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COMPUTER-AIDED SYNTHESIS OF ECOLOGICALLY SAFE PROCESSES OF CHEMICOTHERMAL TREATMENT OF WORKPIECES FROM METALS

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Abstract: This paper deals with the problems of computer-aided select of the mark of metal, way of manufacturing and type of procurement depending on type of hardening and also the problems of select of environmentally safe technological process, equipment, appliances, supplementary materials and regime parameters of determined before type of hardening handling for constructed a part when solving the problems of technological preparation of manufacture of workpieces from metals.

Most of industrial plants have passed to computer technologies in order to increase the efficiency of preparation of manufacture, understanding that without them it'll be hard to survive. Heightening of efficiency of technological projection is based on the development of new shapes of introducing and analysis of technological information. Working out of systems of information support of processes of technological projection based on methods of geometrical modeling, methods of creation and maintenance of object-oriented databases and also methods of identification and storage of design allows to represent and to design environmentally safe technological process in a new way.

The problem of projection of environmentally safe technological processes treats to a category of multi-factor. Its solution can be found by working out of formalized methods acceptable for projection of technological processes and reflecting a real state of manufacturing

In this connection this paper reflects the problems bound with working out of methods of computer-aided solution of the problem of technological preparation of manufacture (**TPM**) for chemicothermal treatment of workpieces from metals taking into account environmental safety of processes of hardening and according to principles of the theory of systems.

The whole complex of problems of TPM of parts from metals forms a multilevel structure and consists of sequence of subsystems integrated by information streams. The result of solving of all complex of problems is design-engineering documentation for a part, required for its manufacture. All operating characteristics and strength properties of a part and of whole workpiece should be also realized.

This paper describes operating of the following subsystems: 1) subsystems of select of the metal mark and type of hardening handling of surfaces of a part, the way of manufacture and type of procurement depending on chosen type of hardening handling, and 2) subsystems of choice of the environmentally safe technological process, equipment, appliances, supplementary materials and regime parameters of determined before type of hardening handling.

On the one hand, the subsystem of choice of metal mark and type of hardening handling of surface of a part, the way of manufacture and the type of procurement depending on chosen type of hardening handling is the main in a system of TPM of parts from metals as it allows to receive one or several marks of metal with corresponding type of its hardening,

the way of manufacture and the type of procurement on the base of aggregated estimates. On the other hand, it is impossible to estimate authentically all expenses bound with manufacture of a part without detailed reviewing of technological processes of mechanical and hardening handling.

Mathematical setting of the problem of computer-aided select of the mark of metal, the way of manufacturing and the type of procurement depending on the type of hardening for workpieces of mechanical engineering

For constructed part with given geometrical sizes L, weight G, service conditions U^d, size of series of production Sp^d and category of significance (degree of responsibility) Kz on set $W_1 = M^d \times Tu^d \times Z^d \times P_z^d \times V_z^d \times V_u^d$ it's required to find such variant $w_1^* \in W_1$, for which the cost of manufacture of procurement from selected mark of steel with the corresponding hardening handling has minimum value. The set W_1 is the Cartesian product of subsets of admissible kinds: materials used for manufacture of a part M^d; hardening handling providing given quality coefficients of workpiece Tu^d; procurements Z^d; ways of manufacturing of procurements P_z^d, supplementary materials for realization of methods of manufacturing of procurement V_z^d and hardening handling V_u^d.

In formalized form the essence of the problem is in searching of minimum of the objective function

$$F_1^{opt} = \min_{W_1}\Big(\big(S_M\left(m^d, G, K_c\right) + S_{TZ}\left(G, L, m^d, K_{p_1}\right) + S_{VS}\left(K_c, G, s_{VS}\right) + \\ + S_{OB}\left(t_{m_3}, K_{p_2}\right)\big)\cdot K_{SS}\left(T_I, f, \rho, L\right) + S_{TR}\left(L, G, k_{SER}, k_{\min}, r\right)\Big) \quad (1)$$

under execution of limitations for operating characteristics and strength properties of workpiece:

$$Xu^d \geq Xu^d_{\lim}, \quad (2)$$

$$L' \leq L, \quad (3)$$

equations of connection:

$$\overline{\phi}\left(M^d, Tu^d, Z, V_z{}^d\right) = 0, \quad (4)$$

$$\overline{\psi}\left(M^d, Tu^d, Z, V_u\right) = 0, \quad (5)$$

representing simplified mathematical models of technological processes of manufacturing of procurement (molding, punching etc.) and hardening handling. In this expression: S_M - cost of material used for manufacture of a part, S_{TZ} - expenditure of labor; S_{VS} - cost of supplementary materials; S_{OB} - cost of handling; K_{SS} - coefficient which characterizes life expectancy of a part; S_{TR} - cost of transportation on delivery of metal from the supplier to warehouse of a plant. Components of criterion are explicitly described in the paper [1].

Mathematical formulation of the problem of computer-aided choice of technological process, equipment, appliances, supplementary materials and regime parameters of hardening handling

For constructed part with given geometrical sizes L weight G, size of series of production Sp^d, and also with selected sort of hardening handling $tu^d \in Tu^d$ and mark of material m^d on set $W_3 = Tp^d \times O_u^d \times P_u^d \times V_u^d$ it's required to find such variant $w_3^* \in W_3$,

for which cost of hardening handling has minimum value. Set W_3 represents the Cartesian product of subsets of technological processes Tp^d for selected type of hardening handling tu^d, valid sets of equipment O_u^d and appliances P_u^d and types of supplementary materials V_u^d.

At realization of technological processes of chemicothermal treatment, such as cementation, nitration, nitrocementing, borating etc., following harmful substances are isolated into the environment: the oxide of carboneum, carbon dioxide, soot, nitric oxides, ammonia, chloro-hydrogen, pyroborate of natrium etc. For providing the protection of environment it is necessary to organize pumping up of end gases from zone of board and their careful decomposition or salvaging on exit into atmosphere.

The majority of works include the economic criterion, however, alongside with economic metrics other quantitative and quality indicators are not less important. The most significant of them are estimation of variant $w_3^* \in W_3$ on scrap rate at manufacture of mechanical engineering parts and manufacturability of aggregate processes of their manufacture. Therefore in this work the problem of computer-aided choice of manufacturing process, equipment, appliances, supplementary materials and regime parameters of hardening handling is a multi-criteria problem.

Unified generalized criterion F_3^{opt} can be written as [2]

$$F_3^{opt}(\alpha) = \sum_{i=1}^{3} \rho_i \cdot \omega_3^i(\alpha) = \rho_1 \cdot \omega_3^1(\alpha) + \rho_2 \cdot \omega_3^2(\alpha) + \rho_3 \cdot \omega_3^3(\alpha), \tag{6}$$

Where ρ_1, ρ_2, ρ_3 - weighting coefficients,

$$\rho = \{\rho_i\} = \{\rho_i : \rho_i > 0 \quad i = 1,\ldots,3, \quad \sum_{i=1}^{3} \rho_i = 1\}; \tag{7}$$

$\rho_i \cdot \omega_3^i(\alpha)$ - fluidized losses on criterion i; $\omega_3^i(\alpha) = \omega_3^i\left(F_3^i(\alpha)\right), \quad i = 1,\ldots,3, \ \alpha \in W_3$ - monotonous functions conversing each function of purpose $F_3^i(\alpha), \quad i = 1,\ldots,3, \ \alpha \in W_3$ to dimensionless type.

$F_3^1(\alpha)$ - economic criterion including expenditures of labor, costs of supplementary materials and materials which were used at manufacture of appliances, costs of the electric power and damage to environment by ejection of contamination into free air; $F_3^2(\alpha)$ - estimation of scrap rate of details; $F_3^3(\alpha)$ - criterion of manufacturability of aggregate processes of hardening handling, and the functions of purpose $F_3^1(\alpha)$ and $F_3^2(\alpha)$ are minimized, and $F_3^3(\alpha)$ - is maximized.

Economic criterion. In the formalized form the essence of the problem is in searching for minimum of the objective function

$$\begin{aligned} F_3^1(\alpha) = \min_{W_3} \Big(& S_{TZ}\left(G, L, m^d, K_p, K_1, V, F, K_F, K_K, v_{ohl}\right) + S_{VS}\left(G_{VS}, s_{VS}, L\right) + \\ & + S_{PR}\left(G_{PR}, s_{PR}, L, K_1, V, F, K_F, K_K, m^d, v_{ohl}, G\right) + \\ & + S_{EN}\left(L, K_1, V, F, K_F, K_K, m^d, v_{ohl}, N, s_{EL}\right) + S_{WW}\left(\gamma, S_{заз}, U, N, h, A, m_e, L\right)\Big) \end{aligned} \tag{8}$$

under execution of limitations:

for technological process on temperature regime

$$t_{op_e}{}^{\min} \le t_{op_e} \le t_{op_e}{}^{\max}, \quad op_e \in Op^d, \tag{9}$$

for material of a part on depth of layer of CTT

$$h_{m^d}{}^{\min} \le h_{op_e} \le h_{m^d}{}^{\max}, \quad m^d \in M^d, \tag{10}$$

for material of a part on hardness

$$HRC_{э m^d}{}^{\min} \le HRC_{э op_e} \le HRC_{э m^d}{}^{\max}, \quad m^d \in M^d, \tag{11}$$

for equipment on overall dimensions of hardened part

$$L_{o_{us}}{}^{\min} \le L \le L_{o_{us}}{}^{\max}, \quad o_{us} \in O_u^d, \tag{12}$$

for appliances on weight of hardened part

$$G \le G_{p_{us_1}}{}^{\max}, \quad p_{us_1} \in P_u^d; \tag{13}$$

coupling equations:

$$\overline{\psi}(G, L, m, tu, O_u, P_u, V_u) = 0, \tag{14}$$

representing mathematical models of technological processes of selected type of hardening handling $tu^d \in Tu^d$.

In this expression: S_{TZ} - expenditure of labor; S_{VS} - cost supplementary materials; S_{PR} - cost of materials which were used at manufacture of appliances; S_{EL} - cost of the electric power; S_{WW} - cost of damage to the environment inflicted by ejection of contamination into free air.

The part, which should be hardening handled is characterized by the following parameters:

$L = \{l_1, \dots l_k, \dots l_{Ng}, v_d\}$ - designer form with given geometrical sizes l_k, $k = \overline{1, N_g}$ and accessory to the definite class $v_{bd}^d \in V_d$, N_g – quantity of geometrical sizes of a part;

$h_{m^d}{}^{\min} \le h \le h_{m^d}{}^{\max}$ - depth of layer of chemicothermal treatment;

$HRC_{э m^d}{}^{\min} \le HRC_э \le HRC_{э m^d}{}^{\max}$ - surface layer hardness.

Components of criterion are explicitly described in paper [3].

Estimation of scrap rate at manufacture of parts. Because of imperfection of technology of manufacturing waste is inalienable component, which tends to reduce to minimum. In this paper searching for $w_3^* \in W_3$ the registration of scrap rate is made by using of the following formula

$$F_3^2(\alpha) = \min_{W_3} \prod_{j=1}^{E_{tp_u}} Br_j, \tag{15}$$

where Br_j - scrap rate which take place at manufacture of parts, taking into account: the type of technological operation and equipment with appropriate appliances.

Searching for minimum of given criterion limitations (9) - (13) should be fulfilled and coupling equations (14) should also be fulfilled.

Criterion of aggregate processes manufacturability of hardening handling. Manufacturability of the process is convenient and easy to realize permitting to fulfil the process providing getting of given outcomes, with the least costs of direct and materialized labor.

$$F_3^3(\alpha) = \max_{W_3} \prod_{j=1}^{E_{tp_u}} Te_j, \tag{16}$$

where Te_j - manufacturability of j-process of hardening handling taking into account: the type of technological operation and equipment with appropriate appliances.

Searching for minimum of given criterion limitations (9) - (13) should be fulfilled and coupling equations (14) should also be fulfilled.

Algorithm of solution of the problem of computer-aided choice of metal mark, the way of manufacturing and the type of procurement depending on the type of hardening for workpieces of mechanical engineering and the problem of computer-aided choice of technological process, equipment, appliances, supplementary materials and regime parameters of hardening handling

As the dimension of sets W_1 and W_3 is finite (< 10000 variants) then, taking into account fast response time of modern PCs, the problem solving is reduced to series of consecutive sorting out of all variants of valid marks of metals, ways of manufacturing of procurements, types of hardening handling and types of possible procurements, which can be used for manufacture of a part, for the problem of computer-aided choice of metal marks, the way of manufacturing and the type of procurement depending on the type of hardening for workpieces of mechanical engineering, and also valid technological processes of hardening handling, sets of equipment, appliances and types of supplementary materials, which can be used for manufacturing of a part, for the problem of the computer-aided choice of manufacturing process, equipment, appliances, supplementary materials and regime parameters of hardening handling and the choice of their combination, where the criteria F_1 and F_3 reach minimum value, under condition of execution of all limitations. Thus, it is possible to find an overall minimum of criteria F_1^{opt} (1) and F_3^{opt} (6).

The creation of sets W_1 and W_3 implements with using of information knowledge base including relational database of mechanical engineering and a rule-base, regulating the choice of its units. The database contains information on different marks of steels, information on ways of manufacturing of procurements, stability of material, operation conditions, data about constructed part, classifications of parts of mechanical engineering etc. The rule-base is formed according to the given principle: if < condition >, then < corollary >.

At software engineering for solution of the problem of computer-aided choice of marks of metal, the way of manufacturing and the type of procurement depending on the type of hardening for workpieces of mechanical engineering for a person who makes the decision (PMD) the possibility to keep candidate solutions, for which the value of criterion F_1 satisfy the condition below for further consideration is stipulated:

$$F_1^o \cdot \tilde{k}_1 \le F_1^{opt}, \qquad \tilde{k}_1 < 1, \qquad o = \overline{1, \tilde{O}_1}, \tag{17}$$

where $\tilde{k}_1$ - coefficient expanding the set of solutions of the problem, used at further consideration (is set by PMD); F_1^o - value of criterion of the problem for candidate solution o; $\tilde{O}_1$ - set of valid solutions. It is stipulated by the fact that at solution of the problem aggregated cost and time estimation for manufacturing of a part (its consignment) is used, which are updated by detailed consideration of technological processes of mechanical and hardening handling.

Methods of computer-aided solution of the problem of technological preparation of mechanical engineering manufacturing

When solving the problem of computer-aided choice of marks of metal, the way of manufacturing and the type of procurement depending on the type of hardening for workpieces of mechanical engineering [1], using the criterion F_1 (1), including expenditures of labor, cost of supplementary materials and materials which were used at manufacturing of

constructed part, the cost of handling and transportation costs on delivery of metal from the supplier on warehouse of a plant, we receive $\tilde{O}_1$ variants of its solution, for which the value of criterion F_1 satisfy the condition (17). It is stipulated by the fact that at solution of the problem aggregated cost and time estimations for manufacture of a part (its consignment) is used, which are updated by detailed consideration of manufacturing processes of mechanical and hardening handling.

Components of each variant are: material used for manufacturing of a part, the way of manufacturing and the type of procurement, and also the type of hardening handling providing given figures of quality of workpiece.

For each o_{1i} variant of problem 1 solution the problem of computer-aided choice of technological process, equipment, appliances, supplementary materials and regime parameters of hardening handling [3] is solved simultaneously. When solving the problem 3, using generalized criterion F_3 (6), components of which are: economic criterion F_3^1 (8), including expenditures of labor, cost of supplementary materials and materials which were used at manufacturing of appliances, cost of electric power and damage inflicted to the environment by ejection of contamination into free air, estimation of scrap rate of details F_3^2 (15) and criterion of manufacturability of aggregate processes of hardening handling F_3^3 (16), we receive the variant with following components: type of manufacturing process of hardening handling with an appropriate set of equipment, appliances and type of supplementary materials.

Besides, the problems 1 and 3 general arrangement of problems of TPM includes the problem of computer-aided choice of manufacturing process, equipment, appliances, supplementary materials and regime parameters of mechanical handling [2], which is not described here, because execution of technological conditions of exploitation of constructed part is provided by solving the problems 1 and 3.

When solving the problem 1 the cost of hardening handling was evaluated aggregately(1), therefore solution of the problem 3 serves for amplification of costs on its realisation (8). To make a final choice of optimum alternative of solution of general research problem, it is necessary to calculate complex criterion $F = \min_{W}(S_{mw} + S_{tw} + S_{ew} + S_{zw} + S_{aw} + S_{ww})$, where $S_{mw}, S_{tw}, S_{ew}, S_{zw}, S_{aw}, S_{ww}$ - accordingly: the cost of material, expenditure of labor, costs of power, amortization and expenditure of supplementary materials on realization of w variant of development and manufacture of workpiece, and also cost of damage inflicted to the environment by ejection of contamination into free air, minimum value of which allows to receive: material used for manufacture of a part, the way of manufacturing and the type of procurement, the type of manufacturing process of hardening handling with an appropriate set of equipment, appliances and the type of supplementary materials.

The methods offered in this paper were approved on the example of solution of a number of TPM problems (for bracket – the component of upper hot plate, and pin which is included in assembly of container, shaper - vulcanizer FV 2-140 etc.).

Conclusions

Usage of the results of this work will allow to provide:

1. Lowering of cost and improving of quality of development of technological processes (TP);
2. Lowering of costs on TPM due to automation of obtaining of design technological solutions;
3. Rising of capacity factor of expensive materials in mechanical engineering production due to lowering of waste;
4. Decrease of cost of workpiece manufacture due to decrease of TPM cost.

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Автоматизированный синтез экологически безопасных процессов химико-термической обработки изделий из металлов

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Ключевые слова и фразы: технологическая подготовка; химико-термическая обработка; экологическая безопасность.

Аннотация: Рассмотрены вопросы автоматизированного выбора марки металла, способа получения и вида заготовки в зависимости от вида упрочнения, а также выбора экологически безопасного технологического процесса, оборудования, приспособлений, вспомогательных материалов и режимных параметров определенного ранее вида упрочняющей обработки для конструируемой детали при решении задач технологической подготовки производства изделий из металлов.

Automatisierende Synthese der ökologisch ungefährlichen Prozesse der chemiko-thermischen Bearbeitung der Erzeugnissen aus Metalle

Zusammenfassung: Es sind die Fragen der automatisierenden Auswahl der Metallsorte, des Erhaltungsverfahrens und der Werkstückart je nach der Art der Festigung und auch der Auswahl des ökologisch ungefährlichen Prozesses, der Einrichtung, der Hilfsstoffe und der Regimenparameter der Bearbeitung für den konstruierenden Werkstück bei der Lösung der Aufgaben der technologischen Vorbereitung der Erzeugung von Werkstücken aus Metall betrachtet.

Synthèse automatisé des processus du traitement chimique et thermique des métaux qui garantissent la sécurité écologique

Résumé: On a examiné les problèmes du choix de la marque du métal, du moyen de la production et du type de l’ébauche en fonction du durcissement, ainsi que du choix du processus garantissant la sécurité écologique, de l’équipement, des dispositifs, des matériaux supplémentaires et des paramètres des régimes du type du traitement pour la pièce déterminée d’avance pendant la résolution du projet technologique de la production des articles métaliques.