties  $\alpha$  and  $\delta$  (i.e., the condition  $E_\alpha(r_i) \rightarrow E_\delta(r_j)$  is valid) allows one to organize the selection of solutions

$$\exists \theta_\alpha \forall r \forall r_j [E_\alpha(r_i) \wedge E_\delta(r_j) \wedge (\theta_\alpha^{r_i} h_1 t_1) \wedge \bigwedge (\theta_\delta^{r_j} h_2 t_2) \rightarrow (r_i \approx r_j)]. \quad (11)$$

However, in general, condition (11) is not valid, since the interrelations of the properties  $E_\alpha(r_i) \rightarrow E_\delta(r_j)$  of the solutions  $r_i$  and  $r_j$  are often unknown. Moreover, in substantiating the selection of technological solutions and the synthesis of combined methods one must allow for stability of formation of the parameters of the quality of treatment and consider the mechanisms of control over stability of the technological process using feedback [4]. Therefore, it is suggested to use criteria of self-organization as an object function instead of specific values of the combination of the criteria of selection  $t_{q1}, t_{q2}, \dots, t_{qn}$ , since the conditions providing self-organization of surface phenomena and stabilization of formation of the parameters of the quality of treatment are a consequence of an excess structural composition of the considered technological system [5].

### 3. ANALYSIS OF SELF-ORGANIZATION OF SURFACE PHENOMENA

Interrelated processes of motion and exchange of material and information flows in a technological system are described by the entropy [6, 7]

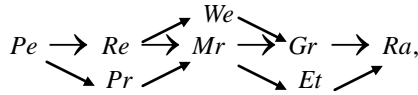
$$\varepsilon = -k \int_0^\infty p \ln p dp,$$

where  $\varepsilon$  is an entropy;  $k$  is a constant factor;  $p$  is a density of the subsystem probable states distribution.

The production of entropy  $\sigma = d\varepsilon / d\tau$  makes it possible to consider the criteria describing different states of the working zone of the technological system.

A study of the state of the working zone and investigation of self-organization of technological processes in combined methods of treatment [8] allowed one to consider the model of analysis of the articles formation processes.

Analytical model of the structural changes and phase conversions of the treated material, establishes the sequence of the structures and phases formation with increase of the power of effects by the criteria of transfer



where  $Pe$  – Peclet number;  $Re$  – Reynolds number;  $Mr$  – Marangoni number;  $Gr$  – Grashof number,  $Ra$  – Rayleigh number;  $We$  – Weber number;  $Pr$  – Prandtl number;  $Et$  – thermoelectrical number.

Use of the criteria of the structures and phases formation greatly decreases the volume of experimental studies of the processes of a surface layer formation in highly efficient methods of treatment.

In cases when the physicochemical mechanisms of a surface layer formation are unknown, it is suggested to describe the processes by the laws of distribution of random quantities rather than by a system of balance equations [8].

The Romanowski relation [9]

$$R = (\lambda_p^2 - k) / \sqrt{2k}, \quad (12)$$

where  $\lambda_p^2$  is the Pierson criterion;  $k$  is the number of degrees of freedom used in calculation of theoretical distribution of statistical characteristics, allows one to judge the degree of correspondence of the statistical data to the selected law of distribution.

A statistical analysis of the parameters of quality of the studied methods of treatment makes it possible to distinguish the most substantial technological factors and to reveal the interrelations between them. Formation of technological rules of the studied methods of treatment only from narrow ranges of the modes restricted by the conditions of self-organization provides conditions for stabilization of the parameters of quality of a surface layer.

In selecting the number of elements and processes realized by a technological complex it is expedient to consider the interrelation of conflicting requirements to a production system on its reliability and plausibility. The reliability-stability and flexibility-adaptivity relationship can serve as a criterion which allows one to decide on a rational structure of a technological complex.

In self-organizing systems one can control flexibility and reliability by changing the number of subsystems [4]. Each subsystem  $i$  has a strictly defined  $q_1$  and a fluctuating with scattered characteristics  $q_2$ . The total yield of the system to a first approximation with account for the additivity of the material and information flows is

$$q^{(i)} = q_1^{(i)} + q_2^{(i)}. \quad (13)$$

Assuming that under the conditions of production  $q^{(i)}$  is an independent random quantity, we present the total yield as

$$Q = \sum_{i=1}^n q^{(i)} \quad (14)$$

Total yield (14), according to the central limit theorem [4], increases in proportion to the number of subsystems  $n$ , whereas the degree of scattering increases in proportion to the square root  $\sqrt{n}$ , similar to relation (12). These estimates are based on an analysis of linear relation (13); in fact, the feedback inherent leads to even more substantial suppression of scattering of the characteristics. Thus, it is expedient to create technological complexes of highly efficient treatment providing stabilization of the parameters of quality of a part and automatic control over technological processes with self-organization of surface phenomena as key factor.

#### 4. MATCHING OF PROCESSES IN COMBINED METHODS

Simultaneous use of several energy fluxes transferred to the working zone by both a technological medium and instrumentation with control elements sharply increases the efficiency of technological operations [8]. However, in the combined use of several fluxes there arise technological limits to stability of combined processes. Therefore, principally new technological complexes for combined treatment can now be created on the basis of self-organization in technological systems [10].

To produce articles by technological complexes, the thermomechanical and electromagnetic flows of substance and energy can be used, since the processes of the production objects surface formation, up to micron accuracy, have basically a thermomechanical character, and electromagnetic flows (due to their simplicity of formation and convenience of monitoring) are most technological.

We consider the whole range of technological operations: deposition, thermal treatment, deformation and cutting of surface layers of treated articles, and the principal combinations of them which should be realized by technological complexes in combined electromagnetic and thermomechanical treatment of articles. The method of electromagnetic fusion is used for deposition of a surface layer, in which particles of ferromagnetic powder are aligned with electrode chains in a constant magnetic field, and, as a result of electric-arc discharges, are welded to the surface of the blank. This method enables to deposit coatings of only a certain thickness; then the formed layer loses stability, and protrusions formed on the surface are destroyed in subsequent discharges. The processes of surface formation are controlled by electromagnetic flows, which, besides the fixation of ferropowder particles, provide intense heat release at the joints and, regardless of the powder used, control the weld layer thickness, changing its electric resistance.

Local inductive electric-contact heating or electric-spark discharge, which, besides heating, alloy the surface layer of the treated articles using ferropowder particles or additives put to lubricating and cooling fluids, are used for surface thermal treatment of products. Electromagnetic flows in the working zone allow to control both the depth and degree of surface layer strengthening in thermal treatment.

Ball rollers are used in technological complexes to strengthen the deformation and change the form of surface layers. In surface plastic deformation, additional degrees of freedom allow the ball, as a result of interaction with the treated surface, to rotate as well as to swing. Without additional heating, the degree of deformation is small and the trajectory of the ball has a loop-like character. In heating, the treated material goes to a plastic state, thus making the degree of deformation and the coefficient of friction increased. This impedes rotation and decreases the length of, first, the peak-like and, then, sinusoidal trajectory of the ball, thus leading to a decrease in the intensity of plastic deformation. So, the process of surface plastic deformation can be controlled by a thermal effect and additional rotation of the ball.

A technological complex makes cutting by traditional cutters, milling cutters, emery disks, and a free abrasive in a magnetic field.

When cutting by traditional cutting tools during treatment with preheating, the equilibrium of intensities of temperature weakening and deformation strengthening is violated, and the zone of chip formation loses stability and begins to shift, changing the shear angle. In this case the process of chip formation can be controlled by additional displacement of the rotating tools, which prevents frozen metal fastening to the blade and restores the working part of the cutting edge, thus excluding a jump of temperature in a localized zone of chip formation. When grinding by an emery disk, with an increase in depth of cutting in incision or oscillations of the allowance, the forces of cutting and friction increase, which facilitate active crumbling-out of abrasive particles of the disk. Due to this, the disk wear and the velocity of transfer of crumbled heated particles increase. As a result, the forces of cutting and friction decrease, thus decreasing the intensity of the crumbling process. These oscillations of intensity, by restoring the abrasive particles of the disk, enable to control the process of grinding.

Treatment of viscous and plastic materials by an emery disk leads to its greasing, thus impeding self-sharpening. In this case the process of grinding is controlled by electromagnetic flows in magneto-abrasive treatment in which metal is removed by unfastened grains of abrasive powder with a ferromagnetic coating under the effect of a constant magnetic field.

## 5. CONCLUSION

Analysis of the self-organization processes in deposition, thermal treatment, deformation, and cutting of surface layers of items, as well as in combined methods of treatment, i.e. in deposition of coatings and thermal treatment combined with deformation and cutting, shows that a technological complex can work continuously and stably in an automatic mode requiring no external control. This gives reasons for the technological complexes designed as autonomous flexible production modules to be used for combined electromagnetic and thermomechanical treatment of workpieces.

## REFERENCES

- [1] PODURAEV, V. (1985) *Technology of Physicochemical Methods of Treatment* [in Russian], Moscow.
- [2] RYZHOV, E., AVERCHENKOV, V. (1989) *Optimization of Technological Processes of Mechanical Treatment* [in Russian], Kiev.
- [3] GOLODENKO, B., SMOLENTSEV, V., (1994) Vestn. Mashinostr., No. 4, pp 25-28
- [4] KHEIFETZ, M., CHEMISOV, B., AKOULOVICH, L., et al., (2002) *Intellectual Production* [in Russian], Novopolotsk.
- [5] ARTOBOLEVSKII, I., ILINSKII, D. (1983) *Principles of Synthesis of Systems of Automatic Machines* [in Russian], Moscow.
- [6] EBELING, V. (1979) *Structure Formation in Irreversible Processes: Introduction to the Theory of Dissipative Structures* [Russian translation], Moscow.
- [7] HAKEN, G. (1980) *Synergetics* [Russian translation], Moscow.
- [8] KHEIFETZ, M., KOZHURO, L., MROCHEK, J. (1999) *The Processes of Self-organization at the surface formation* [in Russian], Gomeł.
- [9] PASKHVER, I. (1974) *Law of Large Numbers and Statistical Regularities* [in Russian], Moscow.
- [10] VASILEV, A., DALSKII, A., KHEIFETZ, M., et al., (2002) *Technological principles of details treatment* [in Russian], Minsk.