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SIMULATION OF GRINDING PROCESS OF 3-D SURFACE ARTIFICIAL KNEE-JOINT

В статье представлена математическая модель формообразования сложной 3-D поверхности искусственного коленного сустава человека на трех координатном шлифовальном станке с ЧПУ с учетом процесса срезания припуска. Математическая модель использована в разработанном модуле моделирования для CAM-системы автоматической подготовки управляющей программы. Модуль автоматически решает задачу формообразования с определением всех параметров процесса резания, необходимых для формирования управляющей программы шлифовального станка с ЧПУ.

In the article the mathematical model of machining for complex 3-D surface of artificial knee-joint of man is presented on three co-ordinate grinding machine-tool with CNC taking into account the process of cutting. A mathematical model is utilized in the developed module of design for CAM-system of automatic preparation of control the program. The module automatically decides the task of forming with determination of all of parameters of cutting process, necessary for calculated of control the program of grinding machine-tool with CNC.

Relevance. In modern mechanical engineering from year to year, the number of details with complex surfaces, which are made of hard materials and which exhibited high surface quality requirements, increase. Therefore, for producing such surfaces as long as there is no alternative treatment by grinding. Grinding 3-D surfaces are performed on CNC grinding machines and require a special-term CAM system to automate the programming of these machines.

The process of grinding the surface differs significantly from the processing of surfaces with constant curvature [1]. The main difference lies in the complex trajectories of the formative movements form tool blanks - that is, in geometric terms. The consequence is a significant change, impermanence of geometric parameters of the layer allowance (changes in dozens times), which is cut off, depending on the area cultivated in the top, which leads to significant changes in cutting forces and other key characteristics of the process. Quasistationary grinding process leads to the appearance of various defects on the machined surface, namely: undulation or cut, the appearance of spotted burns, cracks, change in surface roughness at different parts of the surface details, etc.

All of the above characteristics fully characterize the process of grinding 3-D surface of the prosthetic knee joint of man. Existing CAM system automation training programs for CNC grinding machines [2] in the manufacture of proteases does not take into account the grinding process, but provide only the geometric conditions of formation - a mode of cutting appoint a technologist, who is unable to provide a non-devious control (Fig. 1). This leads to a significant (in several times) loss of the productivity, as in this case the technologist is forced to appoint a permanent cutting regime for a worst-case processing conditions on the all surface, it is artificially undervalued, based on their own experience and the results of the experiment.

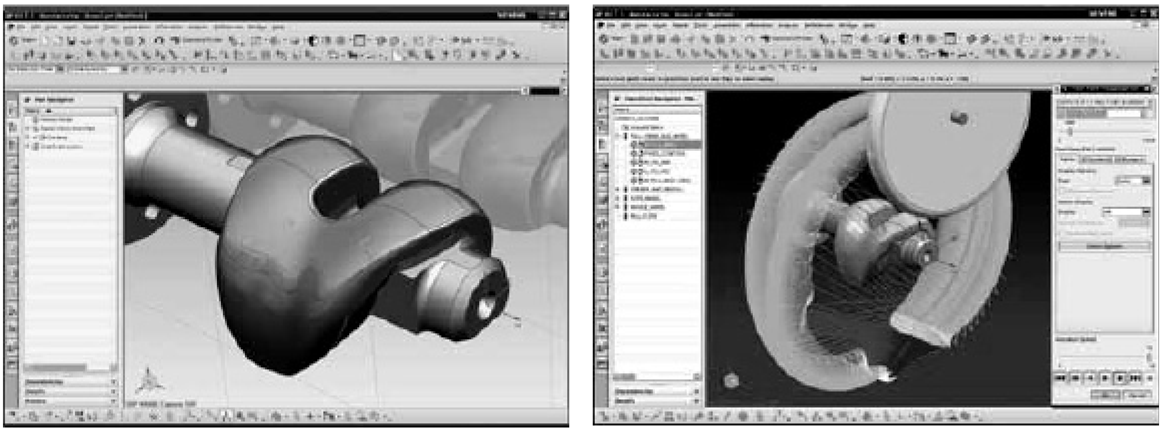


Fig. 1. Designing a CNC control data in CAD/CAM environment ANCAM NX

Thus, scientific and technical problems of a modern CAD/CAM system that would automatically managing a program designed for grinding 3-D surface of the knee joint prosthesis of man including the cutting process is important.

Formulation of the problem. To solve the general problem of a modern integrated CAD/CAM system of computer aided programming CNC assumes several stages, the most important of which is to develop a mathematical model of the cutting allowance provided at grinding forming 3-D surface. Such model should contain one of the modeling blocks of the entire cutting process that occurs in closed technological processing system (TPS) and enable the determination of all cutting process parameters, characterized by a vector analogue speed for cutting allowance [1].

Development of a mathematical model must take place in two stages. The first implies the geometric definition of the terms forming the surface detail and the second - reflects the process of cutting allowance. Taking the fact that the form of 3D surface endoprosthesis initially set as three dimensional digital array, the obtaining the necessary characteristics of the grinding process is possible only with computer simulation by the developed mathematical model.

Solving the problem. The problem of geometric form creation is solved with geometric correlation of scheme (Fig.2). The process of forming 3D surface the artificial joint of man is recommended to perform in three coordinate form creation scheme, which can be realized by the most CNC grinding machines, for example, Studer office [3]. A workpiece grinding 1 is performed by grinding wheel 2, which has the shape of a torus with management at the three coordinates X and Z, which are mutually perpendicular and provide the main formative movement, and the axis C ensures rotational motion of workpiece. Formative movement to axes X and Z performs grinding wheel, and workpiece get the rotational motion provided by coordinate C.

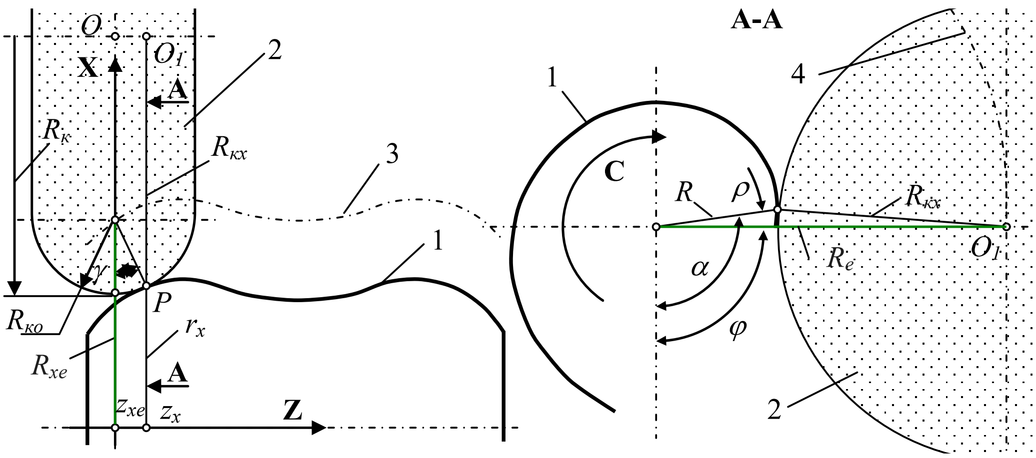


Fig. 2. Formation scheme of human knee joint endoprosthesis

Over the adopted scheme of 3-D detail surface is running by torus of the grinding wheel while moving by equidistant 3 in longitudinal direction by Z coordinate and by equidistant 4 in transverse direction to coordinate X. According to the longitudinal direction equidistant 4 is defined in Cartesian coordinates and calculated using the dependence obtained from the geometrical ratio of the scheme:

$$\begin{cases} R_{xe} = r_x + R_{KO}Cos\gamma \\ z_{xe} = z_x - R_{KO}Sin\gamma \end{cases}, \tag{1}$$

where $R_{ко}$ – rounding radius of the grinding wheel, r_x, z_x – coordinates of detail contour in longitudinal intersection, and γ angle determines from the speed plan: $\gamma = \arctan(V_x / V_z)$, where $V_x = dx/dt$, $V_z = dz/dt$.

From the formative scheme follows that the grinding wheel with radius $R_к$ interact with profile in the particular point that determines a certain radius of wheel at the intersection A-A (Fig.2):

$$R_{KX} = R_K - R_{KO}(1 - Cos\gamma), \tag{2}$$

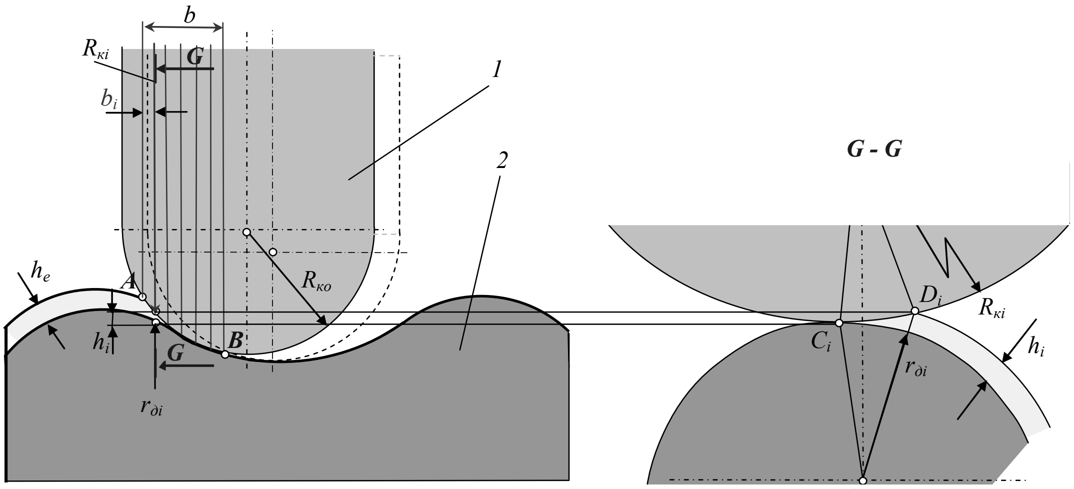
Equidistant 4 is defined in polar coordinate system (see intersection A-A in Fig.2) and is calculated by dependence, which is also obtained from the ratio of geometric-making scheme:

$$\begin{cases} R_e = \sqrt{R^2 + R_{KX}{}^2 + 2RR_{KX}Cos\rho} \\ \phi = \alpha - \arcsin\left(R_{KX}Sin\rho / R_e\right) \end{cases}, \tag{3}$$

where φ – polar angle, $\rho = \arctan(V_r / V_\alpha)$, where $V_r = dR/d\alpha$, $V_\alpha = d\alpha/dt$.

Thus, the obtained geometric model of forming the 3D detail surface which represents a three-dimensional array of points equidistants grinding wheel with prescribed discreteness. Note to play all the process of grinding is necessary to design as well trajectory of idle stations. To solve this problem could be used the approach that was developed in the work [4] and lies in finding such trajectories, which provide minimum acceleration and thus minimize dynamic loads TPS.

To solve the second stage - creation of a mathematical model of the cutting allowance process can be used a scheme, which represents the interaction of instrument and workpiece with evenly distributed allowance in two mutually perpendicular intersections (Fig. 3).



a б

Fig. 3. Before determine the allowance layer that is cut

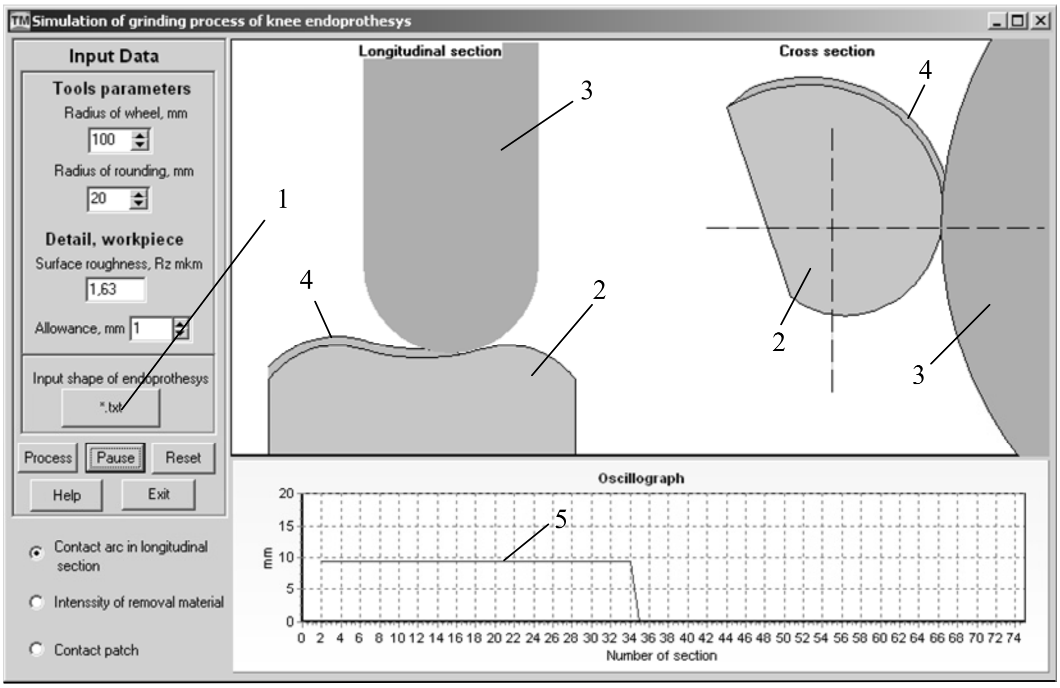
Taking into consideration that the form of detail is in the digital array, the first stage, in result of geometric modeling for forming mathematical model (1) - (3), are formed as digital arrays, which represent equidistants in cross and longitudinal directions. Therefore, for determine the task of the second stage is wisely use digital methods and procedures for determining the intersection points of intersection output tool surface and workpiece, the contour of which is represented by a discrete geometric model.

The general algorithm first involves performing procedures of definition points *A* and *B* intersection of the tool surface grinding wheel and workpiece first in longitudinal section (see Fig.3, a). Then the grinding wheel in width *b* is defined as a set of grinding wheels with original instrumental cylindrical surfaces. The wheel width b_i is determined by accepted step of calculations and its radius $R_{iк}$ depends on the position G-G cross the width of the real grinding wheel. For each such wheel corresponding to interaction scheme in the intersection (see Fig.3, b) defined the intersection points with the workpiece surface and calculated length L_i of arc C_iD_i contact. Arc *AB* contact on each pass is defined as the arc of a wheel radius R_s rounding grinding wheel with the allowance, which was formed in the previous passage of grinding wheel (position of grinding wheel in the previous passage is shown by dashed line in Fig.3,a).

The *Q* analogue of speed removal rate is determined by the formula:

$$Q(\varphi,n)=\sum_{i}^{k} 0.5bL(n)_i^2\,, \tag{4}$$

where *n* – passage number, $k = B_l/b$ – quantity of the cylindrical wheels, which replace grinding wheel, B_l – the width of grinding wheel on the contact line. Other notions were explained above.



Radius of wheel, mm 100
Radius of rounding, mm 20
Surface roughness, Rz mkm 1,63
Allowance, mm 1
Input shape of endoprothesys *.txt
● Contact arc in longitudinal section
○ Intenssity of removal material
○ Contact patch

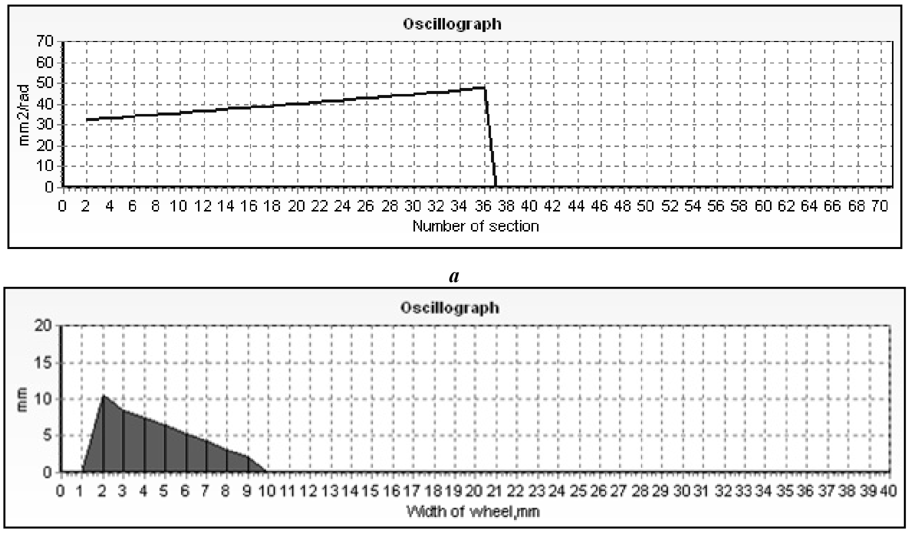
Fig. 4. The main interface of modeling program

Modeling. To check the functioning of the mathematical model by the presented methodology was developed application program, its main interface is demonstrated in Fig.4. On the left are situated the windows for entering initial data, the control buttons, and on the left - window of animation modeling calculations.

The program provides objective geometric parameters of the grinding process endoprosthesis knee of man in the relevant windows of the main interface, and digital array specifies the model knee joint endoprosthesis from a text file using the dialog button 1. On the left is situated graphical window of animation grinding process, where represented the two types: longitudinal section and cross section in the place of cutting allowance. On the views detail 2 are marked with a light color, the grinding wheel 3 is darker, on the surface profile is situated allowance 4. In the bottom is placed a virtual oscilloscope, a window in which can be printed according to the mark at the round windows the values (on the left of oscilloscope). Appointment of the control buttons is follow with inscriptions on them.

The main interface is shown in the moment of grinding simulation process of knee endoprosthesis with an displaying on the oscilloscope screen the contact arc length *AB* in cross section - line 5 (see Fig.3, a). Simulation showed that the length of contact arc depends on a step change in polar angle by profile and from number of passage and varies from 4mm to 10mm.

In the same grinding wheel position, which corresponds to a certain point of modeling, on the oscilloscope screen are derived an analogue of speed cutting allowance (Fig. 5, a) and spot the contact grinding wheel and workpiece (Fig. 5, b). Analog of speed cutting allowance, which characterizes by the intensity of the grinding process, has non-stationery character and increases with increasing the arc of contact in longitudinal direction of joint profile.



a

б

Fig. 5. Modeling results

As to the contact spot, it characterizes the distribution of intensity grinding process for the instrumental surface grinding wheel, which will affect its wear.

Conclusions

1. The simulation results of endoprosthesis confirmed the significant non-stationary process cutting allowance in all of its characteristics.
2. It is proved that the developed of methodology can be obtained during the modeling the most important characteristics of 3D surface endoprosthesis grinding process, which are the basis for determining the control law to stabilize the cutting process on the entire surface and its further optimization.
3. Found the practical implementation of developed the numerical simulation procedure, which showed the good results and high speed performance.

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