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## THE CAD/CAM SYSTEM MODULE FOR DESIGN OF NC DATA FOR 3D SURFACES MACHINING OF HUMAN KNEE-JOINT PROSTHETIS

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### МОДУЛЬ САД/САМ СИСТЕМЫ АВТОМАТИЗИРОВАННОГО ПРОЕКТИРОВАНИЯ УПРАВЛЯЮЩИХ ПРОГРАММ ДЛЯ ОБРАБОТКИ 3Д ПОВЕРХНОСТЕЙ ПРОТЕЗОВ КОЛЕННОГО СУСТАВА ЧЕЛОВЕКА

***Purpose.** Computer-aided design of the NC data for 3D surface manufacturing of prosthetic of human knee-joints on CNC machine with the management by the feed for stabilizing of process of cutting along of all shape-generating trajectory.*

***Methodology.** The new module of CAM system of preparation of the NC data for 3D surface of prosthetic of human knee-joints is created on CNC machine. The module provides preparation of the controls programs for three methods of shaping: milling by a spherical and cylindrical milling cutter, grinding wheel in the form of torus. All three methods can be realized on CNC machine at the use of only three axes. The module automatically executes planning of shape-generating trajectories and on the basis of results designing process of cutting allowance expects the management by the questioner serve so that to stabilize a cutting process in the manufacturing. At planning of management by the serve on lines approach which provides the identical (set) roughness of all surface is used. At planning of management for grinding the border algorithm of cutting allowance is used on passage-ways, and also the trajectory of lost motion is optimized on the criterion of minimum of the dynamic loadings on the drives of machine. All of it results in the increase of the productivity of manufacturing and providing regular quality of 3D surface both for roughness and on the structure of surface layer.*

***Conclusion.** The presented results of practical approbation of functioning of the module for 3D surfaces manufacturing of three types of prosthetic appliances of human knee-joints confirm efficiency of the created module of CAD/CAM system.*

***Keywords:** CAM system, CNC machine, 3D surface manufacturing of human knee-joint prosthesis.*

#### Introduction

By a main problem there is cutting of a complicated 3D form of working surface at producing of prosthetic of human knee-joints. The cutting process complicates not only difficult form but also that prosthetic appliances are made from hard cutting materials (titanic alloys, alloys on the basis of cobalt) of detail and the knee-joint of everybody has an especially individual geometrical form. All of it conditions the necessity of application of flexible technologies, CNC machine and high requirements to accuracy and roughness of working surface require application of finishes operations of grinding.

For automation of preparation of the NC data for CNC machine in modern production widely use computer-integrated CAD/CAM system, and at programming of cutting of working surface of prosthesis in general it is impossible to do without them. At the market of high technologies is present much computer-integrated CAD/CAM-system, among which it is possible to select more known and more widespread:

- program technological planning (CAM subsystem) in composition the PLM-decision of the UGS company;
- CAD/CAM system of Mastercam to the company CNC Software;
- CAD/CAM system of CATIA of the company Dassault Systems;
- program system of planning of technological processes of manufacturing, created by the CNC Software company POWERMILL;
- package of programs of CAM (PTC company) for a lot of axial cutting, controls programs development for CNC machine for three-dimensional by models CAD-system created in *Pro-Engineering*;
- program system of planning of technological processes of manufacturing, created by the *Siemens PLM NX CAD/CAM*;
- system automated planning of technological processes ADEM.

Such systems provide everything automation of creation of the NC data for cutting of 3D surfaces, however abandoned majority from them is by opened by the questions of setting of the cutting condition [1]. On such reason modern CNC machine, which are able to change the cutting condition in a wide range, at cutting of 3D surfaces use the programmed permanent modes of cutting, that considerably reduces efficiency of their application.

The analytical review of the modern state of technology of producing of prosthetic of human knee-joint is conducted, to the necessity of medicine in area of prosthetics, and also research in area of management by CNC machine confirm actuality and importance of problem of creation of the system of the automated programming of CNC machine for cutting of prosthesis of human knee-joints, that automatically will determine all parameters of cutting process.

In a theoretical plan there is actual the problem of development of conception of optimum cutting (by grinding and milling) process control, creation of informing mathematical model of cutting process adequate, to automation of process of technological preparation of grinding and milling cutting of prosthesis of human knee-joints on CNC machine the CAM-system of technological preparation of the NC data. Absence of reliable mathematical algorithm which would be used for the design of grinding process for creation of intermediate file of management with the automatic calculation of trajectory of shape-generating motions with determination of the optimum mode of cutting and it would be realized at modern programmatic level restrains the process of introduction of front-rank technologies in this direction.

### Objective

Thus, creation of computer-integrated CAD/CAM system of computer-aided design of the NC data is the primary objective of work for CNC machine, development of the simplified scheme of shaping, providing of flexibility and possibility of NC data design both for milling and for grinding of 3D surfaces of prosthesis of human knee-joints.

For achievement of primary objective the successive decision of the following tasks is needed:

- ✓ to develop the scheme of shaping of 3D surfaces of artificial human knee-joints on CNC machine, which minimize the amount of co-ordinates which are managed;
- ✓ to develop the method of task of basic data which describe 3D surface, in accordance with the system of shape-generating co-ordinates as a three-dimensional numerical array and presentation them as splines;
- ✓ to develop the mathematical models of shaping of 3D surfaces of artificial joints to millings and grinding;
- ✓ to develop the algorithms of automatic choice of strategy of shaping, that provides the necessary roughness of 3D surfaces and to project the optimum (after the minimum of the dynamic loadings of drives of CNC machine) trajectories of moving on single motions, taking into account application of HSM of cutting, in particular, at grinding;
- ✓ to create the application programs of design cutting processes, that automatically will determine all parameters of process which are necessary for planning of management with the purpose of stabilizing of cutting terms for to all shape-generating trajectory;
- ✓ to create the module of the system automatic programming of CNC machine for producing of 3D surfaces of artificial human knee-joints;
- ✓ to conduct experimental researches with cutting by all developed methods of shaping of working surfaces of prosthetic appliances on CNC machine with NC data which are projected in created CAD/CAM system, to conduct the estimation of quality of the cutting surface and its accuracy;
- ✓ to develop practical recommendations to the use of created CAD/CAM module of NC data for producing the prosthetic of human knee-joint.

### Solving the problem

The conducted analysis of possible schemes of shaping of 3D surface of prosthetic give opportunity to choose the optimum (after the least of co-ordinates which are managed) schemes of shaping [2, 3]. All these schemes are provided by cutting on three co-ordinate CNC machine and differentiate by the form of initial instrumental surface and kinematics of process.

**Shaping by tool with spherical instrumental surface.** Such shaping scheme is typical for spherical end milling. For getting given 3-D surface, which on fig.1 show two sections (cross section – A-A), spherical mill move by equidistant.

Synchronized movement by two equidistant is implemented by scheme of cutting «by line» from C coordinate which is set.

On fig. 1: 1 – cross section of prosthesis; 2 – longitudinal section of prosthesis; 3 – spherical mill; 4 – equidistant in longitudinal section; 5 – equidistant in cross section;  $R_{ko}$  – radius of mill;  $R_{kx}$  – radius of mill which are in contact with prosthesis in especial points;  $R_{xe}$  – coordinate of equidistant on longitudinal section;  $R_e$  – distance to equidistant in polar coordinates system;  $R$  – radius vector before points of profile;  $X_{xe}$  – coordinates of X axis of mill position;  $X_x$  – coordinate of contact points of tool and profile;  $r_x$  – radius vector in contact point;  $\gamma$  – contact angle;  $\varphi$  – polar angle;  $\rho$  – contact angle in cross section;  $\alpha$  – polar angle in cross section.

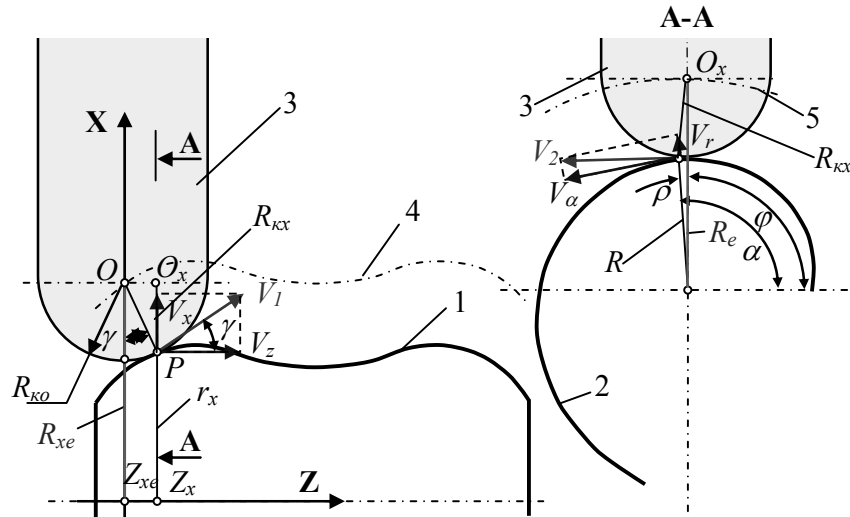


Fig. 1. Geometric scheme of interaction of shaping with spherical instrumental surface

Equidistant 4 determine in Cartesian coordinates system and calculated by formulas, which are got from geometrical relation of scheme of shaping (fig.1):

$$\begin{cases} R_{xe} = r_x + R_{ko} \cos \gamma \\ Z_{xe} = Z_x - R_{ko} \sin \gamma \end{cases} \quad (1)$$

where  $R_{ko}$  – radius of spherical mill, and angle  $\gamma$  are determined from plan of speed:  $\gamma = \arctan(V_x/V_z)$ , where  $V_x = dx/dt$ ,  $V_z = dz/dt$ .

From scheme of shaping – spherical mill by  $R_{ko}$  radiuses which are contacted with profile in certain point, that determined certain radius of mill in A-A section (fig.1):

$$R_{kx} = R_{ko} - R_{ko}(1 - \cos \gamma), \quad (2)$$

Equidistant 5 determine in polar coordinates system (see A-A on fig.1) and calculated by the next mathematical dependence:

$$\begin{cases} R_e = \sqrt{R^2 + R_{kx}^2 + 2RR_{kx} \cos \rho} \\ \varphi = \alpha - \arcsin(R_{kx} \sin \rho / R_e) \end{cases} \quad (3)$$

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

All derivative which are used in formulas (1), (3) are calculated by numerical methods as separate difference of numeric massif [1, 4].

**Shaping by tool with cylindrical instrumental surface.** Such shaping also characteristically for milling by an end milling cutter, but after the new layout scheme of the systems of co-ordinates. Here it is also possible to take advantage of scheme, where set 3-D surface presented by two sections, and a cylindrical milling cutter must move for equidistant (fig. 2). Motions are synchronized for both equidistant is carried out on the scheme of cutting «on lines» from a co-ordinate C, that sets.

On the fig.2 showed longitudinal and cross section of prosthesis with equidistant of movements of end mill. On the scheme accepted next key: 1 – cross section of prosthesis; 2 – longitudinal section of prosthesis; 3 – end mill; 4 – equidistant in longitudinal section; 5 – equidistant in cross section;  $R_{ko}$  – radius of mill;  $R_{kx}$  – radius of mill which are in contact with prosthesis in especial points;  $R_{xe}$  – coordinate of equidistant on longitudinal section;  $R_e$  – distance to equidistant in polar coordinates system;  $R$  – radius vector before points of profile;  $X_{xe}$  – coordinates of X axis of mill position;  $X_x$  – coordinate of contact points of tool and profile;  $r_x$  – radius vector in contact point;  $\gamma$  – contact angle;  $\varphi$  – polar angle;  $\rho$  – contact angle in cross section;  $\alpha$  – polar angle in cross section.

Equidistant 4 determine in Cartesian coordinates system and calculated by formulas, which are got from geometrical relation of scheme of shaping (fig. 2):

$$\begin{cases} R_{xe} = r_x + R_{ko} \cos \gamma \\ X_{xe} = X_x - R_{ko} \sin \gamma \end{cases} \quad (4)$$

where  $R_{ko}$  – radius of cylindrical mill, and angle  $\gamma$  determine from plan of speed:  $\gamma = \arctan(V_x/V_z)$ , where  $V_x = dx/dt$ ,  $V_z = dz/dt$ .

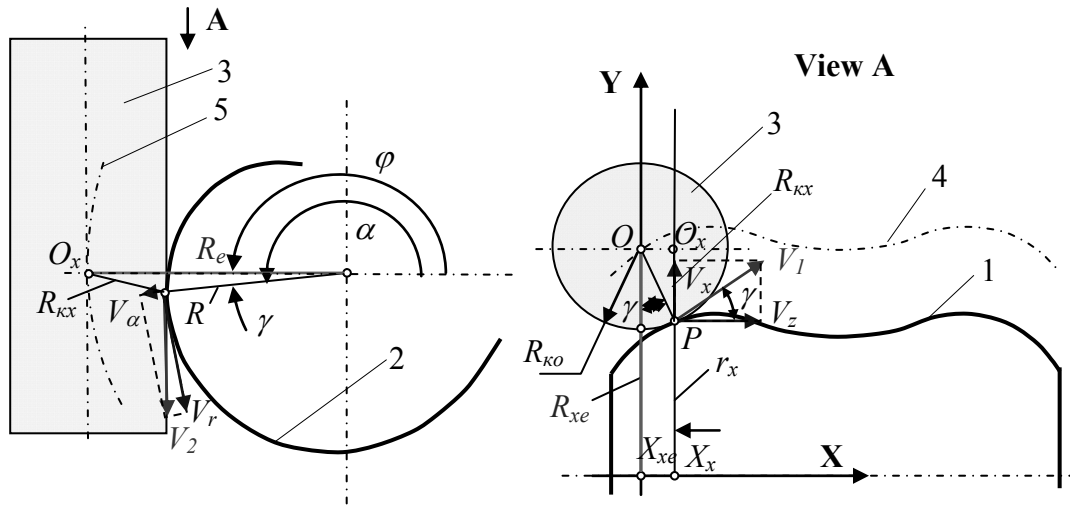


Fig. 2. Geometric scheme of interaction of shaping with cylindrical instrumental surface

From scheme of shaping – cylindrical mill by  $R_{ko}$  radiuses which are contacted with profile in certain point, that determined certain radius of mill in A-A section (fig. 2):

$$R_{kx} = R_k - R_{ko}(1 - \cos \gamma), \quad (5)$$

Equidistant 5 determine in polar coordinates system (see A-A on fig.2) and calculated by the next mathematical dependence:

$$\begin{cases} R_e = R \cdot \cos \rho + R_{kx} \\ \alpha = \varphi + \rho \end{cases}, \quad (6)$$

$$\rho = \arctan\left(\frac{1}{R} \cdot \frac{dR}{d\varphi}\right), \quad (7)$$

where  $\varphi$  – polar angle.

**Shaping by tool with form of torus instrumental surface.** Such scheme of shaping answers the select chart of grinding of type of prosthetic, when cutting is carried out at the rotation of detail about technological axis and moving of grinding wheel from a passage-way to the passage-way.

The task of creation of mathematical model of geometrical co-operation of instrumental surface in the form of torus and detail consists in determination of geometrical parameters of equidistant and decides from the analysis of geometrical correlations of scheme of shaping (fig. 3). For formation of the set 3-D surface, that on fig.3 presented by two sections, a grinding wheel must move for equidistant on the co-ordinate of **Z** and for equidistant on a co-ordinate **X**. Synchronized motions for both equidistant is carried out on the scheme of cutting «on lines» from a co-ordinate **C**, that sets.

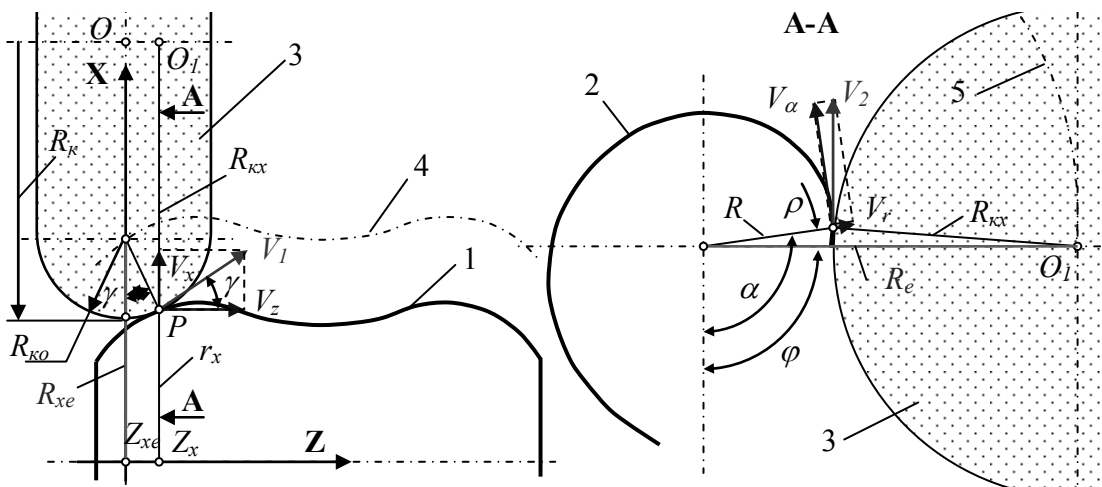


Fig. 3. Geometric scheme of interaction of shaping with grinding wheel with a shape of torus

Mathematical model of shaping are got from geometrical scheme on the fig.3, where 1 – cross section of prosthesis; 2 – longitudinal section of prosthesis; 3 – grinding wheel; 4 – equidistant in longitudinal section; 5 – equidistant in cross section;  $R_{ko}$  – radius of rounding of grinding wheel;  $R_{kx}$  – radius of grinding wheel, which is in contact with profile in certain points;  $R_{xe}$  – coordinate of equidistant on longitudinal section;  $R_e$  – distance to equidistant in polar coordinates system;  $R$  – radius vector before points of profile;  $X_{xe}$  – coordinates of X axis of grinding wheel position;  $X_x$  – coordinate of contact points of tool and profile;  $r_x$  – radius vector in contact point;  $\gamma$  – contact angle;  $\varphi$  – polar angle;  $\rho$  – contact angle in cross section;  $\alpha$  – polar angle in cross section.

In accordance to the developed method, basic data of geometrical model of 3-D surface will be transformed in digital arrays:  $r_x=f(z_x)$ ,  $R=f(a)$ , what correspond to the chosen scheme of shaping on a CNC machine. Due to this approach discrete geometrical models which are used in further calculations for the program design of shape-generating motions are created.

Equidistant 4 determine in Cartesian coordinates system and calculated by formulas, which are got from geometrical relation of scheme of shaping (fig.3):

$$\begin{cases} R_{xe} = r_x + R_{ko} \cos \gamma \\ Z_{xe} = Z_x - R_{ko} \sin \gamma \end{cases} \quad (8)$$

where  $R_{ko}$  – radius of grinding wheel, and angle  $\gamma$  determine from plan of speed:  $\gamma = \arctan(V_x/V_z)$ , where  $V_x = dx/dt$ ,  $V_z = dz/dt$ .

From scheme of shaping – grinding wheel by  $R_{ko}$  radiuses which are contacted with profile in certain point, that determined certain radius of mill in A-A section (fig.3):

$$R_{kx} = R_k - R_{ko} (1 - \cos \gamma), \quad (9)$$

Equidistant 5 determine in polar coordinates system (see A-A on fig.3) and calculated by the next mathematical dependence:

$$\begin{cases} R_e = \sqrt{R^2 + R_{kx}^2 + 2RR_{kx} \cos \rho} \\ \varphi = \alpha - \arcsin(R_{kx} \sin \rho / R_e) \end{cases} \quad (10)$$

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

In accordance with the method set forth above it is necessary to provide the continuous simulation of process of shaping with the generation of NC file. Therefore presented higher than dependence (8) - (10) make the mathematical model of the proper procedure of planning of trajectories of shaping of 3D of surface of prosthetic appliance of knee-joint grinding wheel with an instrumental surface in the form of torus and exactly they will be fixed in basis of the proper module of computer-integrated CAD/CAM system.

The new method of control program design is offered for CNC machine, including the special kinematics of shaping, which consists in the design of geometrical co-operation of 3D surface with an instrument by numeral methods with the use of regenerate in the three-dimensional numerical arrays of 3D form, that is processed, in the set system of co-ordinates of machine.

Such method allows not only to project the NC data of shaping but also mortgages possibilities of subsequent design of cutting allowance (taking into account the form of workpiece) for the automatic planning of cutting process control at shaping on the following stages:

1. Stabilizing of cutting condition along a shape-generating trajectory;
2. Optimization of cutting process;
3. Correction of shape-generating trajectories.

Thus, NC data design of cutting process of working surface of prosthesis on CNC machine must be conducted on the generalized scheme which is presented on fig.4.

Introduction of initial is the first stage, where a working surface is set by the text file of 3-D of geometrical model in the Cartesian system of co-ordinates [2, 3], and also co-ordinates of technological axis and geometrical parameters of initial instrumental surface, thus in the case of cutting by grinding except for the radius of rounding off  $R_i$  it is necessary to set the radius  $R_k$  of wheel. It is necessary to notice that technological information, which will determine both the level of stabilizing of the cutting mode and parameters of quality of the cutting surface, will may need on the next stages. On the second stage there is the count of initial file in the polar system of co-ordinates and interpolation by the functions of spline [2]. The file of digital arrays which present that surface in the arctic system of co-ordinates of machine-tool with the set (chosen) step of change of argument is the job performance of the proper procedures.

It is farther executed geometrical calculations, which determine technological trajectories on preliminary passage-ways on the chosen strategy of cutting allowance and, eventually, equidistant for a finish passage-way. The calculation of trajectory of shape-generating motions is executed on an algorithm which determines the terms of geometrical shaping of a difficult 3-D surface of prosthesis of human knee-joint. An algorithm foresees determination of digital arrays, which present the intermediate file of management of CLDATA on all co-ordinates which are managed.

For determination of feed on a line which will provide the necessary roughness of cutting (height of scallop, that appears between the neighboring passage-ways of instrument), all charts of shaping were considered [4]. As on-the-spot prosthesis places are present with different curvature (from protuberant to concave) the algorithms of calculation must engulf everything such cases.

The determine part of roughness of the cutting surface appears at crossing of two neighboring positions of spherical instrumental surface, for example milling cutter, at the change of curvature of surface of detail. The decision of such task will allow to expect step of change of feed «on a line», that is needed for forming of the program of planning of shape-generating trajectories for the **Z** axis.

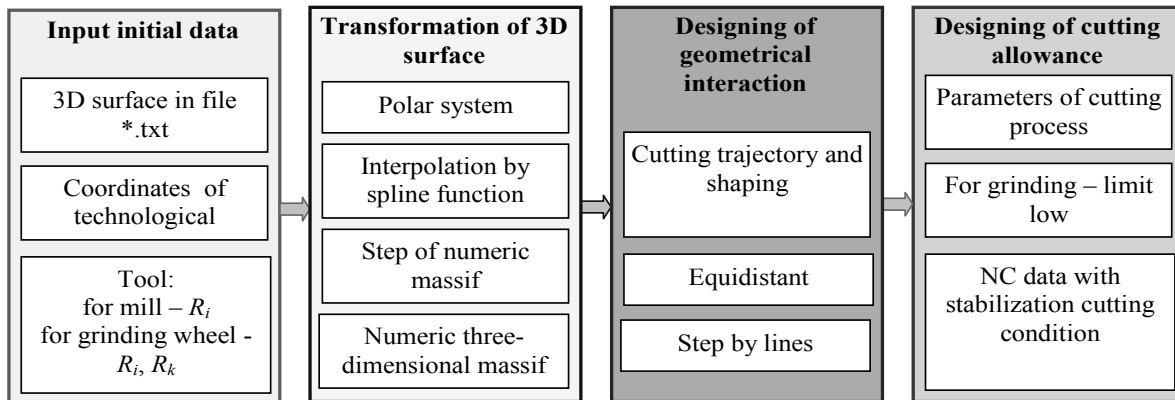


Fig. 4. Enlarge algorithm of designing NC data

Consequently, for the decision of this task it is necessary to have the array of radiuses of curvature of surface, that is processed. As the surface of detail is presented as digital arrays, for the calculation of arrays of radiuses of curvature it is expedient to take advantage of numeral methods [1] which settle accounts derivative from a digital array as separate differences.

Thus, the location of trajectories of shaping for the axes of **Z** in the developed module concerns on procedure which automatically expects the array of radiuses of curvature of surface and on set in basic data of parameter of  $R_z$  of necessary roughness calculates the necessary feed on a line.

On the last of stage there is the design of process of cutting allowance at motion of instrument (in the chosen chart) for equidistant. The parameters tied to the shape-generating co-ordinates become the job performance of such procedures layer of allowance that is cut away on every step of design at the even change of managing co-ordinate. In the internals of co-ordinate, that sets, an polar corner is adopted in the polar scheme of shaping. Thereon the stage the calculation of management coefficient is executed by the serve on condition of stabilizing of cutting process on all shape-generating trajectories.

At the control program design for cutting by grinding certain procedures are added.

At first, as grinding is a cutting process with the high level of selection warm, that can result in undesirable structural transformations of superficial layer and, in addition, being the finish operation, which must provide not only the necessary roughness of working surface but also quality of superficial layer, application of maximum law of management by speed of cutting allowance is obligatory on all cycle of grinding. Consequently, such law must be experimentally certain and entered in the algorithm of planning [5].

Secondly, taking into account that at grinding of 3D surface of prosthetic for stabilizing of quality it is necessary to provide the meeting (passing) grinding, in the trajectories of shaping necessarily there are the areas of single motions. At in relation to high speeds of feed, that sets, (rotation on an polar co-ordinate), the task of planning of such trajectories appears. A trajectory must provide as possible smooth transition from one position of wheel (on leaving from the maximal radius of 3D of surface) in the second position for grinding at a minimum radius. This task in the created module decides automatically during minimization of the dynamic loadings on the drives of machine-tool with the use of the special developed algorithms [6].

So that, the intermediate file of management, which is processed by the module of post-processor for the proper CNC machine, is automatically created as a result. All procedures of algorithm are built on the use of numeral methods, which does him universal, able to design the NC data for any forms of prosthesis of human knee-joint.

On the presented method and mathematical formulas, which present the application program of CAD/CAM module of the automated NC data design for CNC machine at cutting of prosthesis of human knee-joints. In the CAD/CAM module the automated NC data design is foreseen for implementation of the following operations of cutting of 3D surface of prosthetic:

- milling by an end spherical milling cutter;
- milling by an end cylindrical milling cutter;
- grinding by wheel, in the form of torus.

On fig.5 the interface of the developed main module of CAD/CAM system is shown, which 3 images are located on (possible scheme of shaping). Every image has reference to the separate module of CAD/CAM system (milling by a spherical milling cutter, milling by a cylindrical milling cutter, grinding by wheel in the form of torus).



Fig. 5. Common view of interface of module CAD/CAM system

On the left above every interface a window is located for introduction of basic data necessary for the NC data and design of process of cutting allowance: radius of instrument (radius of rounding off of grinding wheel or spherical milling cutter), to the necessary roughness of the treated surface which concerns by the parameter of  $R_z$ , of allowance which it is necessary to cut away for the last passage-way. Farther, at pressure on the button of «Control law» the maximum algorithm of management (for grinding is maximum law is admittance-speed of cutting allowance, for milling is cutting force - speed of cutting allowance) is entered, and at pressure on the button of «Lost motion» - single motions are used at grinding, in case if it not is pushed-in treatment is carried out by «swinging».

For introduction of basic data it is necessary to press the key button of «\*txt», whereupon a dialog box will be opened for the choice of input file with the co-ordinates of a working 3D surface of prosthetic, which it necessary to process.

After such manipulations button of «Apply» is pushed and application of all entries parameters is carried out, and in the graphic window of a 1 interface appears 3D model of surface of prosthetic with the certain system of co-ordinates, and down is oscillograph, where line 1 presents the type of prosthesis in the longitudinal section, line 2 is law of change of radius of curvature, line 3 – projected equidistant, after which the center of instrument will move with the risks which correspond to the step between passage-ways (fig.6).

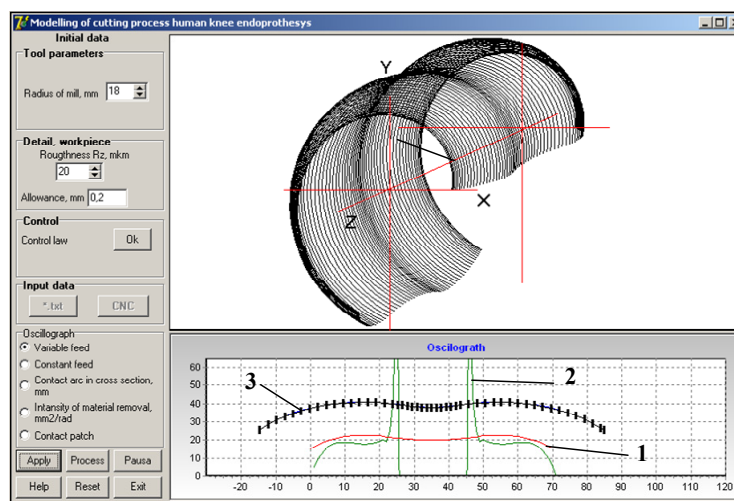
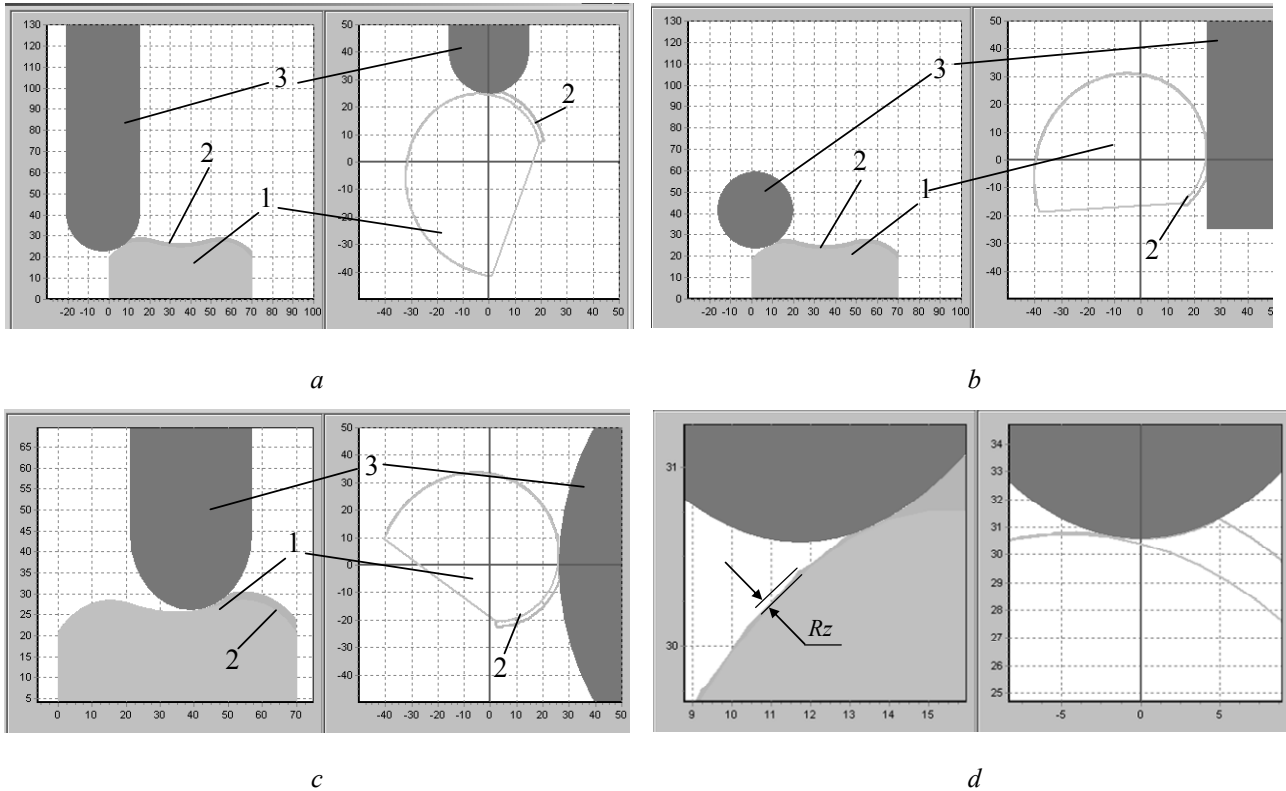


Fig. 6. Interface of program after inputting initial data

A step between passage-ways is expected so that to provide even set before roughness of surface on the height of scallops which appear between passage-ways. Appearance of such images testifies to faultless introduction of basic data and program readiness to the subsequent actions.

For initializing of design it is necessary to press the button of «Process». During implementation of design there are the calculations of parameters necessary for determination of management layer of allowance, that is cut away on every step of designing, and the animation image of process of cutting appears in the graphic windows of interface (fig.7). Thus, as function specially designed numeral procedures, on the animation image hatches really graphic image of the state of workpiece and instrument. The animation image allows at any point the designs to multiply any area, for example, in the area of contact with an instrument, as it is showed on fig.7, d. It is possible to look after formation of surface of detail with the scallops of height of  $R_z$  between the lines of cutting by the coordinate Z.



**Fig. 7. Graphic window of designing cutting process:**  
**a – spherical mill; b – cylindrical mill; c – grinding wheel in shape of torus; d – area of contact**  
**(1 – workpiece, 2 – allowance, 3 - tool)**

At pressure on the button of «Pause» the design is temporally halted, for continuation of designing it is enough to press the button of «Process». After pressure of the button of «Reset» the process of design is stopped and all parameters of design must be entered at first. The key of «Help» will open a dialog box in which short description of the developed application program and instruction is presented on pressuring of all buttons. For a program exit it is enough to press the key of «Exit».

In addition, during the design the program allows at choice to look after the change of major parameters of process cuttings allowance, which are calculated also on the special numeral procedure and is used for the automatic planning of management with the purpose of stabilizing of cutting process on all shape-generating trajectory.

The arc of contact (cutting arc) of instrument and workpiece is such parameters in the cross section (fig.8, a), intensity of cutting allowance (and more precisely its analogue) is a size which depends on the volume of material of allowance, that is cut away for one radian of change of corner of co-ordinate, that sets (fig.8, b), and also form of spot of contact of instrument and workpiece in accordance with its location on an instrumental surface (рис.8, c). After the arc of contact and intensity of cutting allowance the management by feed, that sets, for stabilizing of process, and the location of spot of contact after an instrumental surface gives possibility to forecast the wear of instrumental surface.

At planning of management by the feed, that sets, speed of cutting allowance sets to the criterion of stabilizing of cutting process (MRR - Rate Removal Material):

$$MRR = \omega_C \int_{l_1}^{l_2} \frac{1}{2} (L_{\kappa})_i^2 b_i dl, \quad (11)$$

where  $\omega_C$  – feed, which are set,  $(L_{\kappa})_i$  – arc of contact on the elementary section  $b_i$  round by the length  $l$ .



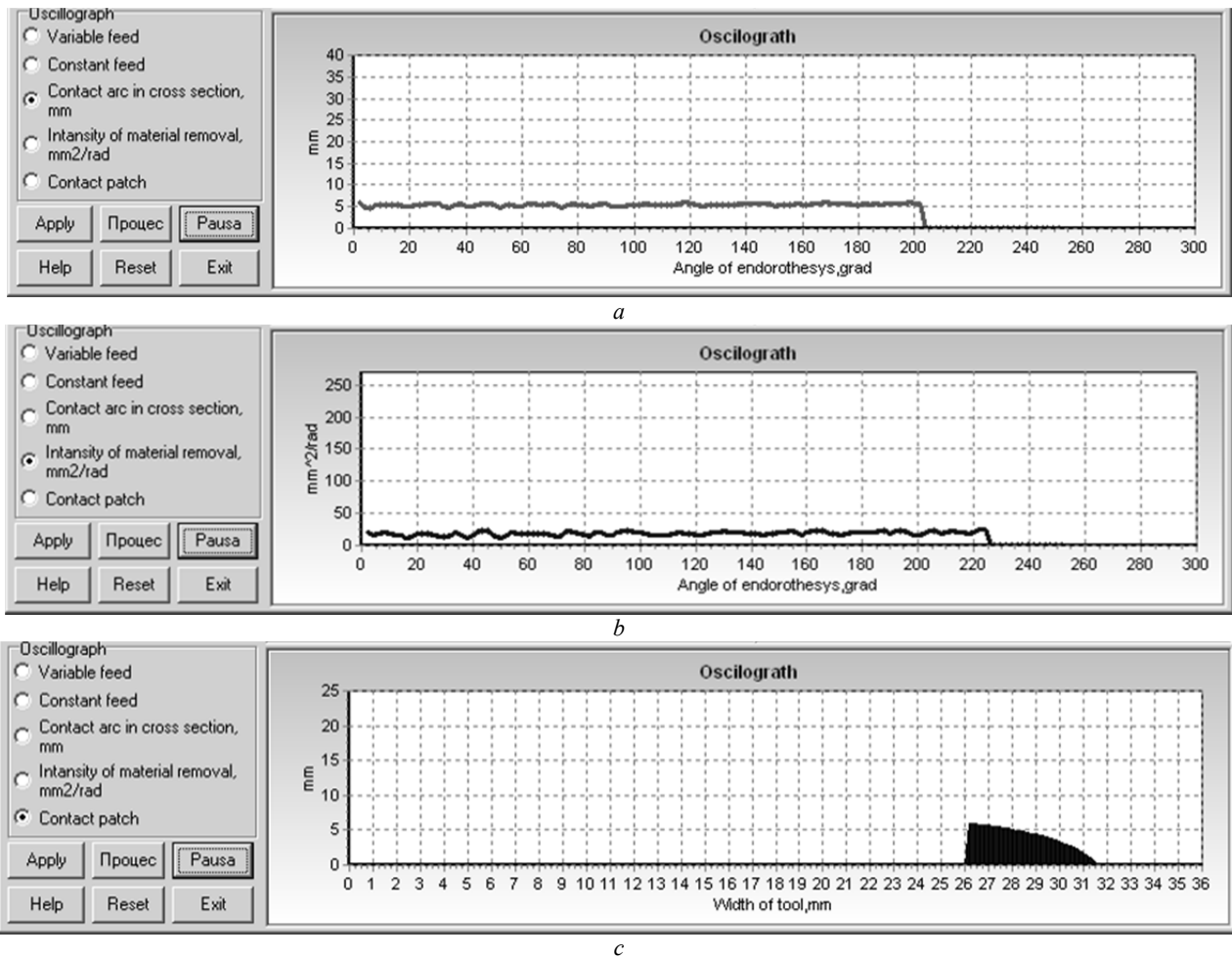


Fig. 8. Condition of oscillograph during designing

After ending of all cycle of design, inscription of «Save» appears and the key of «CNC» is activated on the panel of interface.

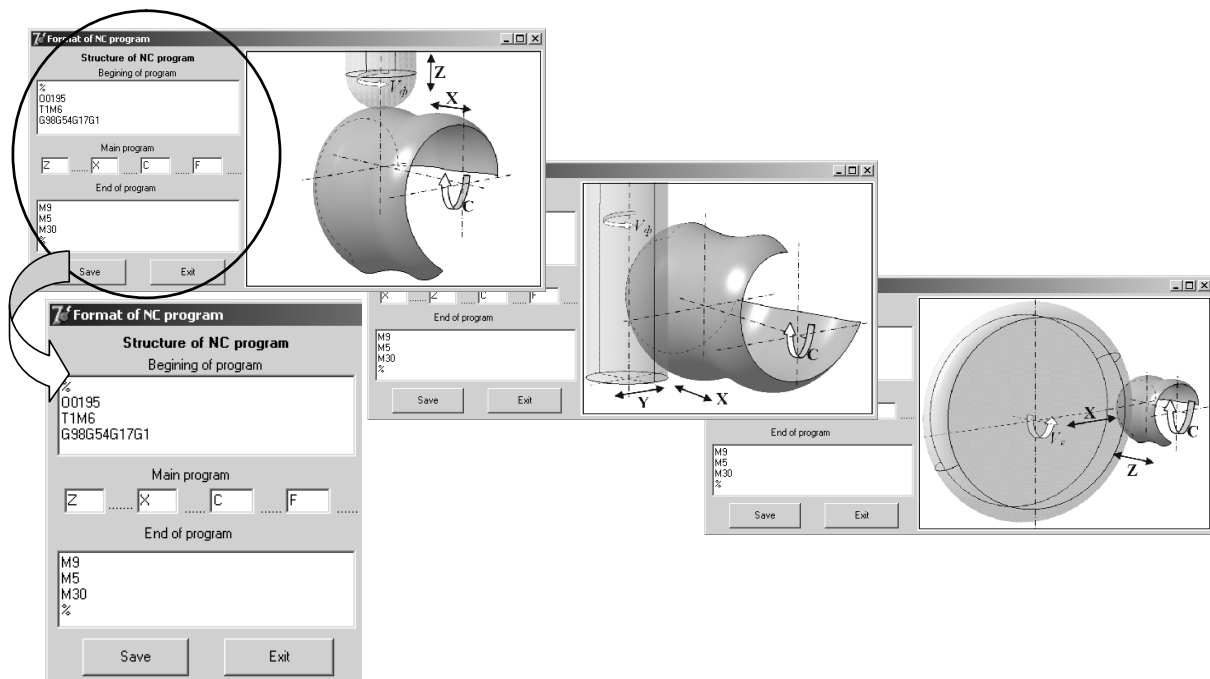


Fig. 9. Interface of CAD/CAM module for saving NC file

After pressing on her possibility to write down the file of the NC data is given. On fig.9 the interfaces of the module CAD/CAM system are represented for storage of file for CNC machine, structure of the control program and scheme of co-ordinates. A program structure is divided into beginning of the program (the so-called «begin» of the program is here entered, where the name of the program enters, choose the instrument which are used, gets out attachment of machine and other), program body (essential part of the program, where the co-ordinates of shape-generating motions and speeds of serves are presented) and end of program (feed out of instrument from the detail, switch off the spindle or emulsion, and others like that).

With using of the developed module of CAD/CAM system the NC programs were projected for manufacturing of three different type of 3D surfaces of knee-joint prosthesis on CNC vertical milling machine by Schaublin 60. As a result it was made 3 experimental model of human knee-joints prosthesis, the general view of which is presented on fig.10.

The design NC data allows stabilizing a cutting process, that was marked on the sensor indication of loading CNC machine during cutting process, and the made 3D surfaces respond to request both for accuracy and for roughness.

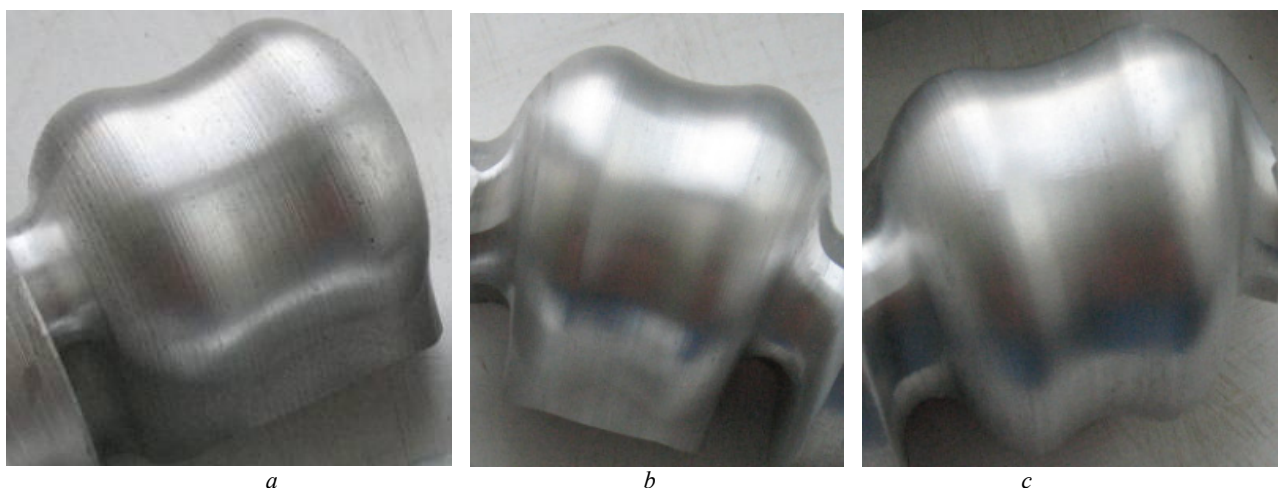


Fig. 10. Common view of produced 3D shape of prosthesis:  
a – stretch, b – left, c – right

### Conclusion

1. The module of CAD/CAM of the system is developed in order to automate preparation of the NC programs for treatment of 3D of surfaces to prosthetic of human knee-joint after three types of shaping: by spherical and cylinder milling cutters and grinding wheel in the form of torus.
2. Projected of running the program of machine-tool from CNC provides not only geometrical shaping but also stabilizing of cutting terms on all areas of shaping of trajectory due to the management by the serve, that sets.
3. NC program for grinding of 3D surfaces to prosthetic appliance of knee-joint of man takes into account the maximum algorithm of cutting away of admittance after passage-ways, and also provides minimization of the dynamic loadings on the areas of single motions.
4. Approbation of the developed module of CAD/CAM of the system proved possibility to provide the NC programs design for all three charts of shaping, and making of 3D surfaces of prosthetic appliances by the projected NC programs practically confirmed its efficiency.

*Анотація.* Представлений новий модуль САМ системи автоматизованої підготовки управляючих програм оброблення 3D робочих поверхонь протезів колінного суглоба людини на верстатах з ЧПК. Модуль забезпечує підготовку управляючих програм для трьох способів формоутворення: фрезерування сферичною і циліндричною фрезою, шліфування кругом у формі тора. Всі три способи можна реалізувати на верстатах з ЧПК при використанні всього трьох координат, що управляються. Модуль автоматично виконує проектування формоутворюючих траєкторій і на основі результатів моделювання процесу зрізування припуску розраховує управління подачею таким чином, щоб стабілізувати процес різання в циклі оброблення. При проектуванні управління за подачею по рядках застосовується підхід, що забезпечує однакову (задану) шорсткість всієї поверхні. При проектуванні управління для шліфування використовується граничний алгоритм зрізування припуску за проходами, а також оптимізується траєкторія холостих рухів за критерієм мінімуму динамічних навантажень на приводи верстата. Все це приводить до підвищення продуктивності оброблення при безумовному забезпеченні рівномірної якості 3D поверхні. Представлені результати практичної апробації функціонування модуля для виготовлення 3D поверхонь трьох типів протезів колінних суглобів.

*Ключові слова:* САМ система, верстати з ЧПК, оброблення 3D поверхні протезу колінного суглоба людини

**Аннотация.** Создан новый модуль САМ системы подготовки управляющей программы обработки 3D поверхности протезов коленных суставов человека на станках с ЧПУ. Модуль обеспечивает подготовку управляющих программ для трех способов формообразования: фрезерование сферической и цилиндрической фрезой, шлифование кругом в форме тора. Все три способа можно реализовать на станках с ЧПУ при использовании всего трех управляемых координат. Модуль автоматически выполняет проектирование формообразующих траекторий и на основе результатов моделирования процесса срезания припуска рассчитывает управление задающей подачей таким образом, чтобы стабилизировать процесс резания в цикле обработки. При проектировании управления подачей по строчкам применяется подход, который обеспечивает одинаковую (заданную) шероховатость всей поверхности. При проектировании управления для шлифования используется граничный алгоритм срезания припуска по проходам, а также оптимизируется траектория холостых ходов по критерию минимума динамических нагрузок на приводы станка. Все это приводит к повышению производительности обработки при безусловном обеспечении равномерного качества 3D поверхности, как по шероховатости, так и по структуре поверхности слоя. Представленные результаты практической апробации функционирования модуля для изготовления 3D поверхностей трех типов протезов коленных суставов человека подтверждают эффективность созданного модуля САМ/САМ системы.

**Ключевые слова:** САМ система, станки с ЧПУ, обработка 3D поверхности протеза коленного сустава человека

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