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IMPROVING THE EFFICIENCY OF GRINDING TEETH BY COPYING WITH THE CONTROL OF DYNAMIC TECHNOLOGICAL CONNECTIONS

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A B S T R A C T

The conception of dynamic technological connections during machining is developed. Dynamic technological connections are presented that act during the formation of surfaces and indicators of the production quality of the product and its components during machining. Managing of relationships are sources of improving the quality of manufacturing parts. Some output technological parameters that form the quality of parts during machining are investigated, and factors influencing them. The mechanism and pattern of changes in the actual depth of cut during grinding of teeths by copying were identified. The method was determined to ensure its stability with by control of dynamic technological connections. Achieved improved quality of grinding teeth and processing performance when grinding teeth with copying compared with the traditional method.

K E Y W O R D S

Dynamic;
Technological connections;
Grinding;
Control;
Depth of cut;
Quality.

1. Introduction

Recently, the exploration of outer space and the bowels of the globe, the creation of high-tech military equipment and their production, the development of advanced technologies in mechanical engineering place increased demands on the creation of technical objects with high performance indicators.

In accordance with the requirements of their own functional purpose, the design of machine parts and tools (for example, shaped cutters, parts of stamps and molds, rollers of tools for rolling profiles, etc.) have different shaped surfaces [1-4].

Their working conditions determine the high accuracy and quality of the working surfaces. Therefore, they are usually grinding. The grinding of these surfaces by the copying method provides not only high processing accuracy, but also relatively high productivity [3-7].

These quality requirements also include the geometric parameters of the working surfaces of the teeth and the quality of the surface layers of material.

Performance indicators of product quality in modern conditions of a market economy and at the modern level of science and technology are of paramount importance. These indicators of any technical means, including gears, are formed by the manufacturing quality of its components individually and collectively – assembled [6-11].

Gear parts and gears are widely used in various machines and aggregates [4,11,12]. Often they must have high performance indicators. One of the effective ways to ensure such indicators of gears is the grinding of the working involute surfaces of gears and wheels during their manufacture. Grinding the teeth of gears is the most reliable method of finishing, providing high accuracy and quality of working surfaces, usually hardened gears. One of the main methods of grinding involute profiles is the copying method when using profile grinding wheels [11-14].

In mechanical engineering, advanced methods of assessing quality indicators are used to improve product quality. A rational solution in this direction is to determine general and specific relationships between production indicators and product quality indicators. Therefore, it is relevant to develop indicators of product quality and criteria for their assessment, as well as to study the relationship between them.

From the point of view of the formation mechanism, the system of technological connections is a complex three types: of static, kinematic and dynamic connections of [5,15].

This type of relationship has been noted in a number of studies. However, they reflect only the essence of static relations, the essence of the problem is not taken into account when classifying kinematic and dynamic technological relations [5,15].

Product quality indicators obtained on surfaces with any type of machining are formed as a result of the type and nature of technological connections acting on them. High quality processing and quality management can only be ensured by identifying, researching and managing these relationships. The influence of dynamic technological relationships on the quality indicators formed during machining plays an important role in the processing of complex rotating surfaces. Research in this direction is based on the processing of complex rotating surfaces.

The aim of the work is to identify technological dynamic connections during machining and by management them to increase the efficiency of grinding surfaces of the involute profile of cylindrical gears by copying.

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Research method

During machining, all quality parameters of surfaces of a complex profile are formed by dynamic technological connections [5, 15].

Dynamic technological connections. Connections between the elements of the technological system formed during the removal of the material (performing the operation), generating the input, intermediate or output prameter (indicator) of the process and functionally related to it are called technological dynamic.

Studied and systematized the dynamic connections between the elements of technological systems, taking into account all the indicators of accuracy, surface roughness and quality of the surface layer, which determine the quality of manufacturing parts for various machining methods [5, 15-18].

The revealed dynamic connections between the elements of technological systems act during machining are generalized by the authors and are schematically presented in figure 1.

During the formation of the surface by mechanical processing, due to dynamic bonds, material is removed from the workpiece, while the surface to be machined and the chip material to be removed are simultaneously formed. These three technological actions form the basis of dynamic connections. The following five types of derivative technological compounds are formed from them connections of:

- the material removing;
- the friction of workpiece-tool and tool-chip;
- the plastic deformation of workpiece, tool and chip;
- the elastic deformation of workpiece, tool and chip;
- the wear of tool.

These connections form of quality indicators when cutting metal and other connections of input and output parameters of the technological operation (fig. 2). Given the role of these connections in the formation of the surface, it is proposed to distinguish them and call them:

- material removing – technological dynamical connections of the first type,
- frictions of workpiece-tool and tool-chip – technological dynamical connections of the second type,
- plastic deformation of workpiece, tool and chip – technological dynamical connections of the third type,
- elastic deformation of workpiece, tool and chip – technological dynamical connections of the fourth type,
- tool wear – technological dynamical connections of the fifth type.

Now let's consider the technological connections of the main indicators of the quality of machining.

Product quality and its life cycle is expressed as a model of a complex system [15]. On figure 1 the developed system model of product quality is presented graphically as a connections between its subsystems in the form of technological dynamical connections.

Proposed the use of the quality system model and its detailed form in solving issues related to the definition (design) and maintenance (production), as well as the maintenance (operation) of the quality of the product at all stages of his life cycle.

Quality formation connections. Now let's look at the technological ratio of the main indicators of the quality of machining. The technological relationships in the formation of 7 quality indicators are generalized and shown on the basis of the study of the mechanisms for the formation of quality indicators during machining and existing research works.

In the figure 2 shows mechanism of formation of dimension connections during machining processing is shown schematically.

The dimensional connections of technological systems in machining applicable to all types of machining is shown in figure 2. The diagram shows the dimensions and settings of the tool for static connections. When the machined size matches the tool size, the shim is excluded from the table. Although the quality of the surface layer of the paste affects the size of the processed material through dynamic links, it is included in the group of static links, since it is a static factor. Determination of the processed size on CNC machines, transfer of the tool to a given size and movement control are carried out mainly using kinematic mechanisms and connections. Of course, managerial relationships and other

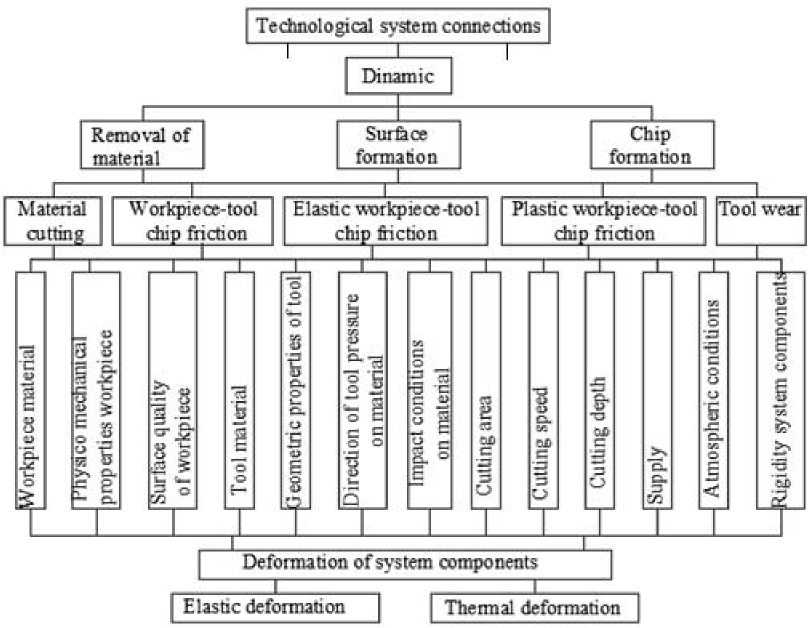

Fig.1. Dynamic technological connections

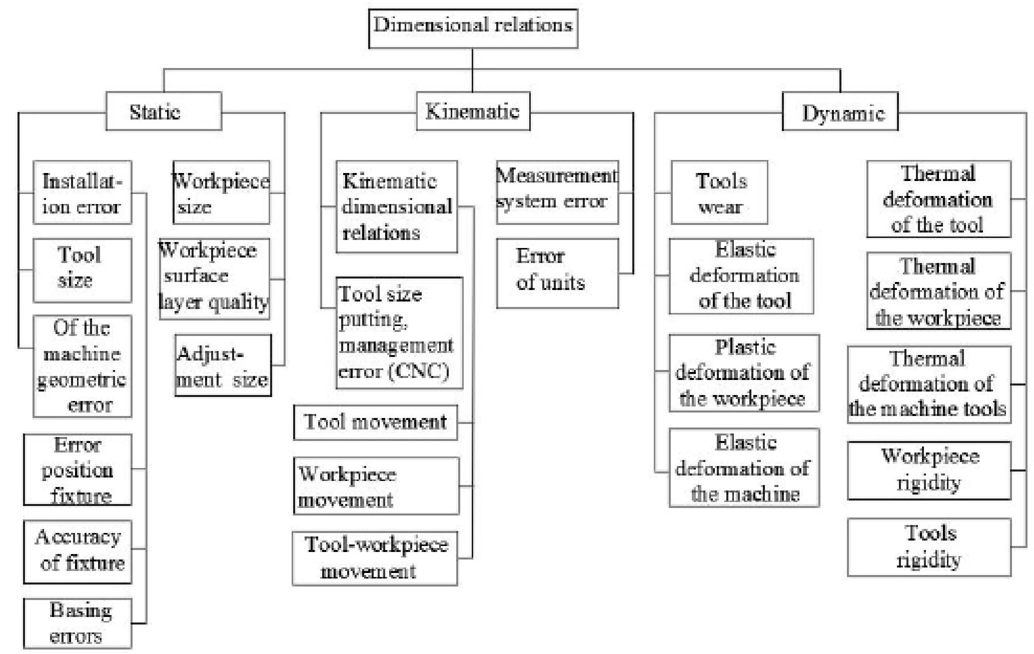

Fig.2. Dimensional connections in machining

kinship relationships can also be attributed to the group of intellectual relationships.

Depending on the machining scheme, some factors that affect the technological output parameters of the surfaces given in the schemes can be ignored, since they may do not have any effect. By modeling the design and production subsystem of quality using the relationships that form the quality of design and production, presented in figure 2. Applying the generalized system model for the product quality subsystem and its components can be expressed as follows:

$$f(M_i,P_j,E_k,Y_n)=K_i=\begin{cases} < m_1,m_2,...,m_i > \\ < F_{p1},O_{p2},Y_{p3},Y_{np4},S_{hps},S_{qp6},... > \\ < F_{e1},O_{h2},Y_{h3},Y_{nh4},S_{hes},S_{qe6},... > \\ < Y_1,Y_2,Y_3,...,Y_n > \end{cases} \quad (1)$$

where M_i – are the a bunch of quality characteristics of the material;

P_j – are the a bunch of quality characteristics of the workpiece;

E_k – are the a bunch of quality characteristics of finished part;

An is the set of quality indices for the assembly units and products;

m_1, m_2, … m_i – are the relations corresponding to the quality characteristics of the material;

F_{p1} and F_{e1} – are the relations corresponding to the geometric shape characteristics of the workpiece and part;

O_{p2} and O_{h2} – are the relations corresponding to the dimensional characteristics of the workpiece and part;

Y_{p3}, Y_{h3} and Y_{np4}, Y_{nh4} – are the relations corresponding to the positional and orientational characteristics of the surfaces of the workpiece and part;

S_{hps}, S_{hes} and S_{qp6}, S_{qe6} – are the relations corresponding to the geometric and surface layer characteristics of the workpiece and part;

Y_1 – denotes the relations corresponding to the quality of the connections between individual elements;

Y_2 – denotes the relations corresponding to the quality of the elements that are connected;

Y_3 – denotes the relations corresponding to the quality of the mutual position of the assembly units (components);

Y_n – denotes the relations corresponding to the quality of the mutual position of the individual elements of the products.

It is clear that each product usually consists of several nodes, each node of several parts, each part of several surfaces, and so on. Therefore, each of them should be considered in the model of the generalized quality subsystem (1). It should be noted that although the quality of the product is based on the main parameters of the design subsystem, its model is similar to the K_i – model. The difference is that if K_i – represents the range of changes in the actual values of the elements – parameters obtained as a result of the production process, then K_i – practically reflects the intervals for changing these parameters provided for in the design. That is, for K_l, you can write – respectively:

$$\{< B,ET,T,L >\}\Rightarrow K_l=\begin{cases} < m_1',m_2',...,m_i' > \\ < F_{p1}',O_{p2}',Y_{p3}',Y_{np4}',S_{hps}',S_{qpb}',... > \\ < F_{e1}',O_{h2}',Y_{h3}',Y_{nh4}',S_{hes}',S_{qeb}',... > \\ < Y_1',Y_2',Y_3',...,Y_n' > \end{cases} \quad (2)$$

Here the parameters m_1', m_2'..., Y_1', Y_2', Y_n' – indicate in (1) the corresponding values, data on the drawing (generally allowable corresponding tolerances). The adoption of the inscription in the last statement {<*B*,*ET*,...>} is due to the fact that these components are somewhat abstract.

It is clear that from the point of view of the organization of production, all parameters of the model (1) must be within the parameters of the model (2), i.e. $K_l \in K_i$

Thus, by controlling the dynamic technological connections presented above, it is possible to achieve an increase in the efficiency of machining. Using the example of grinding a tooth by copying, let's consider an increase in the efficiency of grinding.

Developing a way to manage dynamic technological connections. The stability of the quality and accuracy of the machined surface over the entire surface is ensured by the stability of the elements of the cutting mode and the parameters of the cutting pattern over its entire area. That is, technological heredity also plays a special role in ensuring high processing accuracy [3,5].

Technological heredity – is a bright, visual result of dynamic technological connections.

It has been established that when cutting teeth of the involute profile of gears by copying, the depth of cut takes on values that change along the involute profile [7,13,14]. However, the pattern of changing the depth of cut along the profile, its mathematical model has not been derived. Also, according to preliminary studies, it was found that some input technological factors involved in the formation of grinded surfaces when copying and grinding teeth have different values in different parts of the surface.

In the process grinding by copying teeth, elements of the cutting mode – the depth of cut and cutting speed along the involvent profile, as well as changes in the contact area of the tool with the paste along the length of the tooth, the cutting path, each abrasive grain along the involvent profile at the end of the working stroke – at the tip of the tooth – causes changing the cutting path along the length of contact of the abrasive grain with the material both along the involvent profile and along the length of the tooth. Due to the influence of these independent input parameters, variable derivative factors arise, changes in physical and mechanical processes on the surface: the pressure forces acting on different areas of the grinded surface of the tooth vary, changes in the length and pressure of the abrasive cause a change in the temperature regime-temperature gradient on the surface.

To derive a mathematical model of the pattern of change in the actual depth of cut along the involute profile, a functional relationship has been established between the actual depth of cut tx at the current point A of the involute profile and the share of processing *Z* in the normal direction, the profile is used, as well as the involute formation mechanism (fig. 3).

Suppose that the radius of the main circle of the evolvent profile is rə, and its radius of curvature at point *A* is *AM*. At the point *A* of the grinded current of the involvent profile, the actual cutting depth is $CA = t_x$, and the share of processing in the normal direction of the profile is $AB = Z$ (Fig. 3). Let us denote the angle of rotation of the point E of the beginning of the involvent profile from the plane of symmetry of the abrasive circle (OO_1), thar is, the angle corresponding to half of the interdental depression on the main circle φ, $\angle O_1OE = \varphi$. In this case, the polar angle of the involvent at point *A* of the profile is $\angle EOA = \theta$, and the angle corresponding to the radius vector is θ_x, $\angle AOM = \theta_x$.

Without geometry and from the properties of involution: $BM \perp MO$; $AC \,||\, OO_1$;

CBAB. Then from ΔBAC:

$$\frac{AB}{AC} = \cos(\angle BAC) \qquad (1)$$

$AC \approx t_x$ is accepted here. Hence the expression (1)

$$t_x = \frac{AB}{\cos(\angle BAC)} = \frac{Z}{\cos(\angle BAC)} \qquad (2)$$

Using the geometric connections in the diagram, the angles

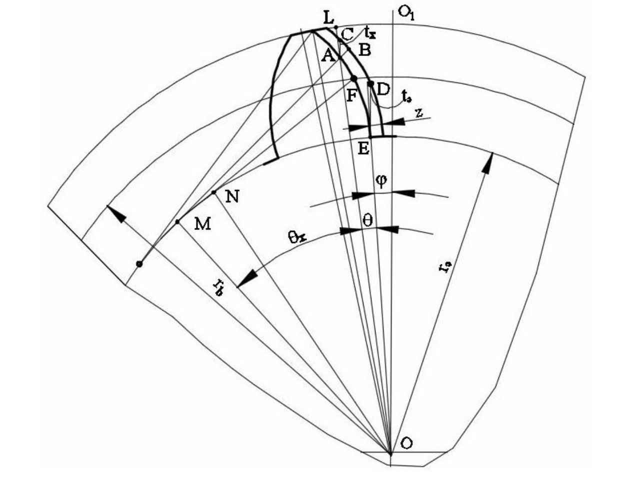

Fig.3. Scheme of formation of the actual depth of cut in the grinding of teeth by copying

in expression (2) are determined and the last expression is taken into account:

$$t_x = \frac{Z}{\cos(90 - \theta_x - \varphi - \theta)} \qquad (3)$$

According to the properties of involvent

$$\theta_x inv\theta = tn\theta - \theta \qquad (4)$$

Thus, expression (4) is taken into account in (3) we get:

$$t_x = \frac{Z}{\cos(90 - tn\theta - \varphi - 2\theta)} = \frac{Z}{\cos(90 - tn\theta - \varphi - 2\theta)} \qquad (5)$$

Here $\theta \geq 0$, its maximum value θ_{max} is limited by the height of the tooth, $0 \leq \theta \leq \theta max$.

The last expression is a mathematical model of the dependence of the actual cutting depth *t* on the processing share Z in the normal direction and the radius vector θ of the involvent profile, $t_x = f(Z,\theta)$.

It should be noted that $AC \approx t_x$ was taken when deriving the mathematical model of the depth of cut. In fact, since $AB = Z = 0.3 \div 0.6$ mm is very small, the Δt error is generally not large. However, at the beginning of the involvent profile (point *E*, $\theta = 0$) and around it Δt => max. This part of the profile is often not grinded. In particular, $m = 5$ mm of a gear made of steel 12XH3A material, which was accepted as the object of research; For grinding $z = 34$, $b = 25$ mm, the expression (5) was applied and the graph $t_x = f(z,\theta)$ was constructed.

Sometimes gears have radial at a certain depth at the bottom of the tooth (for example, $a = 0.35$ mm in the object of our study) and this area is not required to be grinded (fig. 4). At the lower point of the active profile of the tooth (that is the point *F*, fig. 4), the radius of curvature is ρ_0 ($\rho_0 = NF = 14.46$ mm on the gear wheel under study). Therefore, since the profile to be grinded corresponds to a certain, initial angle of rotation θb of the evolvent, it must also be taken into account in expression (5). That is, in this case, the range of change of the angle θ, $\theta_b \leq \theta \leq \theta_{max}$ must be taken. Thus, from ΔONF (fig. 4):

$$tn\theta = \frac{\rho_0}{r_e}; \qquad \theta_b = arctg\frac{\rho_0}{r_e} \qquad (6)$$

According to the design of the gear, the tooth head coefficient is $k = 1$, and the grinded involvent profile of the tooth is required to correspond to its height $h = 7.8$

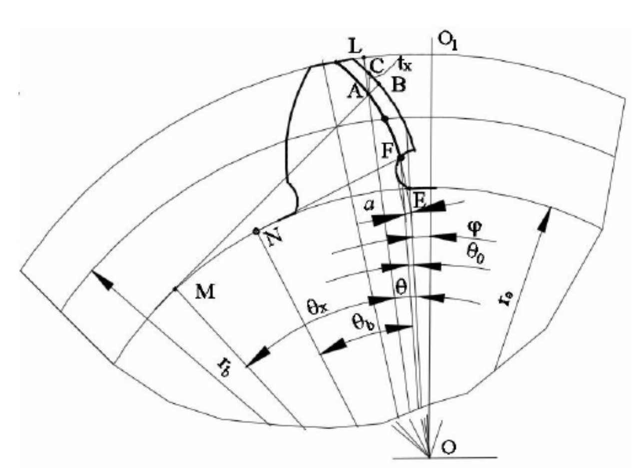

Fig.4. Scheme of formation of the actual depth of cut when grinding the teeth (with rounding of the beginning of the profile) by copying

mm. Therefore, the initial rotation angle of the evolvent corresponds to a depth of 2.8 mm from the diameter of the distribution circle θ_b. Is taken the expression (6) and considering the above:

$$t_x = \frac{Z}{\cos\left(90 - tn\left(\theta - arctg\frac{\rho_0}{r_e}\right) - \varphi - 2\left(\theta - arctg\frac{\rho_0}{r_e}\right)\right)} \quad (7)$$

Because the teeth to be grinded are located almost vertically in the machining area, the cutting speed in the grinding varies along the evolvent profile. The change in cutting speed in grinding with an processed abrasive circle is the significant.

The influence of the regularity of the actual depth of cut on the quality of grinding is carried out by experiments on grinding the involute tooth profiles of the surfaces of the gear wheels under production conditions. Teeth grinding was carried out on a Gleason Pfauter P400G machine in accordance with the purpose of the study, both according to the schemes and modes traditionally used at the enterprise, and in various options under conditions that improve the quality of grinding.

The number of teeth z = 34, modulus m = 5 mm, tooth length l = 25 mm, hardness HRCЭ 57-63, gear wheel made of steel 12XH3A is accepted as the object of research.

The experiments were conducted in two stages. In both cases, the processing share (total cutting depth) in the normal direction of the profile for grinding on the involvent profile surface was assumed to be Z = 0.30 mm.

In the first stage, the profiles of the grinded teeth of the gear are placed in a vertical position in accordance with the method used in production. The grinding process was carried out with two rough and two clean transitions. In each rough passage, the radial clearance was 0.10 mm, in the third clean passage 0.06 mm and in the fourth passage 0.04 mm. Actual cutting speed $V \approx$ 35 m/s; double travel speeds were taken as 3000 mm/s for the first three passes and 1800 mm/s for the last clean pass.

In the second stage, according to the proposed method, the profiles of the teeth in the inclined position were turned under the maximum possible angle of rotation $\alpha \approx 60°$ relative to their vertical position. Thus, the 6th inclined teeth, located on the right and left in relation to the plane of vertical symmetry, were grinded. Compared to the first stage, the actual cutting depth was reduced by about 50%.

The grinding process was carried out in two rough and one clean passages. Radial transmission was taken in the first passage, 0.18 mm, in the second, 0.09 mm and in the third passage 0.03 mm. Actual cutting speed $V \approx$ 35 m/s; double processing speed was 3000 mm/sec for 1-2 transitions, 1800 mm/sec for the last switch.

After grinding, the parameters of accuracy were measured: tooth thickness, pitch, total normal length, diameter of the distribution circle and surface quality (roughness parameters, microhardness). Analysis of the accuracy and surface quality parameters of the surfaces after grinding showed that all these parameters are within the requirements of the part line. That is, they have an accuracy of 7C according to GOST 1643-81, and the average deviation of the roughness profile of the working evolute surface is Ra = 2.5 μm.

Studies on the effect of the actual cutting depth on the surface roughness in the grinding of teeth by copying have shown that the grinding of inclined teeth reduces the roughness of the surface [13]. Therefore, the results of research on the quality of the surface layer – the change in microhardness of the surface layer are presented here.

To study the surface quality of ground involute profiles, thin sections (25×10×10 and 15×15×10 mm) were made using modern techniques and equipment (fig. 5).

Microhardness was measured first the Netherlands-made INNOVATEST series NEXUS 7501 with a weight of 10 kg applied to the tip of a diamond pyramid in the factory laboratory, in and then in a «Metallography» laboratory of AzTU on a measuring device type MikroMet 5101.

Accuracy parameters (tooth pitch, tooth thickness, total normal length, etc.) and surface quality (roughness, microhardness) were measured on grinded teeth. The study of the parameters of accuracy and surface quality showed that all the gears meet all the requirements for them in the design. However, it was found that at the beginning of the involvent profile (fig. 6; areas 7, 8, and 9), the microhardness is, on average, ≈8-14% higher than the microhardness at the tooth tip (areas 1, 2, and 3), and the surface roughness parameter Ra is ≈12-24% turns out to be high (a detailed presentation and study of experimental results will be presented in the following articles).

According to the results of the experiments, the technology of grinding the teeth by copying gears was improved, despite the decrease in the number of double strokes, the required accuracy was ensured, as well as the reduction of the main time.

Fig.5. Scheme of areas for investigating the surface quality of grinded teeth and thin sections for measuring microhardness

Conclusion

1. The mathematical models of the actual depth of cut along the profile when grinding the teeth of the evolvent profile by copying are presented.

2. It was found that at the beginning of the evolvent profile, the microhardness is, on average, ≈8-14% higher than the microhardness at the tooth tip, and the surface roughness parameter Ra is ≈12-24% turns out to be high.

3. Despite the decrease in the number of double strokes, the required accuracy was ensured, as well as the reduction of the main time.

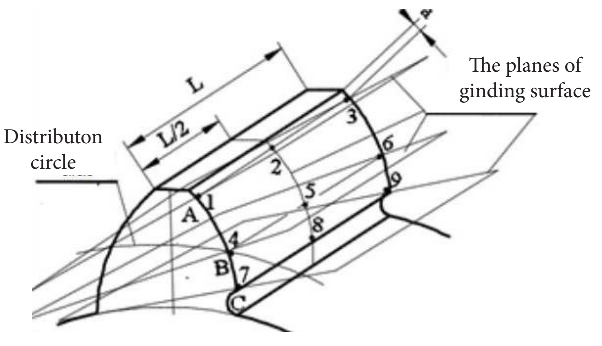

Fig.6. Scheme of areas for investigating the surface quality of grinded teeth and thin sections for measuring microhardness

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Повышение эффективности шлифования с копированием зубов с управлением динамическими технологическими связьями

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Реферат

Разработана концепция динамических технологических связей при механической обработке. Представлены динамические технологические связи, действующие при формировании поверхностей и показателей качества изготовления деталей и его составных элементов при механической обработке. Управление такими связями являются источниками улучшения качества изготовления деталей. Исследуются некоторые выходные технологические параметры, формирующие качество деталей при механической обработке, и факторы, влияющие на них. Выявлены механизм и закономерность изменения фактической глубины резания при шлифовании зубьев копированием, определен способ обеспечения его стабильности за счет управления динамическими технологическими связями. Достигнуто повышение качества шлифования зубьев и производительности обработки при шлифовке зубьев с копированием по сравнению с традиционным методом.

Ключевые слова: динамическое; технологическая связь; шлифование; управление; глубина резания; качество.

Dinamik texnoloji əlaqələri idarə etməklə surətköçürmə ilə diş pardaqlama səmərəliyinin yüksəldilməsi

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Xülasə

Mexaniki emal zamanı təsirdə olan dinamik texnoloji əlaqələr konsepsiyası işlənmişdir. Emal zamanı hissənin və onun tərkib elementlərinin istehsal keyfiyyəti göstəriciləri və səthlərin formalaşması zamanı təsirdə olan dinamik texnoloji əlaqələr təqdim olunur. Belə əlaqələrin idarə edilməsi isə hissələrin keyfiyyətlərinin yüksəldilməsini mənbəidir. Emal zamanı hissələrin keyfiyyətini formalaşdıran bəzi çıxış texnoloji parametrləri və onlara təsir edən amillər tədqiq edilir. Surətköçürmə üsulu ilə dişlərin pardaqlanması zamanı faktiki kəsmə dərinliyinin dəyişikənliyinin mexanizmi və onu idarəetmə istiqaməti müəyyən edilir. Dinamik texnoloji əlaqələri idarə etməklə faktiki kəsmə dərinliyinin stabilliyini təmin etmək üsulu müəyyən edilir. Ənənəvi üsulla müqayisədə, dişlərin surətköçürmə ilə pardaqlanması keyfiyyəti və emal göstəriciləri yüksəldilirməsi əldə edilir.

Açar sözlər: dinamik; texnoloji əlaqə; pardaqlama; idarə etmə; kəsmə dərinliyi; keyfiyyət.