GENERAL METHODOLOGY AND MAIN PRINCIPLES OF MACHINING SPATIALLY MODIFIED COUPLING TEETH

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Abstract: A general theoretical approach to raise quality and efficiency of making coupling teeth with the special side surface geometry is presented in the paper. The proposed tooth geometry provides trim among the teeth and linear contact of their working surfaces. A general methodology of making coupling teeth with the special geometry of the working surfaces has been developed in the paper. The methodology is based on the development of a number of structural versions of the technological process based on the principle of successive approximation of the coupling tooth theory to the theoretically accurate one. The method of machining of the coupling tooth special geometry from the theoretically accurate working surface is given in the paper.

Key words: toothed coupling, technological process, method of copying, method of testing, surface treatment, spatially modified geometry of teeth.

1. INTRODUCTION

To join shafts of the technological systems that operate under the presence of misalignments and shifts of the joint shafts tooth couplings are widely used in various branches of economy at present. As far as speed and loading of the tooth couplings increase, the tooth couplings with the teeth having the barrel-type working surface are widely used. The applied tooth working surface geometry does not exclude the load maldistribution in the coupling gear and does not remove edge contacts under the tooth misalignments relative to each other (fig. 1), (Mikhaylov, A.N., et.al., 1987).

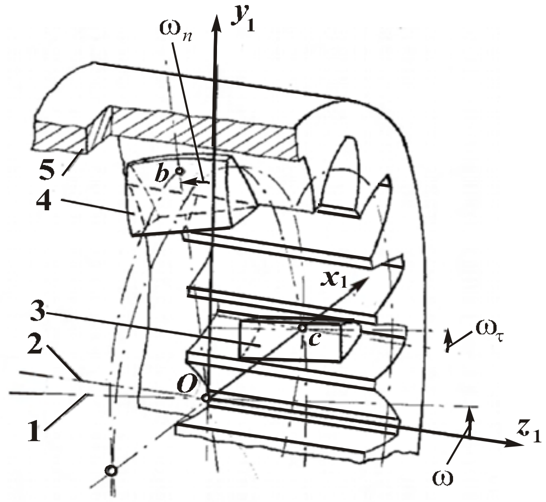


Fig.1. Special positions of the teeth of the centered coupling at the presence of the bush axe misalignment relative to the ring ω

Figure 1 shows special positions of the teeth of the centered coupling in the presence of misalignments of the bush axes relative to the ring ω. The following is shown here: *1* - external gear ring axe, *2* – internal gear ring axe, *3* – external gear ring (bush) tooth, *4* – internal gear ring (ring) tooth, *5* – internal gear ring (ring). There are special positions of the bush teeth relative to the ring in the points *b* and *c*.

That is why to level loading in the gear coupling tooth gearing and to make linear contacts of the teeth of the coupling operating under the axe misalignments and shifts the special tooth geometry which is called *the spatially modified coupling tooth geometry* has been developed, (Finichenko, V.A., et al., 1987, Finichenko, V.A., et al., 1987, Finichenko, V.A., et al., 1987). This coupling tooth geometry provides load leveling in the gear and the linear contact of the tooth working surfaces at the presence of their misalignments for the centered gear couplings. It is related to the fact that the process of making of the spatially modified coupling teeth is based on the developed machining method the ground of which is Olivier's second mode and fulfillment of two principles to make teeth, (Mikhaylov, A.N., et.al., 1987).

It should be mentioned that the technology of making spatially modified tooth geometry based on Olivier's second mode does not allow making of the given geometry by highly productive ways. It is related to the fact that to make machining with Olivier's second mode it is possible to use only honing operation with the application of the internal gear of the tool and machined teeth of the coupling

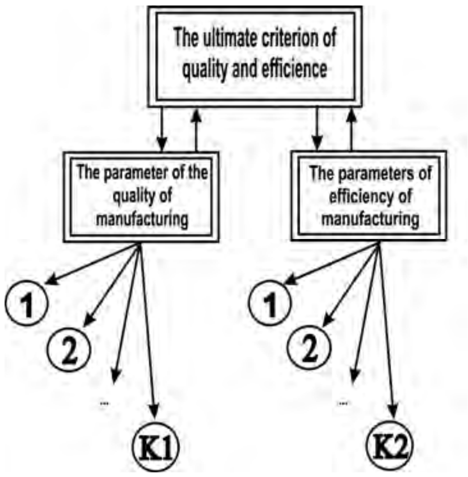


Fig 2. Hypothec diagram of connections at ensuring of the quality and efficiency parameters of SMTC manufacturing

bush. The removed allowance under the tooth honing usually makes up (50…70)μm. Thus, in number of cases, removing of the big allowances for the spatially modified teeth by this method is a long low productive way, and is impossible for the large module teeth. It does not allow getting the accurate spatially modified coupling tooth theory.

On the ground of the above-mentioned, it is reasonable to have teeth preliminary making with the working surface geometry close to the spatially modified one, but obtained by the highly productive methods. The accurate tooth spatial modification the machining of which is based on Olivier's second mode, is obtained at the final stage. In this case, the machining allowances can be within 70 μm and the necessary spatially modified coupling tooth geometry can be obtained.

However, to solve the problem the development of the structure of the certain technological process which supplies highly qualitative and highly productive ways, to make spatially modified coupling tooth geometry is needed.

The goal of the work is to raise quality and efficiency of making of the spatially modified coupling teeth (SMCT) based on the development of the general approach, methodology and principles of the synthesis of the technological process structure and facilities based on the successive approximation of the tooth working surface geometry to the theoretically accurate spatially modified geometry with the application of Olivier's second mode, (Mikhaylov, A.N., et.al., 1987).

According to the goal, the following tasks are planned to be solved: to develop a general approach of the successive approximation of the tooth working surface geometry to the theoretically accurate spatially modified geometry obtained by the application of Olivier's second mode; to develop a general methodology and principles of synthesis of the technological process structure and that of successive approximation of the tooth working surface geometry to the theoretically accurate spatially modified geometry; to develop a special technological process of approximation of the tooth working surface geometry to the theoretically accurate spatially modified geometry; to develop a method and facility of making of the theoretically accurate spatially modified coupling tooth geometry obtained with the application of Olivier's second mode.

2. GENERAL INFORMATION

2.1 The contents and results of the work

The general theoretical approach of the successive approximation of the tooth working surface geometry to the theoretically accurate spatially modified geometry (SMGC) obtained with the application of Olivier's second mode is based on the following main principles:

1. Complexity of the quality and efficiency of making of the SMGC;
2. Marginal criterion of efficiency and quality of making of SMGC;
3. Recurrence of design of the structure of SMGC making technological process;
4. Provision of the linear contact of the teeth and load leveling in the SMGC gear;
5. The successive approximation of the structure and parameters of the technological process of the SMGC making to Olivier's second mode.

The complexity principle of the SMGC making quality and efficiency solves the problems related to the quality and efficiency of SMGC making at all stages of the complex technological process. It is the complex approach in creation of the structure of the technological process of making of the qualitative and efficient SMCT that allows efficient making of the SMGC and gear couplings operation.

The creation of the most qualitative SMGC geometry is possible only on the basis of the marginal criterion of quality and efficiency of making of the SMGC. That is why the proposed principle of provision of the SMGC making quality and efficiency marginal criterion is one of the main tasks in the SMGC making. Figure 2 shows the hypothetical scheme of links to provide the SMGC making quality and efficiency parameters. The links are to be taken into account during the development of the structure of the technological process of making the SMGC at all stages of the complex technologic process.

The application of the recurrence principle to design the technological structure of the SMGC making solves the problems related to the synthesis of the necessary structure of the technological process of the SMGC making and to the necessary movements back and forward to the certain stages of the complex technological process.

The feedback among separate stages of the complex technological process is constantly provided. This principle allows complex creation of the rational or optimal structural versions of the technological processes of the SMCT making.

Figure 3 presents the recurrence process of synthesis of the structure of the technological process of the SMGC making. It shows a lot of technological operations of the technological process of the SMGC making *Str*={1, 2, …, *i*, …, *n*} recurrently linked by the successive direct and return couplings.

The load maldistribution among the teeth along the gear perimeter as well as the presence of the edge contacts at the tooth end and tips because of the normal ω_n and tangential ω_τ angles of the tooth misalignments relative to each other are typical for the gear couplings operating at the presence of the tooth misalignment (fig. 1).

That is why the development of the measures to eliminate the phenomenon is the most important task of the synthesis of the tooth geometry and the technology of their making.

Thus, the principle of the tooth linear contact (fig. 4) and load leveling in the SMGC gear (fig. 5) is

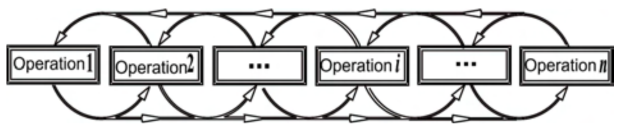


Fig. 3. Recurrence process of synthesis of the structure of the technological process of the SMGC making

one of the main tasks of the geometry synthesis and development of the technological process to obtain it.

Figure 4 shows the linear contact *1* of the conjugate surfaces of the bush tooth spatially modified surface and usual evolvent surface of tooth *2* of the ring *3* of the coupling, which is presented with the lines. The contact line *a-a* at the parametric angle of the

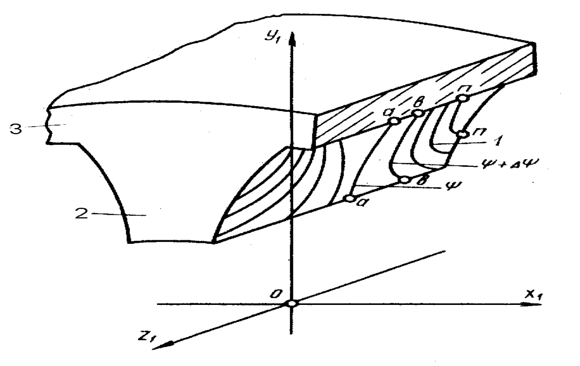


Fig.4. The scheme of the linear contact of the SMGC teeth

coupling turn ψ; the contact line at the angle $\psi+\Delta\psi$ and so on up to the contact lines *n-n* are shown here.

Figure 5 shows the distribution diagram of the SMGC load distribution if there is the element axe misalignment.

It shows that the load in the gearing is evenly distributed among the teeth at the II and IV quarters along the tooth gearing **perimeter**. In this case, the loading (without taking into account the tooth step error) is evenly distributed among the tooth gearing of the value P_0.

The developed technology based on the Olivier's second mode, (Mikhaylov, A.N., et.al., 1987) of making of the conjugate surface allows making tooth geometry with the working surface linear contact and even distribution of the load among the teeth, (Finichenko, V.A., et al., 1987, Finichenko, V.A., et al., 1987, Finichenko, V.A., et al., 1987).

The second Olivier's mode of making of the spatial gearings with the linear touch of the tooth surface is based on two conditions:

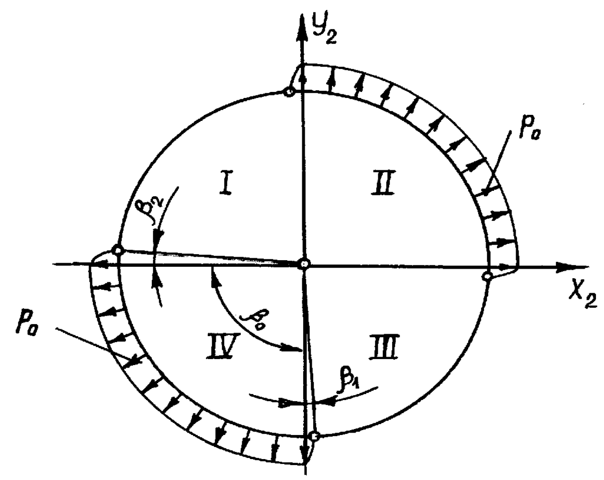


Fig. 5. Diagram of distribution of the load of SMCG if there is the misalignment of the element axis

1. Cutting of the tooth surface of one of the mechanism links (gear coupling) is made by the tool surface which completely coincides with the surface of the other link in the gear (gear coupling);
2. During making of the coupling teeth on the technological system, the structure of the relative movements of the tool and the work piece coincides with that of the tooth mechanism (gear coupling) during the operation.

The movement structure at the coordinate system transform in the relative movements of the SMGC tooth enveloping and enveloped surfaces at the presence of the axis misalignment was developed on the basis of the Olivier's second mode for the second condition.

Figure 6 shows the system relative movement structure to get the tooth spatially modified surface.

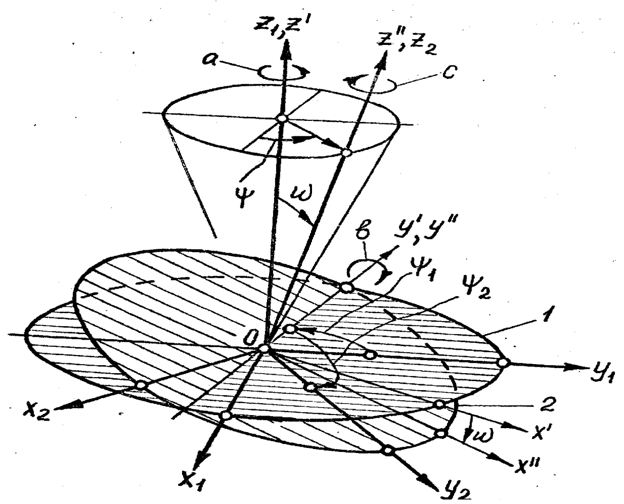


Fig. 6. Movement structure at coordinate system transform in the relative motions of the enveloped and enveloping surfaces of the SMGC teeth with the axis misalignment

As it is known from analytical geometry, it is possible to transfer from the coordinate system x_1,y_1,z_1 to the coordinate system x_2,y_2,z_2, having a single origin coordinates with the help of three consecutive turnings *a, b,c* (fig. 6) of the coordinate axis by defining of three Eulerian angles in the three-dimensional Euclidean vector space.

First one needs to turn the system x_1, y_1, z_1 about the axis Oz_1 at an angle ψ_1, we obtain a system of coordinates - *x'y'z'* - about the axis Oy' at an angle ω, we obtain the system $x''y''z''$. Next, turning the system $x''y''z''$ about the axis Oz'' at an angle ψ_2, we get the system $x_2y_2z_2$. To fulfill the second condition of the Olivier second mode, the angles ψ_1 and ψ_2 must be equal and displayed as

$$\psi_1 = \psi_2 = \psi ,$$

where ψ is gearing turning angle.

To implement the first condition of the Olivier's second mode, the tool is made as the evolvent surface. The tool evolvent profile equations in the coordinate writing are as follows:

$$\left.\begin{aligned} x_1 &= r_b\left[\sin(\varphi-\varphi_c)-\varphi\cos(\varphi-\varphi_c)\right] \\ y_1 &= r_b\left[\cos(\varphi-\varphi_c)+\varphi\sin(\varphi-\varphi_c)\right] \\ z_1 &= r_b tgv. \end{aligned}\right\} (1)$$

where r_b – the tool main cylinder radius;

φ - evolvent parametric angle;

v – point parametric angle in the cross-section.

Here

$$\varphi_C = \frac{\pi}{2z} + inv\alpha_w$$

where z is tool tooth number;

$inv\ \alpha_w$- the evolvent angle corresponding to the profile point on the reference cylinder.

Thus, Olivier's second mode solves the problems of obtaining the theoretically accurate coupling tooth spatially modified geometry. That is why the paper offers the method and facility to implement it which allows honing of the SMGC working surface at the final stage of the technological process.

It should be mentioned that the technology of obtaining of the tooth spatially modified geometry based on Olivier's second mode does not allow getting the geometry by the highly productive methods. It is because to make machining by Olivier's second mode honing with the usage of the inner tool gearing and coupling bush machined teeth is only possible. The removed allowance at tooth honing in this case usually makes up 50 … 70 μm. That is why the removal of big allowances for the spatially modified teeth is, in number of cases, long and low-productive process. As far as the large module tooth is concerned, it is not possible at all. It does not allow getting the coupling tooth accurate spatially modified geometry.

According to the above mentioned reasons, tooth pre-making is reasonable. Their working surface geometry is to be close to the spatially modified one, but it is to be obtained by the highly productive methods. The tooth accurate spatial modification is offered to obtain on the basis of Olivier's second mode. In this case, machining allowances can be up to 70 μm and the coupling tooth necessary spatially modified geometry can be obtained.

The work is based on the most important technological *principle of successive approximation* of the SMGC making technological process structure and parameters to Olivier's second mode.

At the same time, only joint application of the above-mentioned principles to design the SMGC making technology solves the problems of complex raise of quality and efficiency of SMGC making. Figure 7 shows the structural scheme of the iteration iterative approach in application of the principles of development of the SMGC making complex technology. The iterative approach allows complex and successive application of the offered principles to create progressive technologies of the SMGC making.

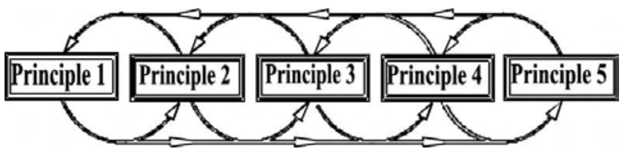


Fig.7. Iterative scheme of application of the design principles in the general theoretical approach of the successive approximation of the tooth working surface geometry to the SMGC theoretically accurate one

Figure 8 shows the structural scheme of the general approach to rise of quality and efficiency of the SMGC machining. First of all, this approach is based on the application of the complex technological process of the SMGC making which consists of n different technological operations in which doing of the technological process separate stages is stipulated. These stages are as follows: rough machining, semi-finish machining, finishing machining. The fulfillment of the successive approximation of the obtained geometry to the tooth spatially modified geometry is stipulated at every stage of the complex technological process: approximation of the first order geometry – at the complex technological process first stage; approximation of the second order geometry – at the complex technological process second stage, …, at the k stage of the complex technological process – the approximation of the k order, …, and so on. In this case, obtaining of the SMGC accurate geometry is stipulated for the complex technological process n stage or n operation. The technological operation based on honing according to Olivier's second mode is to be done.

The corresponding approximation of the structure of movements of the technological scheme and geometry of the machined tool to the parameters of two conditions of the second Olivier's mode is stipulated for every stage of the technological process and every order of approximation of the tooth working surface geometry. The fulfillment of the accurate spatially modified tooth geometry is stipulated at the final operation. Thus, two conditions of the second Olivier's mode are to be completely observed in this case.

It should be mentioned that during the development of all operations of the complex technological process of the SMGC making the development of each operation is to be based on the limit criterion of quality and efficiency of gear coupling making. The development of the structural and parametric support of the technological process of the SMGC making is to be done according to these conditions. Only in this case the SMGC making high quality and efficiency are provided. The letter V in figure 8 shows the input flow of the machining pieces (gear coupling work pieces), the letter W shows the output flow of the pieces.

According to the developed general theoretical approach (fig.8), the general method of the synthesis of the complex technological process of the SMGC making has been developed:

1. The complex technological process first operation is fixed;
2. The first operation kinematic structure is defined;
3. The first operation technical support is defined and fixed;
4. The first operation tooth side surface geometrical parameters are found;
5. The coupling tooth geometry approximation degree related to the perfectly accurate coupling tooth spatially modified geometry after the first operation is defined:

$$\max\left(\Delta\Pi^{1}_{0.2,\,н}\right) = h_1$$

where $\Delta\Pi^{1}_{0.2,\,н}$ — increment of the parameters of the tooth real surface to the perfectly accurate

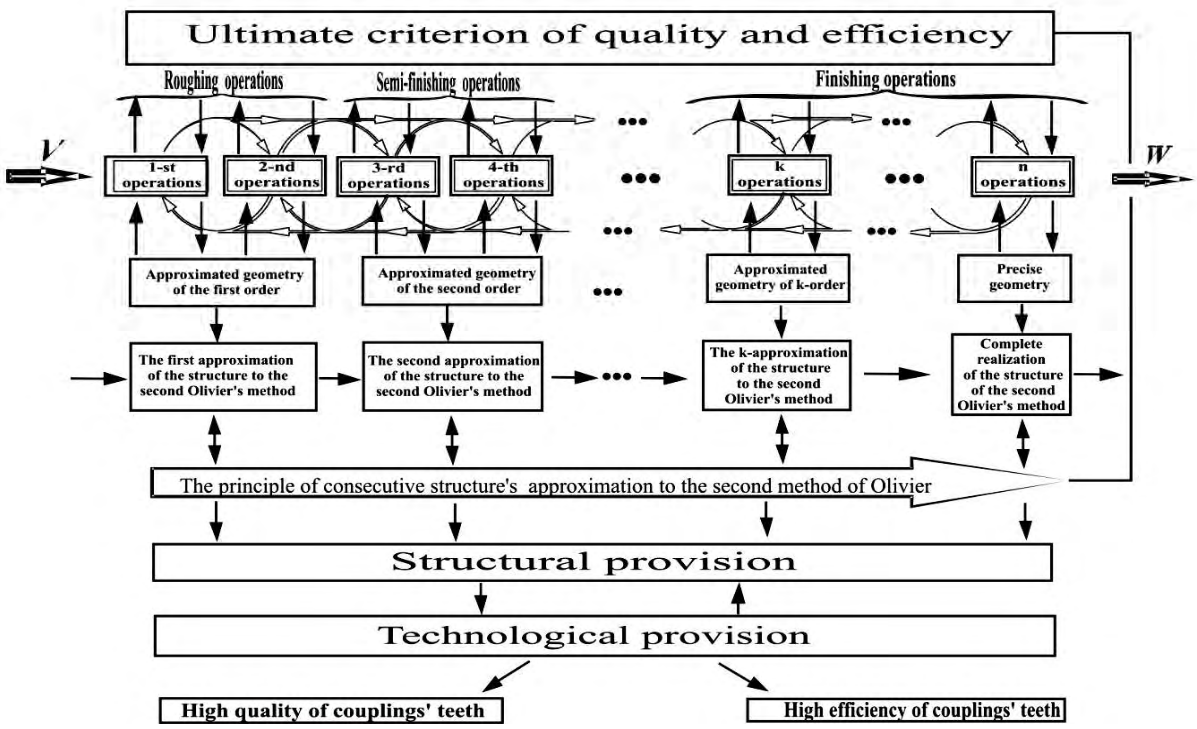


Fig. 8. The structural scheme of the general approach to raise the quality and efficiency of the SMGC machining

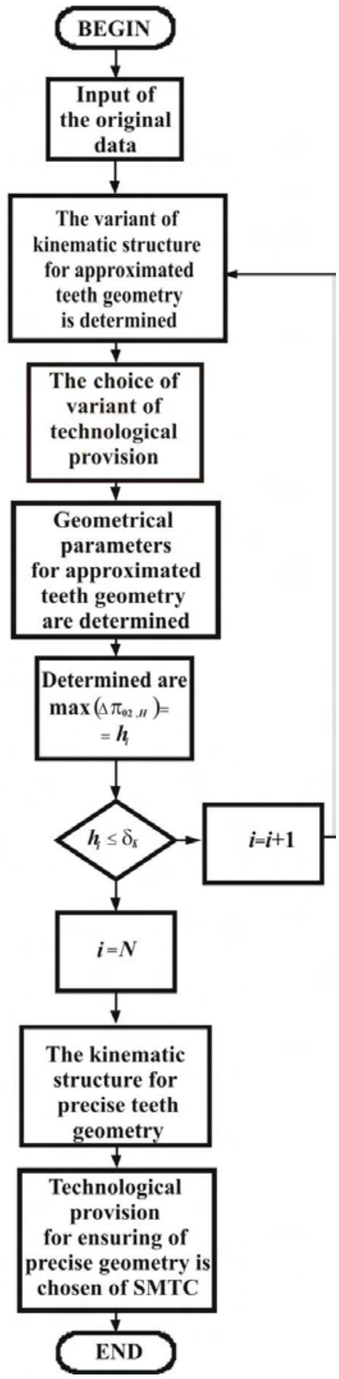


Fig. 9. Algorithm of the general method of synthesis of the structure and technological provision of spatially modified coupling teeth

coupling tooth spatially modified geometry of the first operation; h_1— maximal value of the increment of the tooth real surface to the perfectly accurate coupling tooth spatially modified geometry for the first operation.;

6. If $h_1>\delta_x$, where δ_x - honing allowance, the technological process second operation is fixed;

7. The second operation kinematic structure is defined;

8. The second operation technological support is defined and fixed;

9. The second operation tooth side surface geometrical parameters are found;

10. The coupling tooth geometry approximation degree related to the perfectly accurate coupling tooth spatially modified geometry after the second operation is defined:

$$\max\left(\Delta\Pi^{2}_{0.2,\,н}\right)=h_2$$

where $\Delta\Pi^{2}_{0.2,\,н}$ — increment of the parameters of the tooth real surface to the perfectly accurate coupling tooth spatially modified geometry of the second operation;

h_2 - maximal value of the increment of the tooth real surface to the perfectly accurate coupling tooth spatially modified geometry for the second operation.

R. If $h_{n\text{-}1}= \delta_x$, the *n* - operation of the complex technological process that provides the spatially modified coupling tooth accurate geometry is stated.

R+1. The kinematic structure of the *n* operation is defined.

R+2. N-operation technological provision is defined and stated.

Figure 9 shows the algorithm of the general method of synthesis of the structure and technological provision of the coupling spatially modified teeth. Its succession completely corresponds to the general method of synthesis of the complex technological process of making of SMGC mentioned above.

Thus, the developed general theoretical approach, method and algorithm of creation of the structure of the technological process of the SMGC making are based on implementation of a number of principles of the SMGC making. As to all stages of the technological process, they are based on the principle of the successive approach of the tooth geometry and technological process structure to the coupling tooth spatially modified geometry.

Using the theoretical proposition, the structure of the technological process was developed. It includes the fulfillment of the following operations:

1. Coupling tooth machining made by the copying method. It is based on getting of the approximate geometry obtained by milling made by the disk gear cutters with the tool moving along the line of the initial contour shift on the special line. In this case, the initial contour shift line is defined on the basis of the SMGC accurate geometry;

2. Coupling tooth machining made by the rolling method. It is based on the approximate geometry obtained by milling made by the gear hob cutter with the tool moving along the line of the initial contour shift on the special line. In this case, the initial contour shift line is also defined on the basis of the SMGC accurate geometry;

3. Coupling tooth machining made by the copying or rolling method with provision of the kinematic structure of movements at the machining of the identical operational one in the mechanism. It is based on obtaining of the approximate geometry by milling made by disk or hob gear cutters. In this case, only the second condition of the second Olivier's mode is observed;

4. Way of the coupling tooth machining made by the rolling method with provision of the kinematic structure of movements at the machining of the identical operational one in the mechanism. It is based on obtaining of the approximate geometry through the drawing made by special broach. In this case, the second condition of the second mode of Olivier is observed. The first condition of the second Olivier's mode is partially observed;

5. Development of the method of the finishing treatment. Implementation of the complete adequacy of two conditions of the second mode of Olivier. This operation can be done either by honing or by other methods, such as spark erosion machining.

The first two operations are done by traditional methods with the tool movement along the initial contour shift line the parameters of which are defined in, (Mikhaylov, A.N., et al., 1987). The third and forth operations can be done on special equipment designed according to the inventions presented in, (Mikhaylov, A.N., et al., 1990, Gituni, A., 2007, Litvin, F.L., 1968) (the third operation – with the application of (Mikhaylov, A.N., et al., 1990, Gituni, A., 2007), the fourth - according to Litvin, F.L., 1968.

The final operation is based on obtaining of the accurate spatially modified coupling tooth geometry. In this case, finishing is done through honing (Mikhaylov, A.N., 1988, Mikhaylov, A.N., Gituni, A., 2006) or spark erosion method (Mikhaylov, A.N., et al., 2007), with the complete observance of two conditions of the Oliviers's second mode. In this case, the obtained SMGC geometry completely corresponds to the accurate geometry.

Thus, the given complex of the technological operations provides the successive approximation of the tooth geometry to the accurate spatially modified geometry. Two conditions of the Olivier's second mode with the successive increase of the degree of their approximation to the complete fulfillment are partially observed within the technological process (up to the last operation). The accurate spatially modified coupling tooth geometry is implemented at the expense of the observance of two conditions of Olivier and allowances which do not exceed the normal values at the final stage of the technological process.

The method of finishing machining of the coupling bush teeth by honing could be an example. For this, a special tool to make the SMGC honing is to be selected.

The disk honing tool, which is in the figure 10, *a*, is selected according to the characteristics of the machined material, size of the toothed product, the cartridge into which it is placed, cutting modes and requirements to the machining [9], its durability, and the process efficiency. The honing tool consists of two elements: a metal bush *1* and an abrasive ring *2* with internal teeth.

The width of the honing tool L is defined according to the following formula:

$$L=B_1+A+2a \qquad (2)$$

Here, $B_1=d_a \sin\omega+B \cos\omega$,

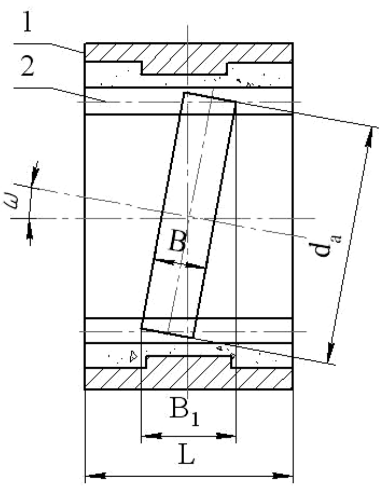
where d_a — the diameter of the product tooth top;

B — width of the product tooth ring;

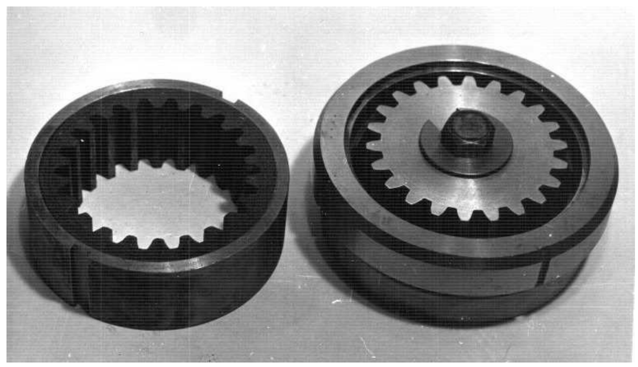
ω — tool axis defect angle;

A — tool alternate motion amplitude;

a — tool unused width reserve.



a



b

Fig. 10. Internal toothing gear hone: *a* - cross-section, *b* – general view and forms to get the honing tool

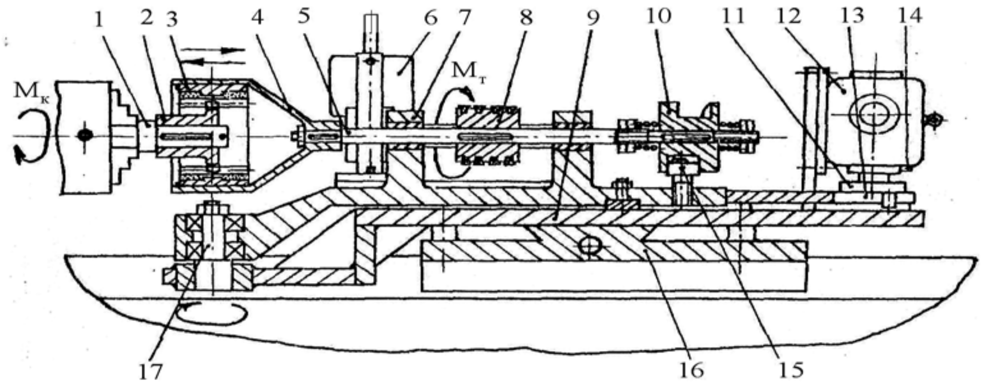


Fig. 11. Sectional device for the tooth spatial modification

Figure 10, *b* shows the general view of the disk honing tool and the form for its making.

The quality of the tooth machined surface, machining productivity and tool resistance depend greatly on the correct and rational selection of the machining modes. According to the proposed mode (Mikhaylov, A.N., 1988), to get the complex of the technological indices during the honing process the tool is turned around the axis which is in the plane of symmetry of the central section of the product tooth ring. This provides simultaneous getting of the accurate optimal form of the product tooth surface, raises productivity at the expense of immediate machining of all teeth, increases the tool resistance as the load along its perimeter is spread uniformly on all teeth and there are no overloaded teeth.

It also should be mentioned that this turning (rotational set over) of the tool is done at a certain angle speed. The tool turning high speed does not allow simultaneous machining of all teeth of the product and the loading along the perimeter of the hone gearing is not spread uniformly and is concentrated on the teeth near the axis of their maximal misalignment. That is why these teeth of the tool are overloaded and the tool resistance is reduced. At a lower speed of the tool turning the machining efficiency is reduced, the tool wear per one product increases as the extra metal layer is removed during the tooth surface forming.

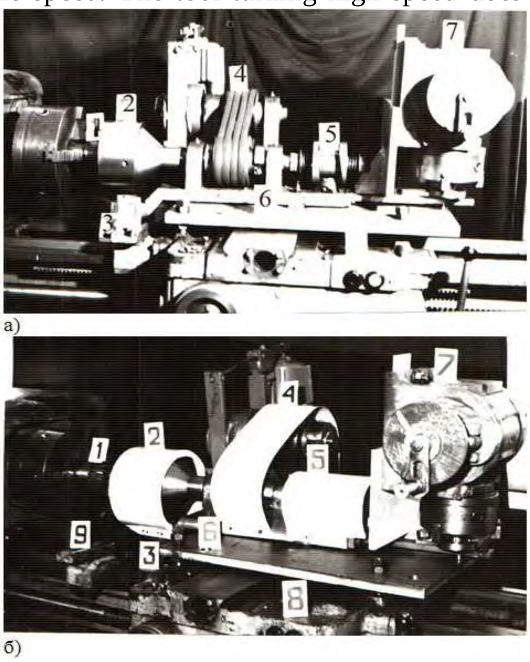


Fig. 12. General views of the device for machining SMGC by honing

Honing of the tooth surface in the tool and product spatial gearing is a multi-factor process and it is rather difficult to take into account the influence of all factors made on the machining technological indices.

Thus, when the machining modes are optimized according to the proposed method, the working cycle structure particular conditions are taken into account.

The following empiric dependence was found experimentally:

$$\dot{\omega} = \frac{\dot{\psi}}{10^4 K_{\omega}} \qquad (3)$$

where $\dot{\omega}$ - angle speed of turning (rotational set over) of the tool around the axis *Y*;

$\dot{\psi}$ - angle speed of rotation of the tool or product around their longitudinal axis *Z*;

K_{ω} - dimensionless transition coefficient which is defined experimentally.

Here, the dimensionless coefficient K_{ω} is functionally dependent on the following factors: cutting speed, load acting on the tool tooth, the machined product tooth ring width, teeth hone abrasive cutting characteristics:

$$K_{\omega} = f\left(V_P, P_H, B, И\right) \qquad (4)$$

For our tests K_{ω} =15. 55 at the cutting speed V_P =3 m/s, load on the tool tooth P_H=71.5 N, product tooth ring width *B*=20 mm, tool made of the green silicon 630 with the main fraction granularity 16.

Figure 11 shows the sectional device for the tooth spatial modification, (Mikhaylov, A.N., 1988). It consists of the tool *3* covering all teeth of the product *2* placed into the cartridge *4*. The latter is assembled on the shaft *5* placed on the footings of the turn-over table *7*. The turn-over table is put on the base *9*; the drive of its turning is the engine, reducer *12* and crank *11* which interacts with the slot *13* of the turn-over table *7*. The axis *17* of the turn over table *7* is in the symmetry plate of the central section of the machined product tooth ring *2*. The machined product *2* is fixed on the work holder *1* in the turning spindle, and the device itself is on its linear type slide *16*. The crown cam *10* has the profile slop which interacts with the roller *15*. The roller and the slot of the crown cam *10* form the drive of the alternate motion of the tool *3*. In this case, the shaft *5* rotates and moves along the rotation axis in the footings of the turn over table *7*. The feedback system consists of the loader *6* which is the block brake connected to the shaft *5* with the help of the pulleys *8* and wedge belts. The scale *14* controls the turning angle of the table *7* on the reducer *12*. The device operates as follows: the tooth product *2* fixed on the work holder *1* rotates with the tooth tool *3* placed in the cartridge *4* on the shaft 5; machining is done due to the fact that the brake *6* slows down the tool *3* through the pulleys *8* and belts. Its reciprocating rotary motions are made due to the drive *10* and *15*. To obtain barrel-shaped tooth surface of the optimal form the tool *3*, which is in the cartridge *4* placed on the shaft *5*, is turned round the axis *17* placed on the base *9*. The shaft *5* is in the slider bearings of the turn-over table *7*. The tool turning is done by the drive *11*, *12*, and *13*; the turning angle is controlled according to the scale *14*. The tool feed and lift when the product is fixed and removed is done by the linear type slide *16* of the turning machine on which the device is fixed.

Figure 12*a* shows the general view of the experimental device fixed on the turning lathe of the model 1K62. Here the work holder *1* is fixed in its spindle. All the teeth of the product are covered with the machining tool (hone) placed in the cartridge *2*. The profile slot is on the face cam *5*. It is made on the sinusoidal law and interacts with the roller for two cycles of the alternate motion per the tool one rotation.

The turn-over table is on the base *6*, its turning drive *7* turns it around the axis *3*. The base *6* is fixed by bolts on the linear type slide *8*.

When the machined product *1* is removed, the slide *8* is turned right from the initial position. When the slide is fed to the initial position the axis *3* of the table turn- over is in the symmetry plane of the tooth ring of the machined product *1*. Thus, the feed of the slide *8* is made along the support *3* fixed at the longitudinal which defines the position of the axis 3 related to the product ring 1 and is preliminary fixed in the necessary position.

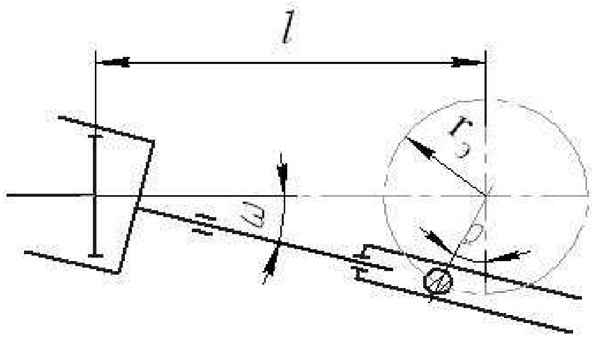


Fig. 13. To the definition of the tool rotational set over angle

The feedback system 4 turns on the loader which is the block brake of the type TT-160, pulleys and wedge belts. The value of the braking torque corresponds to the acting load on the tool tooth 60.5–71.5 N/tooth (the values are obtained experimentally). Figure 12*b* shows the general view of the device to machine the barrel-shape teeth with the rational form of the tooth surface prepared for the operation. Casing *2* prevents COZ spraying, and the casings *4* and *5* cover the rotating parts of the device. COZ is fed on the pipe line to the lower part of the tool. Other items of the figure 12*b* correspond to the items of the figure 12*a*. When the spindle rotates the tooth bush (product) at a constant angle speed $\dot{\psi}$, the angle speed of the tool turning ω round the axis Y is to be constant in all phases of its turning, to provide the volume of the uniform allowance. As the coulisse mechanism turns the tool, the law of change of the angle speed of the drive of the tool rotational set over is to be defined on the basis of the condition which was mentioned above.

As figure 13 shows, the angle of the tool rotational set over ω is related to the crank turning angle Ω according to the following dependence:

$$\omega = \text{arctg}\frac{r_Э \sin\Omega}{\ell - r_Э \cos\Omega} \qquad (5)$$

where $r_Э$ - crank eccentricity radius;

λ - distance from the axis of the tool turning (rotational set over) to the crank rotation axis;

Ω - crank turning angle.

With the application of the accepted signs, let us present the tool rotational set over speed by the following formula:

$$\dot{\omega} = \frac{d\alpha}{dt} = \frac{d\alpha}{d\Omega}\frac{d\Omega}{dt} \qquad (6)$$

Then:

$$\dot{\omega} = \text{arctg}\frac{r_Э(\ell\cos\Omega - r_Э)}{(\ell^2 - 2\ell r_Э \cos\Omega + r_Э^2)}\frac{d\Omega}{dt} \qquad (7)$$

Here:

$$\frac{d\Omega}{dt} = \dot{\Omega} = \frac{2\pi\, n_1}{i} \qquad (8)$$

where $\dot{\Omega}$ - crank rotation angle speed;
n_1 – rotational set over drive rotation frequency;
i – advantage ration of the rotational set over drive reducer.
Based on the formulae (7) and (8), the rotational set over drive rotation frequency is defined by the following formula:

$$n_1 = \frac{\dot{\omega}\, i \left(\ell^2 - 2\ell r_Э \cos\Omega + r_Э^2\right)}{2\pi\, r_Э \left(\ell\cos\Omega - r_Э\right)} \qquad (9)$$

Let us introduce the formula (3) to (9) and get the expression to define the change of the tool rotational set over drive rotation frequency, depending on the device kinematic and geometric parameters:

$$n_1 = \frac{\dot{\psi}\, i \left(\ell^2 - 2\ell r_Э \cos\Omega + r_Э^2\right)}{10^4 K_\omega r_Э \left(\ell\cos\Omega - r_Э\right)} \qquad (10)$$

Thus, using formula (10), the tool rotational set over constant speed can be done due to the provision of the variable frequency of the rotational set over drive rotation. The crank Ω turning angle is limited. The maximal value $\Omega_{\max}$ is defined by the formula (10) by the substitution of n_1 in its left part by the maximal value of the frequency of rotation of the induction motor of the drive of the rotational set over n_{max}.

3. CONCLUSION

Complex research solved a number of tasks related to the development of the technological process of the SMGC making. This made it possible to:
-develop a general approach of successive approximation of the tooth working surface geometry to the theoretically accurate spatially modified geometry obtained by the application of the Olivier's second mode;
-develop a general method and principles of synthesis of a technological process and provision of the successive approximation of the tooth working surface geometry to the theoretically accurate spatially modified geometry;
-develop the certain technological process of approximation of the tooth working surface geometry to the theoretically accurate spatially modified geometry;
- develop the method and device of making of the theoretically accurate spatially modified geometry obtained by the application of the second mode of Olivier.
Generally, the research and developed technology provide complex solving of the tasks related to the quality and efficiency raise in SMGC making.

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