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Purposeful Technological Formation of Machine Parts Quality

A tool is suggested for description of transformation of the product properties during its manufacture. The tool is based on the data on the characteristics of the property transformations for respective conditions of the interaction between technological media of various layers and an object of production. A technological algorithm is proposed, which allows for the effect of the whole cycle of the product fabrication on its performance characteristics.

Keywords: *performance characteristics, technological heredity, production process, technological algorithm*

1. INTRODUCTION

The distinctive feature of the existing methods for the determination and prediction of the quality of engineering products is the use of the principle of the superposition, which implies that each of the technological factors involved acts independently and the result of their combined effect is a partial sum in one form or another [1].

The technological systems are multivariable systems and the objects of production are nonlinear, irreversible and nonequilibrium. However, the use of the principle of the superposition essentially reduces the multivariable interactions occurring in technological systems to simply connected ones neglecting the mutual effect of technological factors [2].

The increased requirements on quality of the machine element production make the methods of the quality assessment and prediction based on the principle of the superposition of little use as the mutual effect of the factors is commensurable with their direct action. The process of a variation of the product properties should be considered as a combination of interacting processes of the variation, as such, and retention of the properties [3].

The multiplicity of product properties, each of which might have many quality characteristics, is also a manifestation of the fact that technological factors affecting the formation of the product quality are multiply connected. The product quality formed during its fabrication is interrelated. However, in engineering practice this fact is taken into account only slightly. A separate consideration of the process of formation of a multiplicity of the quality characteristics can bring about serious mistakes in projecting and implementation of technological processes [4].

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2. METHODOLOGY

Technical problems caused by the description of multiple interactions during the formation of the variety of the quality characteristics of a product during its fabrication can be overcome by using modern information technologies and methodology of making technological decisions [5–7].

A mathematical tool of the methodology is based on the following principles:

- the product quality is formed during its whole technological history. Many component quality characteristics stem from the component technological history;
- any technological and associated with it action on a product changes all characteristics of its quality;
- a change in any quality index changes all the rest ofindices of the product quality.

The knowledge of characteristics of technological media and regularities of their variations has allowed the formulation of the main problem of the purposeful formation of the product quality characteristics, i.e. with the known initial and final properties of the production object, to define the best technological medium as regards the transformation of properties. A technical approach has been proposed to the assurance of purposeful formation of the product optimal properties (Fig. 1).

The most important feature of this approach is the formation of the optimal technological medium for each technological stage of the through process of the production, which affords the rational distribution of the quality characteristics over the stages and imparts the required direction to the process of the formation of the product quality. By varying the medium or its characteristics, one can control the product properties being formed. A comparison between the characteristics of the media of the basic production process and the desired ones allows us to define the required corrective actions for changing the composition, structure and the interaction conditions of both the technological media and components of them with the production object.

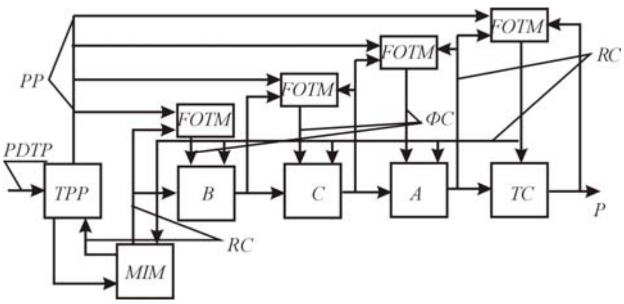

Figure 1. Conceptual scheme of the purposeful formation of product optimal properties: P – the product, PP, RP, FP – preset, real, and being formed properties; TPP – the technological preparation of the production; MIM – the manufacture of the initial materials; B – the preparation of blanks; C – the manufacture of products; A – the assembling; TC – the testing and checking; PDTP– the product design and technological parameters; FOTM – the formation of optimal technological media.

Using the conceptual approach, one can define the following coefficients:

- of a change in the ith quality characteristic when the jth technological method is used $(m_i)_j$;
- of a change in the ith quality characteristic dependent on the conditions of the implementation of the jth technological method $(u_i)_j$;
- of a change in the ith quality characteristic during the interaction with a medium on the operation implementing the jth technological method $(S_i)_j$.

A $(K_i)_j^{\text{op}}$ component of the K_i coefficient is found by

$$(K_i)_j^{\text{op}} = (m_i)_j (K_i)_{j-1} + (u_i)_j (K_i)_{j-1} ,$$

where $(K_i)_j$ is the set of the values of product quality characteristic after the completion of the operation of the product manufacture with the allowance made for the regularities of the technological heredity, $(K_i)_{j-1}$ is the set of the product quality characteristic describing the state of the product after the implementation of the previous operation.

If the method is not implemented, then $(m_i)_j = 1$ and $(u_i)_j = 0$, in other cases, $0 < (m_i)_j \le 1$. A change of the sign and value of the quality characteristic occurs as a result of a simultaneous variation of the $(m_i)_j$ and $(u_i)_j$ coefficients. For each technological method, the normal conditions of the implementation have been established, which define the $(m_i)_j$ values. The $(m_i)_j$ coefficient allows for the normal conditions of the method implementation, particularly normal economic conditions of machining. The $(u_i)_j$ coefficient allows for conditions other than normal as well as the conditions, which give additional characteristics of the medium (the blank position and fixing, elastic characteristics of the components of the technological medium, etc.).

The analytical determination of the $(m_i)_j$, $(u_i)_j$ and $(S_i)_j$ coefficients is impossible. Therefore, these coefficients are found by a statistical manipulation of the experimental results. For a particular method, the $(u_i)_j (K_i)_{j-1}$ summand is separated as a systematic constituent (C) :

$$\left[(K_i)_j^{\text{op}} \right]_r = (m_i)_j \left[(K_i)_{j-1}^{\text{op}} \right]_r + C ,$$

where r is the index of the method implementation.

To define the $(m_i)_j$ value, the methods of the maximal intersection of the sets of input and output quality characteristics and of the averaging of boundaries of their ranges (Fig. 2) are applied. With the known $(m_i)_j$ value, the $(u_i)_j$ value is found by

$$\left[(u_i)_j \right]_r = \left[(K_i)_j^{\text{op}} \right]_r \Big/ \left[(K_i)_{j-1}^{\text{op}} \right]_r - (m_i)_j .$$

With the known $(m_i)_j$ and $(u_i)_j$, $(S_i)_j = (K_i)_j^{\text{op}} \big/ (K_i)_{j-1}^{\text{op}}$. In this case, the lists of averaged values of coefficients of changing of properties during an operation $(m_i)_j$ for basic technological methods of machining of external and internal cylindrical surfaces as well as of flat surfaces are used.

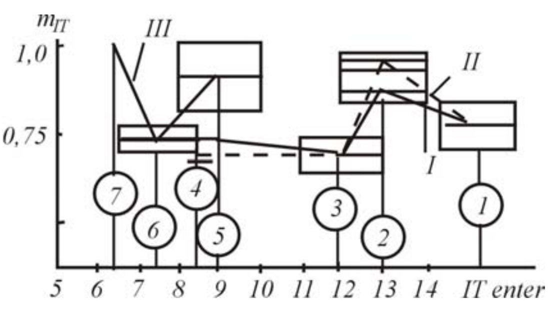

Figure 2. Comparison between the coefficients of the size accuracy change (m_{IT}) for various methods of machining external cylindrical surfaces: 1, 2, 3, 4 are respectively the rough, semifinish, finish and fine turnings, 5, 6, 7 are respectively the rough, finish and fine grindings; *I*, *III* – the method of the maximal intersection of sets, *II* – the method of averaging boundaries.

3. RESULTS AND DISCUSSION

It has been found that the optimal error of the determination of the coefficients of variation of the quality characteristics of the blanks being machined by abrasive methods is about 3 times greater than by cutting, which is indicative of the higher sensitivity of the respective technological media to a change of the conditions of realization and state of the objects that constitute the media.

The mean value of the relative error in the determination of the m_{IT} coefficient of changing of the accuracy of size during an operation is 2.5% and of roughness m_{Ra} is 11.0% for the group of methods of turning and grinding workpieces of structural carbon steel. The dependences of characteristics of technological media of the operation level on the state of the objects that constitute the media are sufficiently represented by linear regression models or by piecewise-linear approximation with a relative error of no more than 10% (Figs. 3, 4).

It has been found that the retention and mutual influence of the properties manifest themselves essentially during the flat-topped diamond-abrasive machining, polishing and superfinish operations where the tolerance being removed is within the limits of the initial cusp height of the roughness.

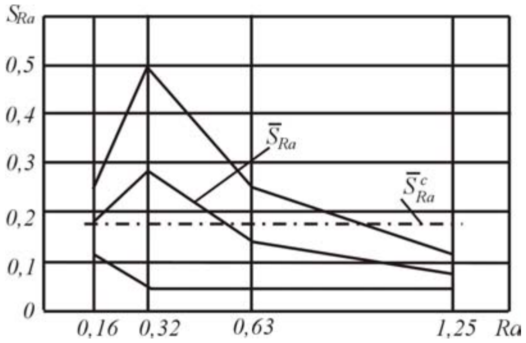

Figure 3. Dependence of the S_{Ra} coefficient on the initial roughness of steel workpieces in superfinishing (S_{Ra}^c is the arithmetic mean value, $\overline{S}_{Ra}^c$ is the averaged constant value)

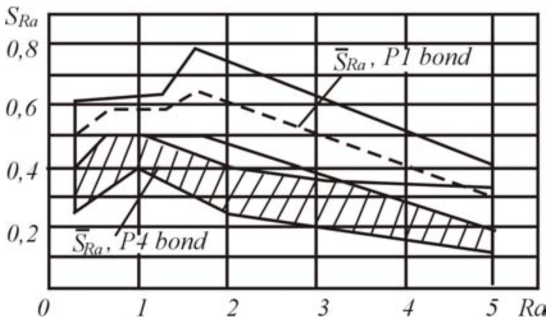

Figure 4. Dependence of the S_{Ra} coefficient on the initial roughness of steel workpieces in grinding with an abrasive belt ($\overline{S}_{Ra}$ is the arithmetic mean value)

The multiply connected nature of technological media, the variety of physical processes that accompany the interaction of the media with the product are the main reason for the absence of the common methodical approach to the determination of the matrix components [k_{ij}]. The coefficients of retention and mutual influence of the properties being formed k_{ij} are found during the implementation of the through technological process of the product manufacture with a continuous examination of the product quality.

The primary k_{ij} value for the initial stage of the process is

$$k_{ij} \approx \left[(K_i)_1 - S_{ij}(K_i)_0\right] / (K_i)_0 \ ,$$

where $(K_i)_{0,1}$ are the values of the K_i coefficient before and after the implementation of the operation, $S_{i,j}$ is the coefficient of the variation of the quality characteristic during the interaction between the product and the technological medium at the level of the operation. Unlike m_i and u_i the k_{ij} coefficients have physical dimensionality.

The suggested approach to the description of the quality characteristic transformation with allowance made for the interaction between them and their mutual influence in multiply connected technological media corresponds to the real processes of the formation of the properties of engineering products and can be used to predict technological solutions. The use of the approach allows one to decrease the relative error of the preliminary determination of the quality characteristic values by a factor of 2–5 as compared to the value found based on the known regularities of engineering technologies [5–7].

4. MATHEMATICAL TOOL

An examination of the mutual influence of technological factors during the interaction of technological media with the product allows one to introduce refinements into the calculation and analytical method of the determination of the total error of the machining. The errors arising in machining are interconnected and affect each other and the total error of the machining. The constituents of the error are a result of the workpiece interaction with the technological medium both at the operation level and at the level of the process. A mathematical tool for the determination of the constituent errors and the total error of the machining has been developed. For the first, the following is true:

$$\begin{bmatrix} \Delta Y \\ \varepsilon \\ \Delta H \\ \Delta u \\ \Delta T \end{bmatrix}_j =$$

$$= \begin{bmatrix} 1 & a_{\Delta Y,\varepsilon} & a_{\Delta Y,\Delta H} & a_{\Delta Y,\Delta u} & a_{\Delta Y,\Delta T} \\ a_{\varepsilon,\Delta Y} & 1 & a_{\varepsilon,\Delta H} & a_{\varepsilon,\Delta u} & a_{\varepsilon,\Delta T} \\ a_{\Delta H,\Delta Y} & a_{\Delta H,\varepsilon} & 1 & a_{\Delta H,\Delta u} & a_{\Delta H,\Delta T} \\ a_{\Delta u,\Delta Y} & a_{\Delta u,\varepsilon} & a_{\Delta u,\Delta H} & 1 & a_{\Delta u,\Delta T} \\ a_{\Delta T,\Delta Y} & a_{\Delta T,\varepsilon} & a_{\Delta T,\Delta H} & a_{\Delta T,\Delta u} & 1 \end{bmatrix}_j \begin{bmatrix} \Delta Y \\ \varepsilon \\ \Delta H \\ \Delta u \\ \Delta T \end{bmatrix}_{\partial j} ,$$

where $(\Delta Y, \varepsilon, \Delta H, \Delta u, \Delta T)_j^T$ are the vector column of the values of constituent errors (the error caused by elastic deformations, the error of the position, the error of the adjustment, the error caused by the dimensional wear, the error caused by thermal deformation) found considering the mutual influence; a are the coefficients of the error transformation, which make allowance for the mutual influence of errors; $(\Delta Y, \varepsilon, \Delta H, \Delta u, \Delta T)_{Dj}^T$ are the vector column of the deterministic values of constituent errors found using the traditional calculation and analytical method.

Squared value of the total error Δ is found as,

$$\Delta^2 = [\lambda_i P_i]^T [P_i],$$

where λ_i are the coefficients that define the shape of the curve of the distribution of error constituent P_i, T is the symbol of the transposition.

Taking into account the fact that technological media are multiply connected, when determining the total error of machining, allows one to increase the accuracy of the existing method of calculation more than twice [5–7].

The developed tool for the description of the transformation of the product properties makes possible the desirable distribution of the product property levels over the stages of the product manufacture. Based on the developed procedure, for any part of the through production process and for any property of the resulting product, the required level of the respective quality characteristics may be found and optimized, if necessary. Thus, after the initial stage, the achieved values of quasistable K_s and variable K_v quality characteristics are defined by

$$\begin{cases} K_s = S_s \cdot K^M + k_s^M K^M \\ K_v = S_v \cdot K^M + k_v^M K^M \end{cases},$$

where S_s and S_v are the coefficients of the variation of the product properties caused by its interaction with the technological medium at the initial stage level; K^M are the quality characteristics of the initial material; k_s^M and k_v^M are the coefficients of the retention and mutual influence of the initial material properties that manifest themselves at the initial stage of the through process of the product manufacture.

Similar relations may be found for the stages of manufacturing and assembling the product. These relations may be considered as a macromodel of the product property formation in the through production process. Practically, for any N stage or the group of operations, the relation of the $K_N = H_N K^M$ type may be found, where K_N is the quality characteristic after the stage N; H_N is the coefficient of the property transformation relative to the initial (K^M). By introducing a set of the criteria for optimization, one can go to the solution of the problems on the quality optimization at each stage (operation) of the production process. As not all the quality characteristics are equisignificant from the point of view of the technological assurance of the workpiece quality, it is advisable to define the required levels not for all but only for difficult-to-guarantee quality characteristics reasoning that other characteristics will be ensured "on default". The use of the product "passport" that includes the data on the most hard-hitting quality characteristics of the product and on the total number of its surfaces allows one to correctly decrease the dimensionality of the technological problems being solved.

A distribution of the quality levels in combination with the determination of the quantitative characteristics of a possible transformation of properties allows us to fundamentally change the existing approaches to the projecting of technological processes.

For a successful implementation of the prescribed set of functions, the technological medium should be supplied with the necessary reserves. The reserve of the technological medium is formed from a set of its characteristics, which are not used in the implementation (by the medium) of the prescribed functions and conditions of their implementation. The medium may be assessed according to each parameter

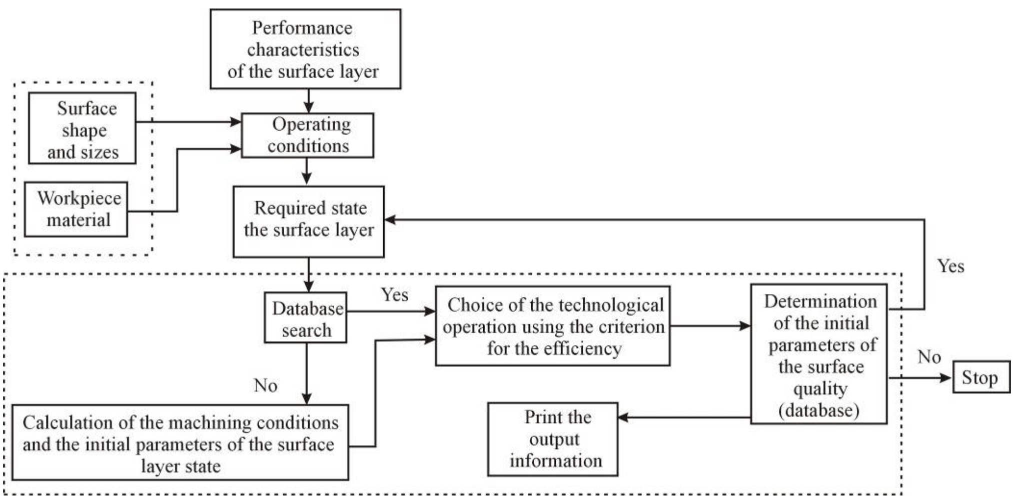

Figure 5. Technological algorithm

using the proposed quality characteristics. The medium of any level must have a reserve of each parameter (potentiality), whose value should correspond to many functions being performed and to the range of possible changes in conditions of the functioning. The choice of technological media and any technological object having rational reserves may be successfully made using the proposed method of the assessment of the quality of respective technological solutions. The medium reserve may be formed by each parameter separately and should take into account both the stochastic nature and interplay of the parameters.

5. TECHNOLOGICAL ALGORITHM

With allowance made for the effect of the whole cycle of the product manufacture and its performance characteristics, we have developed the algorithm, according to which the parameters of the state of the surface layer of the finished product are recommended from the required performance and the production process is chosen that affords the specified parameters. The cutting conditions, characteristics of the tools and equipment, and type of the lubricant are defined, which provide the necessary parameters of the state of the surface layer of the blank and the semifinished product at each stage of machining (Fig. 5).

The technological algorithm includes the following stages:

- based on the performance characteristics and operating conditions, the requirements to the state of the workpiece surface are formulated;
- on the strength of the mathematical models or database search, according to the required state of the surface layer, the machining regimes, tools, equipment, lubricants necessary for the finishing of the given workpiece are established;
- from the parameters of the surface layer state, the machining regimes, tools, equipment and lubricants required for the implementation of the previous operation are established.

The projecting of production processes with allowance made for the mutual influence of the quality characteristics being formed is ineffective without automatization using the modern computer engineering. The individual production routes are desirable to design in the automated synthesis mode with a minimal dialog between the user and the system [5–7].

The strategy of the solution of the problem of automated synthesis of individual production routes, which takes into account the regularities of the variation, retention and mutual influence of the quality characteristics being formed, involves:

- synthesis of individual production routes in the automatic mode on a basis of general-technological principles and establishing of the route fundamental characteristics;
- prediction of the variation of the quality characteristics taking into account the regularities of the property transformation caused by the established production route;
- correction of the production route in the case that the required level of the quality characteristics is not achieved.

6. CONCLUSION

Based upon offered Methodology of insurance of machine parts quality Mathematic description is developed as well as Technological algorithm of operating properties of surface layer controlling is formed taking into consideration the sequence of technological operations fulfillment with effective regimes of blanks processing.

The automatic generation of technological media of the specified level with respect to a given object is possible in principle on the basis of the functional models developed using CALS technologies.

Functional models of multiply connected technological media allow (depending on the setting up of the problem being solved) the reduction of the dimensionality of by separation of a set of essential bonds and suppression of inessential bonds with the retention of correctness and adequacy.

The efficiency of the proposed tool for the description of the transformation of the product properties depends on the sufficiency of the information based on the data on the property transformation characteristics for respective conditions of the interaction between technological media at various levels and the product.

REFERENCES

[1] Kolesov I.M.: *Osnovy tekhnologiy mashinostroeniya*, M.: Bysshaya shkola, 1999.

[2] Suslov A.G., Dalsky A.M.: Nauchnye osnovy tekhnologiy mashinostroeniya, M. Mashinostroenie. 2002.

[3] Suslov A.G., Gorlenko O.A.: Eksperimental’no-statisticheskiy metod obespecheniya kachestva poverhnosti detaley mashin. M.: Mashinostroenie-1. 2003.

[4] Dalsky A.M., Bazrov B.M., Vasiliev A.S. i dr.: *Tekhnologicheskaya nasledstvennost in machino-stroitelnom proizvodstve*, M, Izdatelstvo MAI. 2000.

[5] Vasiliev A.S., Dalsky A.M., Kheifetz M.L. i dr.: *Teckhnologicheskie osnovy upravleniya kachest-vom mashin*, Minsk, PhTI NAS of Belarus. 2002.

[6] Vasiliev A.S., Dalsky A.M., Klimenko S.A. i dr.: Teckhnologicheskie osnovy upravleniya kachest-vom mashin. M., Mashinostroenie, 2003.

[7] Vasilev A.S., Dalsky A.M., Klymenko S.A. i dr.: *Teckhnologichni osnovy zabezpechennya yakosti detaley mashyn*, Zhytomyr, ZhDTU. 2005.