MINISTRY OF EDUCATION AND SCIENCE OF THE REPUBLIC OF KAZAKHSTAN

Kazakh National Research Technical University after K. I. Satbayev

Institute of Industrial Automation and Digitalization

Department of Industrial Engineering

DIPLOMA WORK

Technological process of mechanical processing of the shaft in the CAD/CAM systems. Batch production.

Specialty 5B071200 - Mechanical Engineering

Almaty 2020

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Completed by: Orazbekova M. Zh.

Reviewer   Scientific supervisor
_____   PhD, tutor
_____ Full Name   _____Zhankeldy A. Zh.
«____» _____ 2020 y.   «____»_____2020 y.

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APPROVED FOR PROTECTION
by Head of Department
« Industrial Engineering »
Doctor PhD.
_____ Arymbekov B.S.
«____» _____2020 y.

TASK
for completing a diploma work

Student *Orazbekova Madina Zhumabayevna*
Theme: *«Technological process of mechanical processing of the shaft in the CAD/CAM systems. Batch production.»*
Approved by the order of the University Rector №762-б from «27» january 2020 y.
Deadline for completion of work «___» _____ *2020 y.*
Initial data for the diploma work:
1. Dimensions of the part
2. Steel grade billets
Summary of the diploma work:
   a) *general information about the part;*
   b) *graphical materials;*
   c) *calculation of technical rationing, cutting modes and 3D modeling of machining in programs СПРУТ-ТП and SprutCAM.*
Graphic materials (with a precise indication of the required drawings): *processing sketches and shaft drawings*
Recommended main literature:
   1. Технология машиностроения: учеб. пособие / М.Ф. Пашкевич [и др.]; под. ред. М.Ф. Пашкевича. — Минск : Новое издание, 2008. — 478 с

2. Малов А. Н., В. Н. Гриднев, Досчатов В. В. Справочник технолога-машиностроителя – том 2 – М.: Машиностроение, 1972 – 568 с.
3. Machining technology : machine tools and operations / Helmi A. Youssef, Hassan El-Hofy.

SCHEDULE
Preparation of a diploma work (project)

Name of sections, list of issues being developed	Deadlines for submission to the scientific supervisor	Note
Introduction General information about shaft		
Design and calculation of a shaft		
Automated calculation of shaft processing operations and its 3D modeling in SprutCAM		

Signatures
Consultants and standard controller for the completed diploma work (project) with an indication of the relevant sections of the work(project)

The name of the sections	Consultants , Full Name (academic degree, title)	Date of signing	Signature
Main part	Zhankeldy A.Zh., PhD, tutor		
Standard controller	Zhankeldy A.Zh., PhD, tutor		

Scientific supervisor   _____   Zhankeldy A.Zh.

The task was accepted by the student   _____   Orazbekova M. Zh.

Date   «___» _____2020y.

ANNOTATION

In this diploma work, the technological process of mechanical processing of the shaft was developed. Identified all necessary process steps such as the procurement type, the material, the necessary operations, metal cutting machines, tools, equipment were selected, also cutting modes and processing time was calculated. Since the purpose of the work is to use CAD/CAM systems, a 3D model of the part was created in the КОМПАС program, and an automated calculation of the necessary operations and cutting modes was performed in the program СПРУТ-ТП-Нормирование. The finished 3D model was imported into SprutCAM and the machining was modeled, with generating a control program for the CNC machine.

АННОТАЦИЯ

Бұл дипломдық жұмыста білік бөлшектерін механикалық өңдеудің технологиялық процесі әзірленді. Технологиялық процестің барлық қажетті кезеңдері анықталды, олар: дайындау түрі, материал, қажетті операциялар, металл кесетін станоктар, құралдар, жабдықтар алынды, кесу режимдерін және өңдеу уақытын есептеу жүргізілді. Жұмыс мақсаты CAD/CAM жүйелерін пайдалану болғандықтан КОМПАС бағдарламасында бөлшектің 3D моделі құрылды, СПРУТ-ТП-Нормирование бағдарламасында кесу тәртіптері мен қажетті операцияларды автоматтандырылған түрде есептеу жүргізілді. Біліктін дайын 3D моделі SprutCAM-ге импортталды және ЧПУ станоктары үшін басқару бағдарламасын генерациялау мен механикалық өңдеу үлгіленді.

АННОТАЦИЯ

В данной дипломной работе был разработан технологический процесс механической обработки детали вал. Определены все необходимые этапы технологического процесса, такие как: вид заготовки, материал, подобраны необходимые операции, были подобраны металлорежущие станки, инструменты, оснастка, произведен расчет режимов резания и время обработки. Так как целью работы является использование систем CAD/CAM, была создана 3D модель детали в программе КОМПАС, произведен автоматизированный расчет необходимых операций и режимов резания в программе СПРУТ-ТП-Нормирование. Готовая 3D модель была импортирована в Sprut CAM и смоделирована механическая обработка с генерированием управляющей программы для станка ЧПУ.

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INTRODUCTION

Currently, the problem of speeding up the process and optimizing the technological process of processing parts is urgent. Advanced technologies allow us to design more modern machines and mechanisms with high requirements and quality of production, which in turn allows us to reduce their cost. When modifying the technological process, the basis is taken to ensure productivity, high performance, reliability and efficiency. Automated process control systems are created and implemented with its optimization for all main manufacturing parameters and required qualities.

Progress in mechanical engineering is the use of computer technology in the design of technological processes and mathematical modeling of mechanical processing. Automation of programming of processing processes on CNC machines is carried out. Computer-aided process planning systems for technological processes are being created.

The purpose of this work is to develop a technological process in the CAD/CAM system. The implementation of these programs allows to ensure high quality design, reduce time, and automate tasks at different stages of development and manufacturing of parts.

1. Design of technological process of technological process of mechanical processing
1.1 Technological requirements of part

Mechanical transmission shafts of machines are operated at high loads and speeds, which in turn affects the increased requirements for structures. During operation, the shaft is subjected to forces such as bending and torsion. In some cases, the shaft is stretched and compressed in addition to bending and torsion.

During developing shaft design, high demands are placed on choosing the correct shape. The peculiarity of the shafts is that they work under cyclic bending of the most dangerous symmetrical cycle, so the shaft is under pressure during operation of the acting bending loads. To avoid stress concentration at junction points, avoid sharp cross-section transitions, rough surface treatment, and non-spherical holes.

During the operation of the shaft, failure may occur at the design, manufacturing and operation stages. Problems can cause incorrect shape selection, cuts, cracks, dents, and incorrect adjustment of bearing units. In order for the shaft to last a long time, you need bulk strength for the ability to resist, surface strength, bending stiffness, torsional stiffness.

There is a problem with the formation of corrosion that occurs due to the friction of the connected parts. Corrosion usually appears as a red powder or dark spots, the powder consists of iron oxide. Corrosion occurs due to the concentration of stress at the edges of the joint parts, where complex physical and chemical processes occur. In addition to tight joints, corrosion can occur in threaded, keyed, riveted joints and other places where conditions arise for the mutual movement of mating parts.

1.2 The choice of material and its properties

The production of the shaft material is a responsible process. During operation, the shafts experience various types of stress, bends, torsion, etc. Therefore, the material must be selected in accordance with the technical characteristics and purpose of the part. Since the shafts are basically one of the main and responsible elements of the mechanism that ensure the full operation of the assembly unit. The rigidity of the shaft ensures the normal operation of the parts and is determined by the geometric shape. When choosing a material, the cost and lightness of steel are taken as the basis. Most often used carbon steel Ст3, Ст5 as this type of steel is profitable economically and at the same time has a good quality.

Shafts for critical structures are made of high-quality carbon steels of grades 25, 30, 40, 45, 50 and alloyed chromium steels of 15X, 25X, 35X, 40X, 45X, and

18ХГТ. High-tension shafts that will be used in the machines are made of steel 40ХН, 40ХН2МА, 30ХГТ etc.

This part of the shaft will be used in the conical gearbox of the АПРС-40 lifting unit. Since there are high requirements for the part, it was decided to choose the shaft material alloy steel 40X [1]. The chemical composition is shown in table 1.

Table 1.

Content of elements, %							
C	Si	Mn	S	Ni	P	Cr	Cu
0,36-0,44	0,17-0,37	0,5-0,8	up to 0,035	up to 3	up to 0,035	0,8-1,1	up to 0,3

1.3 Method of production of the billet

The main components of selecting blanks for shafts are their cost and further machining. A rolled billet is used during processing smooth and stepped shafts, since the geometric characteristics are close to the finished part. The most preferable methods of manufacturing blanks that allow us to get them close in shape, size and weight to the finished part.

Progressive methods of manufacturing shaft blanks — stamping in closed dies, landing on horizontal forging machines, hot extrusion, cross-helical rolling, bulk cold forging, radial forging, electric forging. These methods allow us to get a material utilization factor of 0.7 or higher. The use of cross-wedge rolling in the manufacture of shafts provides an increase in the material utilization rate to 0.9, and the high accuracy of the process-reducing the allowance for machining to 1.0...1.5 mm.

The typical process of manufacturing shaft blanks consists of the following operations: cutting hot-rolled bar into dimensional blanks, heating the blanks, forming, heat treatment after forming, and editing on presses. Blanks are cut on presses or scissors. Heating of workpieces is carried out in electro-induction installations. After plastic deformation, heat treatment of the shaft billets is performed to relieve internal stresses. The method of heat treatment is determined by the material of the workpiece.

For the specified part, a billet of the rolled type was selected. The choice of this type is due to the fact that the billet is obtained by rolling on a rolling machine and has a circle shape in the section, which brings the geometric parameters as close as

possible to the part we need, and the billet is profitable from an economic and technological point of view.

1.4 Type of production

There are several types of production. In accordance with GOST 14.004-83, depending on the nomenclature, regularity, stability and volume of production of products, there are three types of production: single, serial and mass.

The type of production of the part is set by the quantitative indicator by the coefficient of fixing the operation (GOST 14.004-81).

At $Kf.o. = 1$ — mass production, $1 < Kf.o. < 10$ — large batch production, $10 < Kf.o. < 20$ — medium batch production, $20 < Kf.o. < 40$ — small batch production, at $Kf.o. > 40$ — unit production.

The specified annual part release program is $Nr = 500$ p. The annual program for the production of parts is calculated using the following formula [2]:

$$N = Nr + k_1 + k_2 \tag{1.1}$$

where k_1 - the coefficient of technological failure;
k_2 - the ratio of work in progress.

$$N = 500 \times 1.05 \times 1.03 = 540.75 \text{p.}$$

Accept 540 p.
The settlement cycle of production [2]:

$$\tau_s = \frac{Ff \times 60}{N} \tag{1.2}$$

where Ff - estimated hours of operation in two-shift mode (accept $Ff = 4015$h.)

$$\tau_s = \frac{4015 \times 60}{540} = 446.1 \; m/p$$

Actual production cycle [2]:

$$\tau_a = \tau_s \times \eta \tag{1.3}$$

where η - the load factor of the equipment ($\eta=0.75 \div 0.85$)

$$\tau_a = 446.1 \times 0.8 = 356.88 \text{m/p}$$

From the calculations above the coefficient of fixing the operation is determined by:

$$Kf.o.{<=}446{,}1/356{,}7 = 1{,}25$$

By following GOST 14.004-81 we determine that type of productions is large batch production, cause $1 < Kf.o. < 10$.

1.5 Development of route and operating technology shaft treatments

The developed technological process must be progressive, ensure increased productivity and quality of parts, reduce labor and material costs for its implementation, reduce harmful effects on the environment.

Technological processes of processing the "Shaft" part are shown in table 2.

Table 2.

№ of operation	Name of the operation and transitions	Equipment
005	Blanking	Rolling machine
010	Lathe	Lathe Screw-cutting machine 16К40П
015	Lathe	Lathe Screw-cutting machine 16К40П
020	Lathe	Lathe Screw-cutting machine 16К40П
025	Lathe	Lathe Screw-cutting machine 16К40П
030	Lathe	Lathe Screw-cutting machine 16К40П
035	Milling	Vertical milling machine
040	Slot-milling operation	Slotted milling machine

045	Thermal	
050	Round grinding	Grinding machine 3M131
055	Round grinding	Grinding machine 3M131
060	Washing	
065	Control	

1.6 Calculation of allowances

Allowance – a layer of material that removed from the surface of the workpiece in order to achieve the specified properties of the part. Factors affecting the amount of allowance: type production, cutting modes, cutting tools, design shapes and sizes of the processed parts.

Calculation of allowance for the surface diameter of $65k6$[3].

The surface will go through the following series of operations:

– Turning - rough;

– Turning - finishing;

– Grinding.

The minimum allowance for diameter dimensions for each transition is calculated by using the formula:

$$2Z_{imin} = 2\ (R_z + h_{i-1} + \Delta_{i-1}) \tag{1.4}$$

where R_z – is the height of surface irregularities;

h – depth of the defective layer;

Δ – total deviations of the surface location.

– rough turning:

$$2Z_{imin} = 2 \cdot (160+250+2695) = 6210 \text{ mcm}$$

– finishing turning:

$$2Z_{imin} = 2 \cdot (50+50+161,7) = 523,4 \text{ mcm}$$

– grinding:

$$2Z_{imin} = 2 \cdot (25 + 25 + 6{,}46) = 112{,}9 \text{ mcm}$$

The calculation of the smallest dimensions for technological transitions begins with the smallest (largest) part size according to the design drawing and is based on the formula:

$$d_{i+1} = d_i + Z_{imin} \tag{1.5}$$

– rough turning:

$$65{,}002 + 0{,}1129 = 65{,}1149 \text{ mm}$$

– finishing turning:

$$65{,}1149 + 0{,}5234 = 65{,}6383 \text{ mm}$$

– workpiece:

$$65{,}6383 + 6{,}210 = 71{,}8483 \text{ mm}$$

The largest limit is found by adding the tolerance to the smallest:

$$d_{imax} = d_{imin} + T_{di} \tag{1.6}$$

– grinding:

$$65{,}002 + 0{,}019 = 65{,}021 \text{ mm}$$

– rough turning:

$$65{,}6383 + 0{,}19 = 65{,}8283 \text{ mm}$$

– finishing turning:

$$65{,}1149 + 0{,}074 = 65{,}1889 \text{ mm}$$

– workpiece:

$$71{,}8483 + 0{,}87 = 72{,}7183 \text{ mm}$$

Actual maximum allowances for transitions:

$$65{,}1889 - 65{,}002 = 0{,}1869 \text{ mm}$$
$$65{,}8283 - 65{,}1889 = 0{,}6394 \text{ mm}$$
$$72{,}7183 - 65{,}8283 = 6{,}89 \text{ mm}$$

Actual minimum allowances for transitions:

$$65{,}1149 - 65{,}002 = 0{,}1129 \text{ mm}$$
$$65{,}6383 - 65{,}1149 = 0{,}5234 \text{ mm}$$
$$71{,}8483 - 65{,}6383 = 6{,}210 \text{ mm}$$

Determination of the total allowances:

$$\Sigma\, Z_{tmax} = 0{,}1869 + 0{,}6394 + 6{,}89 = 7{,}7163 \text{ mm}$$
$$\Sigma\, Z_{tmin} = 0{,}1129 + 0{,}5234 + 6{,}210 = 6{,}8463 \text{ mm}$$

The correctness is checked using the formula:

$$T_{wp} - T_d = \Sigma\, Z_{tmax} - \Sigma\, Z_{tmin} \tag{1.7}$$
$$T_{wp} - T_d = 0{,}87 - 0{,}019 = 0{,}851 \text{ mm}$$
$$\Sigma\, Z_{tmax} - \Sigma\, Z_{tmin} = 7{,}7163 - 6{,}8463 = 0{,}87 \text{ mm}$$

Table 3 - Calculations of allowances for machining.

The contents of the operation	The elements of the allowance			The calculated allowance		Tolerance, mm	Limit size		Limit values of allowances	
	Rz	h	$\Delta\Sigma$	$2Z_{imin}$	Size, mm		max	min	max	min
Billet: rolled type	160	250	250	-	71.84	870	72.7	71.8	-	-
turning										

Roughing	50	50	161	6210	65.63	190	65.83	65.64	6.8	6.21
Finishing	25	25	6.46	523.4	65.11	74	65.2	65.1	0.64	0.52
Grinding										
single	10	20	0	112.9	65.002	19	65.021	65.002	019	0.11

1.7

Equipment and machine tools

Equipment is selected according to the type of production.

Technological equipment for processing the shaft:
- high-precision lathe screw-cutting machine 16К40П;
- circular grinding machine 3М131;
- Vertical milling machine 6Т12;
- Slotted milling machine 5350.

This equipment was selected according to raw data about the billet and type of production. These machines also meet the calculated cutting conditions during processing this part.

Technological equipment includes installation and clamping devices, cutting tools, auxiliary and measuring tools. In the developed technological process, the main nomenclature of auxiliary, cutting and measuring tools is a standard tool [4]:
- Cutter 2102-0031 Т15К6 ГОСТ 18877-73;
- Grooved cutter АГБ2126-4048;
- Milling cutter 2234-0375 ГОСТ9140-78;
- Drill with diameter 5 2317-0008 ГОСТ 14452-75;
- File 2820-0018 ГОСТ1465-80;
- The metal brushes.

1.8 Cutting modes

Calculation of cutting modes of diameter $65k6$ [5].

Cutter: right-hand straight-through lathe.

Working part material: hard alloy Т15К6.

Cross-section dimensions of the cutter body B×H=16×25; the length of the cutter 150 mm.

Geometric parameters of the cutting part [6]:

− shape of the front surface – radius with reinforcing chamfer, the width of radial holes B=2 mm, radius of the hole R=4mm;

  − rake angle γ =15°;

  − rake angle on the reinforcing chamfer γф=15°;

  − the main rear angle α=12°;

  − angle of inclination of the main cutting edge λ=0°;

  − main angle in the plan φ=60°;

  − auxiliary angle in the plan φ1=15°;

  − the radius of the top r =1mm.

Depth of cut:

for finishing: t =65,84−65,22=0,32 mm.

for rough: t =72,74−65,842=3,45 mm.

Feed at finishing turning s_0 =0,6 mm/tur
Feed at draft turning s_0 = 0,7 mm/tur
Cutter durability period T =60 min
Outer turning, hard alloy T15K6, C_v = 350, x_v = 0,15, y_v = 0,35, m = 0,2.
Determining the speed of the main cutting movement:

$$v = \frac{Cv}{T^m \cdot t^x \cdot s^y} \cdot K_V \tag{1.8}$$

Cv – coefficient, table value;
m, x, y – the exponents, a table of values;
T – durability period, min.
The correction factor is determined by the formula:

$$K_V = K_{MV} + K_{IIV} + K_{HV} + K_{\varphi V} + K_{OV} \tag{1.9}$$

K_{MV} − the correction coefficient that takes into account changes in the mechanical properties of the processed material is determined by the formula:

$$K_{MV} = 750\ \sigma_B$$

where σ_B – yield strength, that equals to σ_B= 720 MPa.

$K_{\Pi V}$ – correction coefficient that takes into account the condition of the workpiece surface;

K_{HV} – correction coefficient that takes into account changes in the material of the working part of the tool;

$K_{\varphi V}$ – correction coefficient that takes into account the change in the main angle in the plan φ;

K_{OV} – correction coefficient that takes into account the type of processing;

The total correction factor for the speed of the main cutting movement is determined by the formula:

$$K_{OV} = 1{,}04 \times 0{,}9 \times 1 \times 0{,}9 \times 1 = 0{,}8424$$

Where $K_{MV} = 750 \times 720 = 1{,}04$;

$\qquad K_{\Pi V} = 0.9$ for metal roll details;

$\qquad K_{HV} = 1$ for hard alloy T15K6;

$\qquad K_{\varphi V} = 0.9$ for $\varphi = 60°$.

$\qquad K_{OV} = 1$ for external longitudinal turning.

All found values are substituted into the formula:

finishing: $V_H = 350600{,}2 \times 0{,}320{,}15 \times 0{,}60{,}35 \times 0{,}8424 = 184{,}4$ m/min $= 3{,}07$ m/s

rough: $V_H = 350600{,}2 \times 3{,}10{,}15 \times 0{,}70{,}35 \times 0{,}8424 = 121{,}39$ m/min $= 2{,}02$ m/s

Spindle rotation frequency [6]:

$$n = \frac{1000 \quad v}{\pi \quad D}, \qquad\qquad (1.10)$$

finishing: n $= 1000 \times 184{,}43{,}14 \times 65{,}2 = 900{,}7$ min^{-1}

rough: n $= 1000 \times 121{,}393{,}14 \times 65{,}84 = 587{,}17$ min^{-1}

Setting the actual speed value: n$=1000$ min^{-1}, n $=630$ min^{-1}.

Determining the actual cutting speed:

finishing: $v = \frac{\pi \cdot D \cdot n}{1000} = \frac{3.14 \cdot 65.2 \cdot 65.2}{1000} = 204.7$ m/min $= 3{,}41$ m/s

$$\text{rough:} v = \frac{\pi \cdot D \cdot n}{1000} = \frac{3.14 \cdot 65.84 \cdot 630}{1000} = 130 \text{ m/min} = 2,2 \text{ m/s}$$

Cutting force:

$$P_z = C_{Pz} \cdot t^{x_{Pz}} \cdot s_0^{Pz} \cdot V^{n_{Pz}} \cdot K_{Pz} \tag{1.11}$$

where $C_{Pz} = 300$, $x_{Pz} = 1$, $y_{Pz} = 0,75$, $n_{Pz} = -0,15$.

K_{Pz} – coefficient that takes into account the changed processing conditions;

K_{MPz} – coefficient that takes into account changes in the mechanical properties of the processed material;

$$K_{MPz} = \left(\frac{720}{750}\right)^{0,75} = 0,97$$

where $\sigma_B = 720$ MPa

We determine the overall correction factor for the cutting force using the formula:

$$K_{Pz} = K_{MPz} \times K_{\gamma Pz} \times K_{\varphi Pz} \times K_{\lambda Pz,} \tag{1.12}$$

$$K_{Pz} = 0,97 \times 0,95 \times 1 \times 1 = 0,926$$

$K_{\gamma Pz}$ – coefficient that takes into account the change in the front angle γ, equals to 1 at $\gamma = 15°$;

$K_{\lambda Pz}$ – coefficient that takes into account the change in the angle of the main cutting edge λ, equals to 1 at $\lambda = 0°$;

$K_{\varphi Pz}$ – coefficient that takes into account the change in the main angle in the plan φ equals to 0.95.

All found values are substituted into the formula:

finishing: $P_z = 300 \times 0,321 \times 0,60,75 \times 204,7 - 0,15 \times 0,926 = 27,28$ kgs $= 367,62$ N

rough: $P_z = 300 \times 3,11 \times 0,70,75 \times 130 - 0,15 \times 0,926 = 317,45$ kgs $= 3114,18$ N

The power required for cutting is equal to:

finishing:

$$N = \frac{Pz \cdot V}{1020 \cdot 60} = \frac{27.28 \cdot 204.760}{1020 \cdot 60} = 0{,}91 \text{ kW}$$

rough:

$$N = \frac{Pz \cdot V}{1020 \cdot 60} = \frac{317.45 \cdot 130}{1020 \cdot 60} = 6{,}84 \text{ kW}$$

We check whether the machine drive power is sufficient: $N_C \leq N_{PS}$
Power (kW) on the machine spindle by drive according to the formula:

$$N_{PS} = N_d \times \eta$$

In the passport data of the 16К40П machine we find: $N_d = 10$ kW; $\eta = 0.75$
$N_{PS} = 10 \times 0.75 = 7.5$ kW
For finishing turning: 0.91 < 7.5, i.e. processing is possible.
For rough turning: 6.84 < 7.5, i.e. processing is possible.

1.9 Calculation of technical time standards

010 Turning operation:
Basic time:

$$T_b = \frac{L \times i}{n \times S} \tag{1.13}$$

L- cutting length, mm;
n- rotation frequency, Rev/min;
S- feed, mm / Rev
The stroke length of cutter L:

$$L = \frac{D - d}{2} + y + \Delta \tag{1.14}$$

The infeed cutter:

$$y = t \times \text{ctg}\varphi,$$

$y = 1{,}3 \times 0{,}58 = 0{,}754$ mm
Movement of cutter $\Delta = (1 \div 3)$ mm; accept $\Delta = 2$ mm.

$$L = \frac{80-0}{2} + 0.754 + 2 = 42.754 \text{mm.}$$

$$T_b = \frac{42.754 \times 1}{1630 \times 0.35} = 0.19 \text{min}$$

Auxiliary time [7]:

$$T_{ax.} = T_{i.r.} + T_{a.d.} + T_{m.} + T_{m.p.} \tag{1.15}$$

$T_{i.r.}$- time to install and remove a part, min;
$T_{a.d.}$- time to attach and detach a part, min;
$T_{m.}$- the time associated with the management of the machine, min.;
$T_{m.p.}$- time to measure the part, min.

$$T_{ax.} = 2.8 + 1 + 0.40 + 0.70 = 4.9$$

where $T_{i.r.} = 2.8$ min, [9]
$T_{a.d.} = 1$ min, [9]
$T_{m.} = 0.40$ min, [9]
$T_{m.p} = 0.70$ min, [9]
The operating time:

$$T_{op.} = 4.9 + 0.19 = 5.09 \text{ min.}$$

Piece time:

$$T_{p.} = T_{op.}\ (1 + (t_{o.w.} + t_{m.w.} + t_{w.b.})/100) \tag{1.16}$$

Where $t_{o.w.}$ - Time of organizational maintenance of the workplace;
$t_{m.w.}$ - The maintenance time of the workplace;
$t_{w.b.}$ - Time of work breaks.

$$T_{p.} = (1 + (0.254 + 0.1527 + 0.1018)/100) = 5.11 \text{min}$$

Where $t_{m.w.} = (4 - 6\ \%)5.09 = 0.254$ min,
$t_{o.w.} = (2 - 6\ \%)5.09 = 0.1527$ min,
$t_{w.b.} = (2 - 4\ \%)5.09 = 0.1018$ min.

The unit calculation time:

$$T_{u.c.} = (15/10) + 5.11 = 6.61 \text{min.}$$

Table 4 - Calculated data for rationing for all operations.

Operations	Time min.
010 Turning End face treatment diameter 64	6.61
015 Turning End face treatment diameter 48	6.28
020 Turning Roughing diameters 64, 70, 65	25.6
025 Turning Roughing diameters 48, 60, 65	14.48
030 Turning Finishing diameters 60, 70, 65, 65.	19.7
035 Milling	15
040 Slotted milling processing	9.2
045 Thermal	-
050 Round grinding	6.5
055 Round grinding	8.9
060 Washing	-
065 Control	-

Time required for processing the workpiece 112.27

2. Design of the technological process in CAD/CAM
2.1 Modeling of the shaft in КОМПАС

CAD systems are widely used in engineering and have long helped automate the design process. The shaft drawing was created using the КОМПАС program. The program created a 2D, 3D model of the part, as well as a sketch of the technological process.
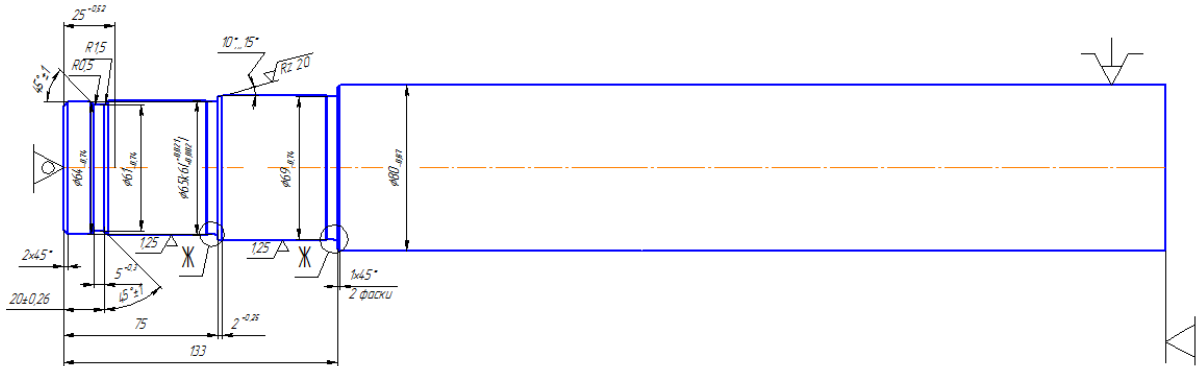
Figure 1 - 020 Turning operation, diameters processing 64, 70, 65.
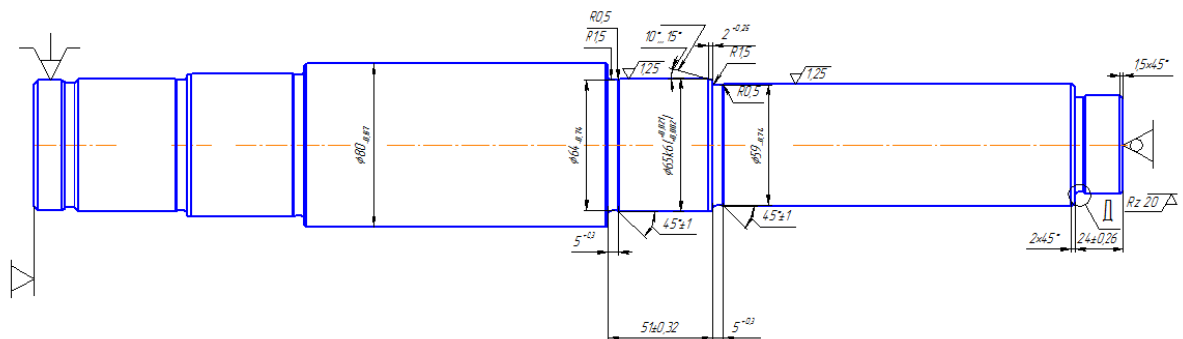
Figure 2 - 025 Turning operation, diameters processing 48, 60, 65.
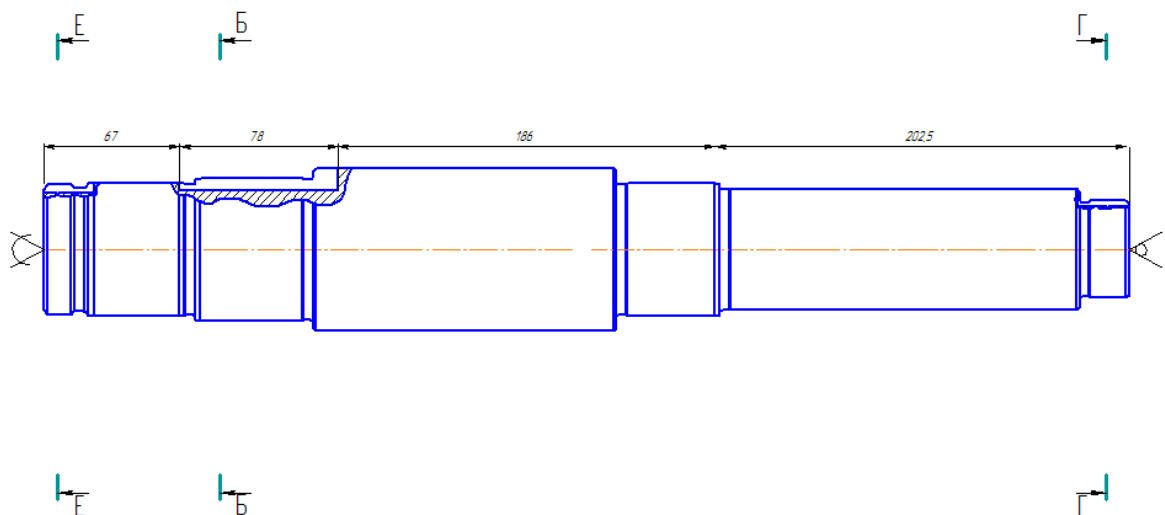
Figure 2 - 035 Milling operation, groove processing

25
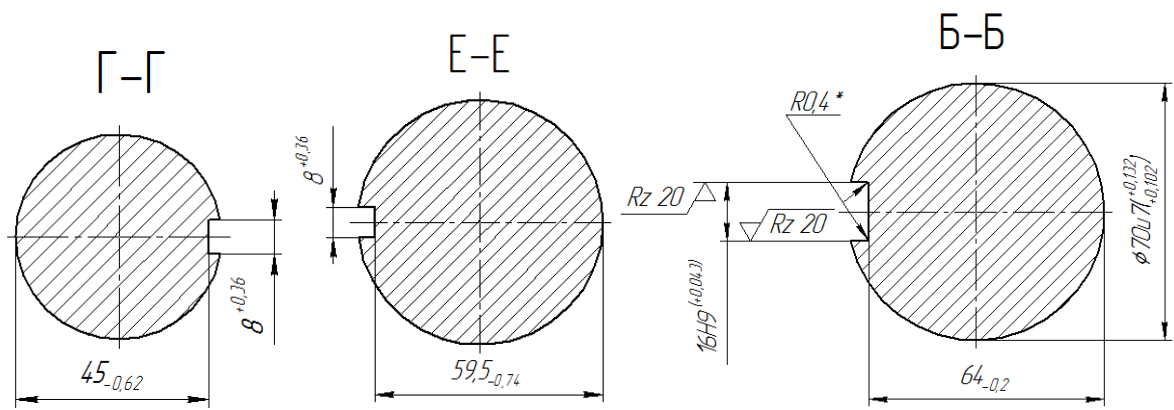
Figure 2.1 – Cross section of keyways
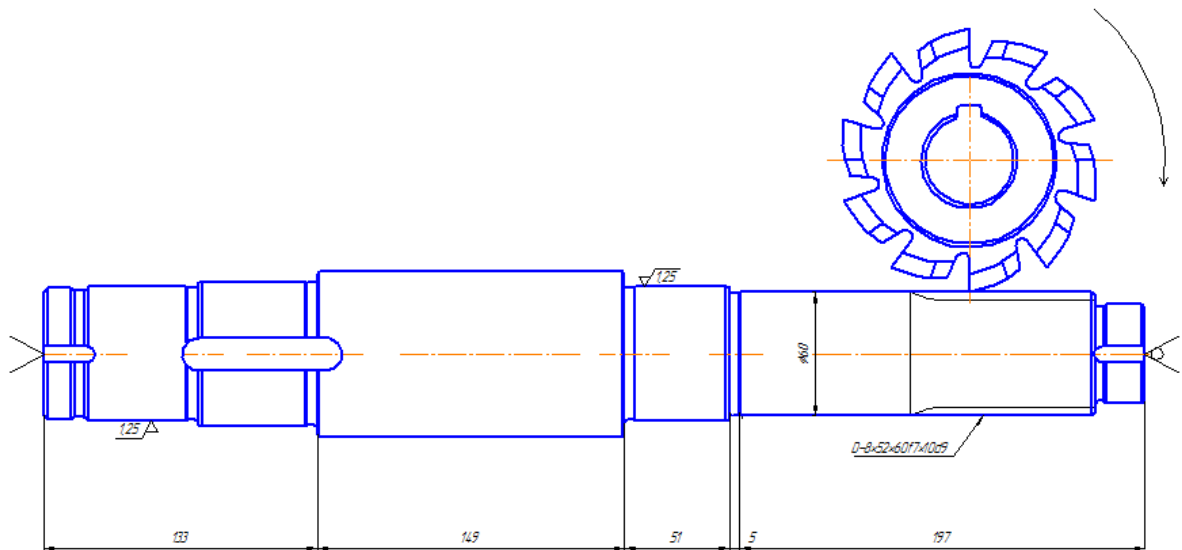
Figure 4 - 040 slot-milling operation
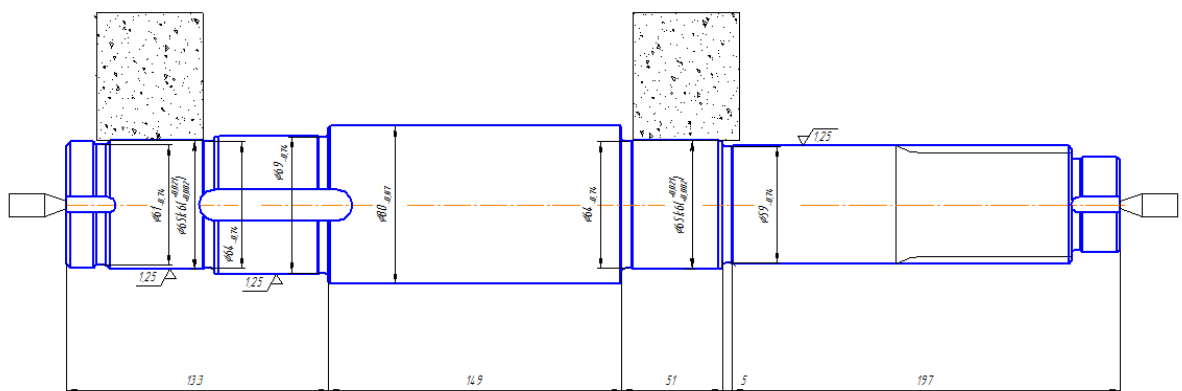
Figure 5 - 060 Round grinding

2.2 Automated calculation of technical rationing in the program " СПРУТ-ТП".

The program "Спрут-ТП-Нормирование" refers to the CAPP (Computer - Aided Process Planning) system. The system in automated mode constructs technological processes, allows you to calculate the norms of time and processing mode, which saves time and human resources for the selection of equipment, machines, tools, etc. The program has a database that includes all the information from more than 40 reference books on production rationing.

This allows to get ready-made results after entering the initial data. The process was created and verified according to the information about shaft. To start the process data such as diameters, length, grooves, threads, etc. was entered (Fig. 6).
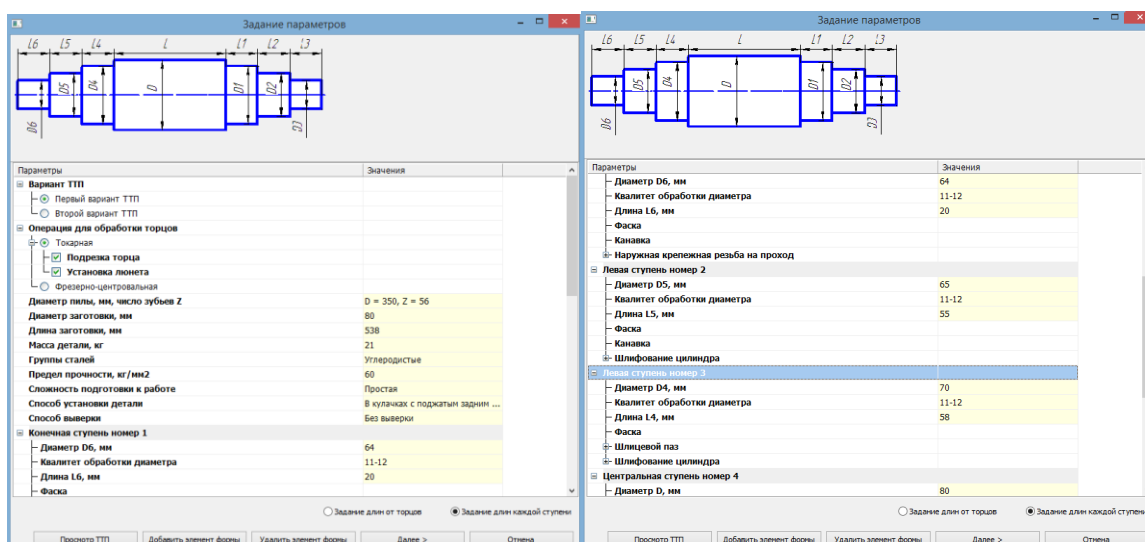
Figure 6 - The setting of parameters

Next, the program selects the required operations and suitable equipment with tools for full-fledged machining of the part. Depending on the input data, the processing route is assigned and the unit time is calculated. (Fig. 7)
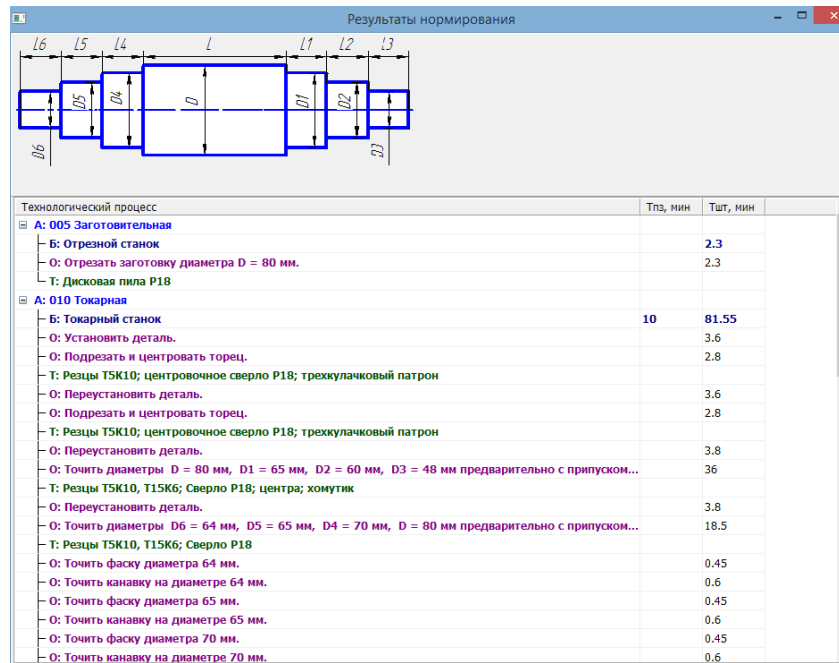
Figure 7 - Result of rationing

Also, a calculation for the cutting mode was made. The results are shown below (Fig. 8).

Figure 8 - Calculating the cutting mode

During the comparison of data obtained using the program and data obtained by numerical method, it was found that the risk of errors is minimal.

2.3 Generating a control program for the CNC in SprutCAM

The development of the control program for shaft turning on a CNC machine was performed in the SprutCAM 11 system. For complete visualization, the Mori Seiki nl 2500 lathe and milling machine was selected. (Fig. 9)
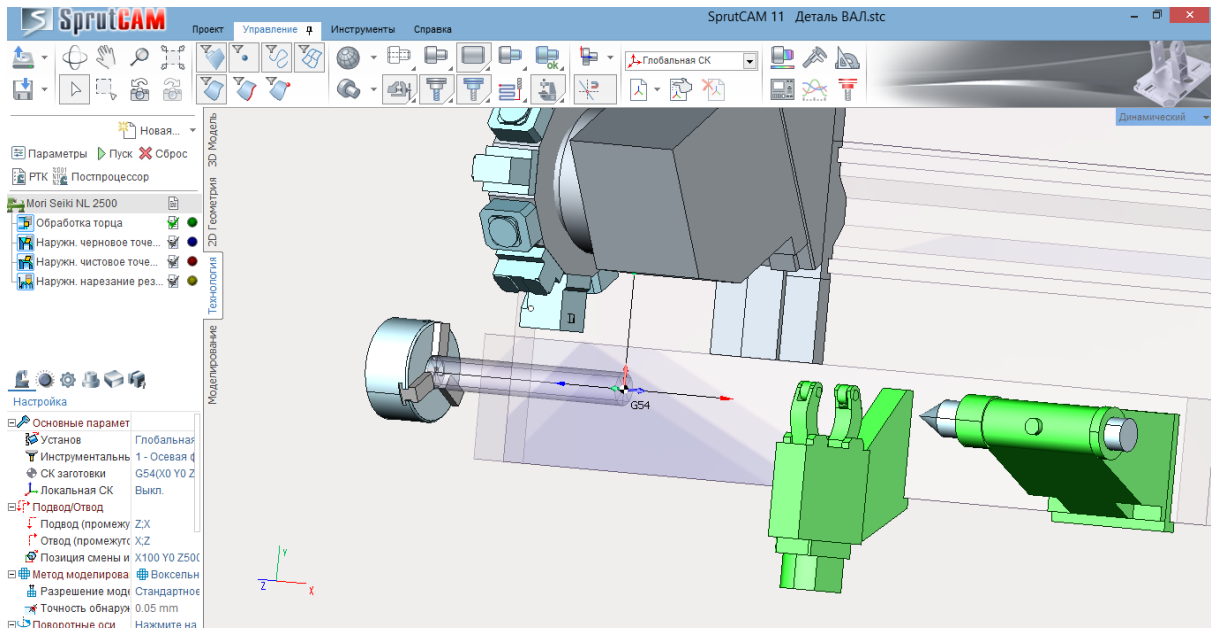
Figure 9 - Mori Seiki NL 2500 lathe and milling machine.

The finished 3D view of the shaft is imported from the КОМПАС program file. Next, the type of workpiece is selected and the required operations are assigned. The program creates an animation of machining in the "Modeling " section, which allows to fully control the process and make changes. Consider the simulation of roughing and finishing of diameters 64, 65, and 70. (Fig. 10, 11, 12). During creating an operation, the program sets the processing path and the work task, which are highlighted with hatched lines. If the operations are set correctly and nothing interferes with processing, the operations enter the "Modeled" status.
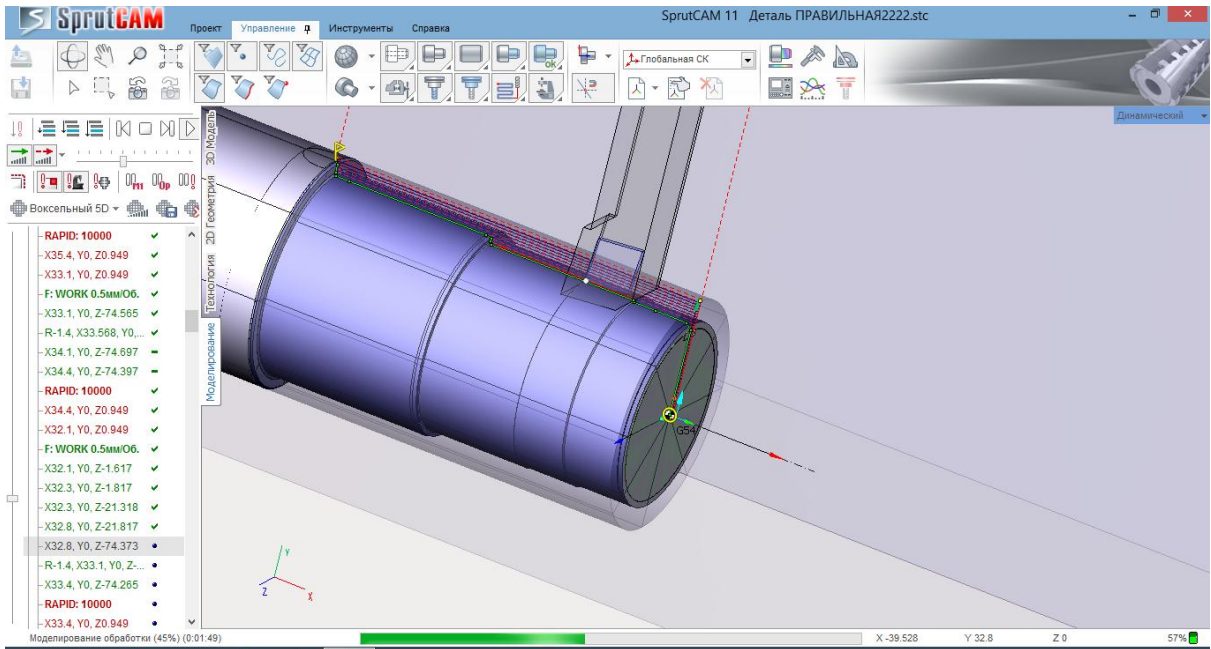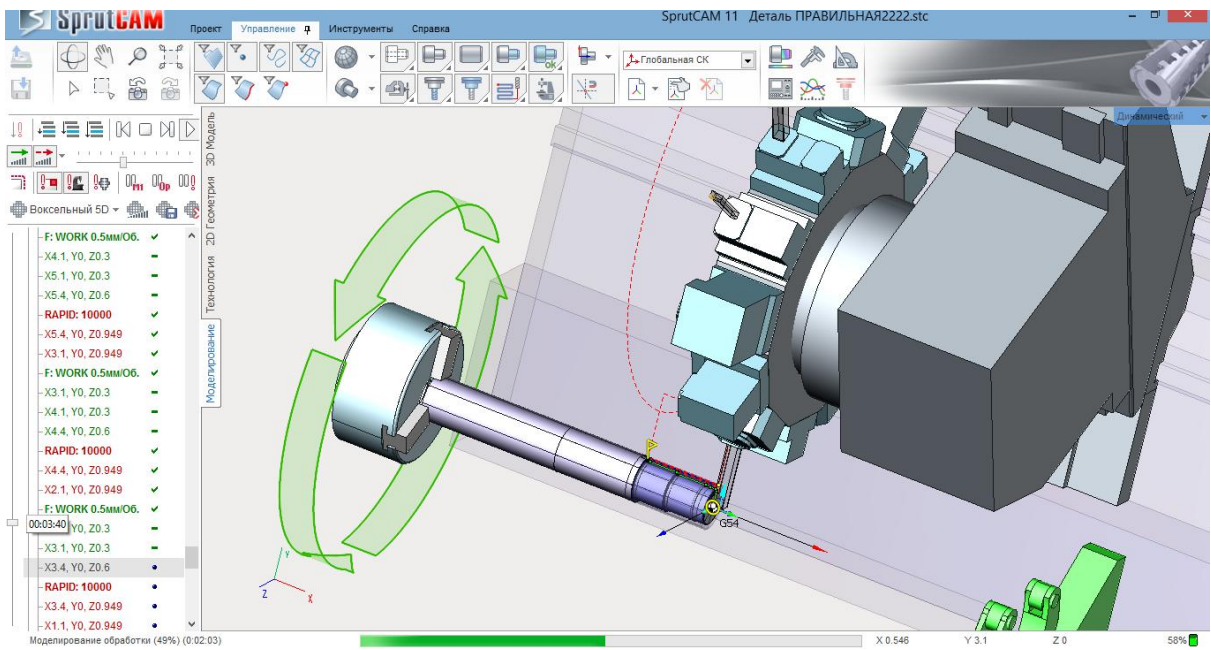
Figure 10 - The outer roughing

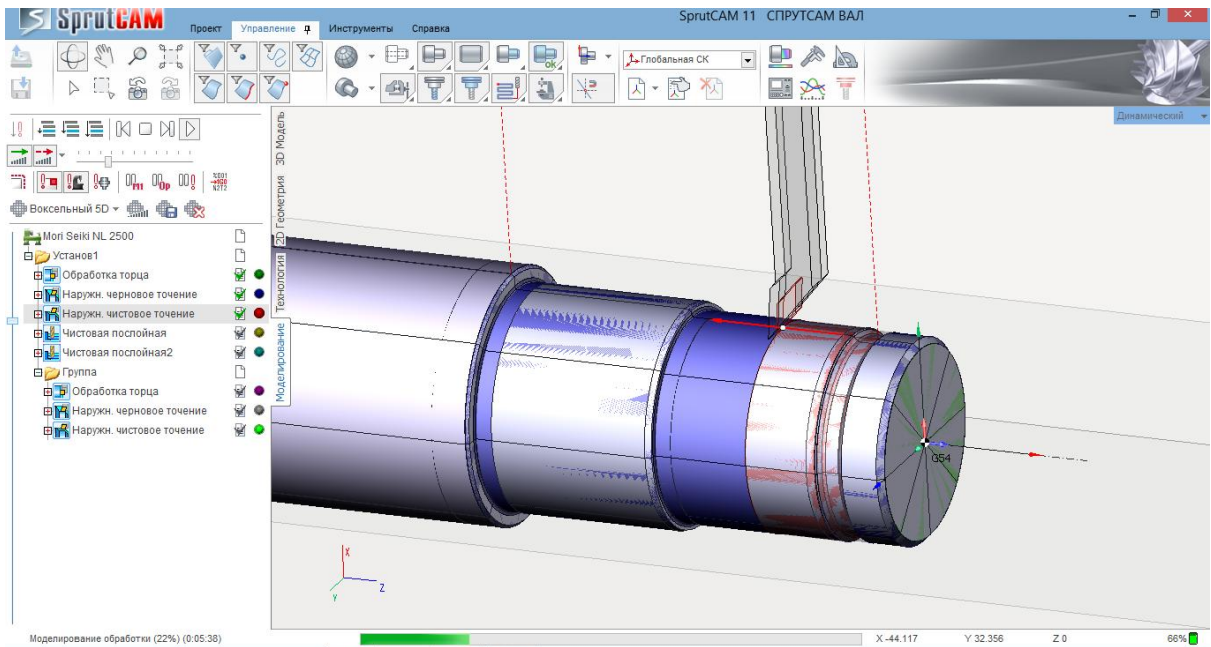Figure 11 - Overall view of the rough processing

Figure 12 - Finishing processing

The rest of the operations for full shaft processing are created in the same way. The "Postprocessor" section generates the control program. (Fig. 14). The 3D view of processing each operation is given in the Application.
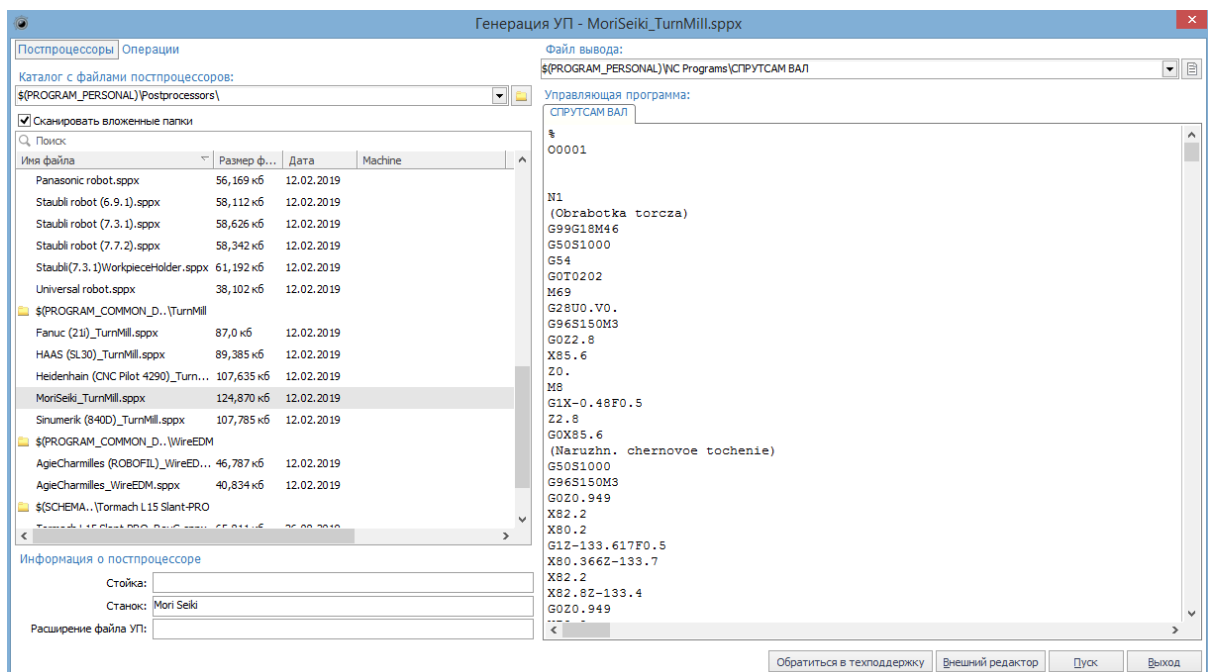

Figure 13 - Generation of control program

CONCLUSION

In the result of this diploma work, the technological process of machining the part was presented. During the work, it was revealed that the time spent on designing and modeling processes was reduced by using modern CAD/CAM systems. The use of systems allows to fully automate the process of designing the technical process, calculating the cutting mode and rationing the technological time spent on processing. The mechanical processing of the part is modeled and controlled, which eliminates the possibility of errors and deviations. Also the CNC control program was generated.

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Supplement A.

table A.1

Cutting modes	Cutting depth t mm	Feed S mm / Rev	Cutting speed V m / min	Spindle speed n min-1	Cutting power Ncut kW
trimming the end face	1,3	0.35	158,3	630	1,37
Rough turning Ø65k6, *l*=55 mm	3,45	0,7	130	630	6,84
Finishing turning Ø65k6, *l*=55 mm	0.32	0,6	204,7	1000	0,91
Rough turning Ø65k6, *l*=46 mm	3,45	0,7	130	630	6,84
Finishing turning Ø65k6, *l*=46 mm	0.32	0,6	204,7	1000	0,91
Rough turning Ø70u7	3,45	0.7	152,4	630	6,84
Finishing turning Ø70u7	0,32	0,6	222,44	1000	0,91
Rough turning Ø60f7	3,45	0,7	132,6	630	6,84
Finishing turning Ø60f7	0,32	0,6	191,04	1000	0,91
Turning Ø80 up to Ø77.74	1,13	0,8	152,4	630	4,07
Ø77.74 - 72.04	2,5	0,8	142,5	630	6,5
Ø72.04-Ø64	4,37	0,5	80,4	400	4,5
Keyway B=16 mm	16	0,05	20,09	400	0,82

Turning Ø80 up to Ø72.04	3,98	0,5	90,5	400	3,07
Ø72.04 - 67.04	2,5	0,6	142,5	500	2,96
Ø67.04 - Ø48	9,52	0,5	139,37	630	5

table A.2

Grinding (once)	t, mm	n_3, min^{-1}	S_0, mm/rev	$V S_{пр}$, m/min	$V_к$, m/min	$N_{рез}$, kW
Ø65k6, l=55mm	0,1	172	18,9	3	35	5,5
Ø65k6, l=46mm	0,1	172	18,9	3	35	5,5
Ø70u7	0,1	172	18,9	3	35	5,5
Ø60f7	0,1	172	18,9	3	35	5,5

Supplement B.

Figure B-1. Detail drawing
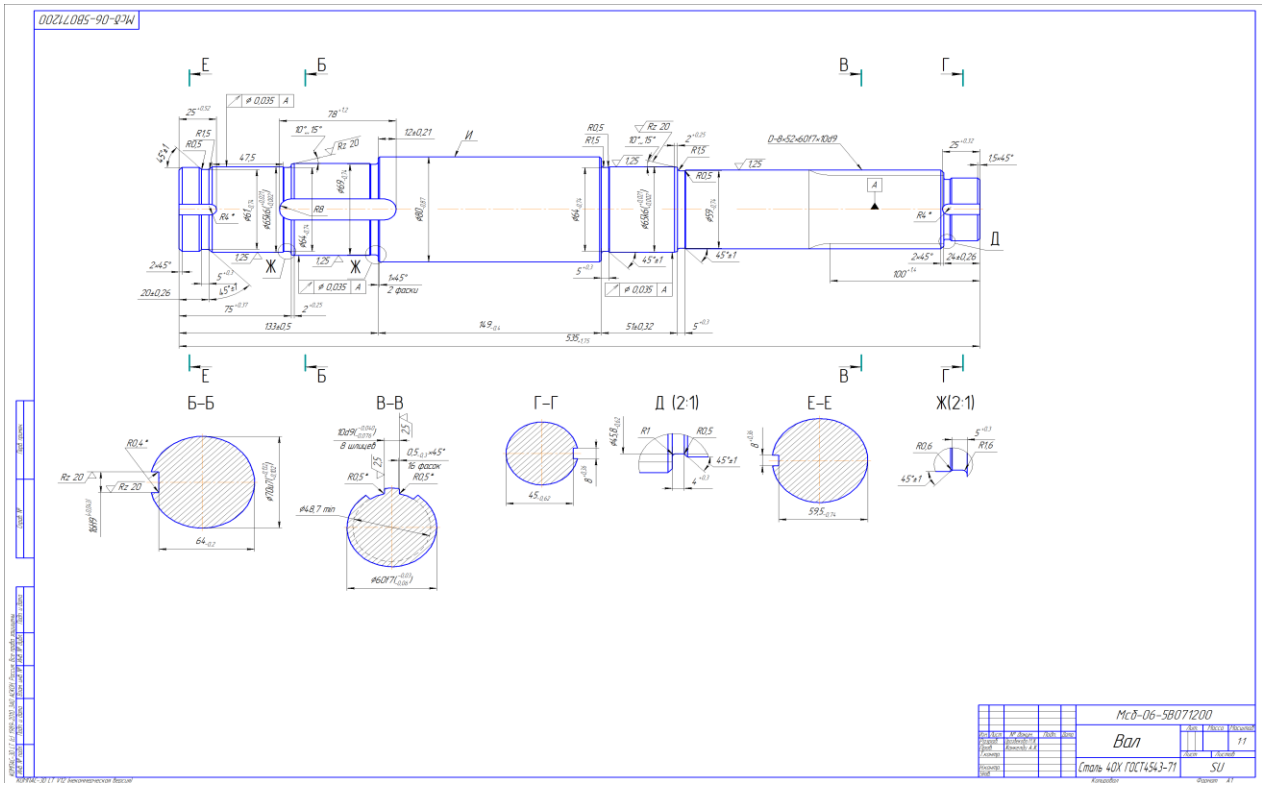
Figure B-2. 3-D model of detail
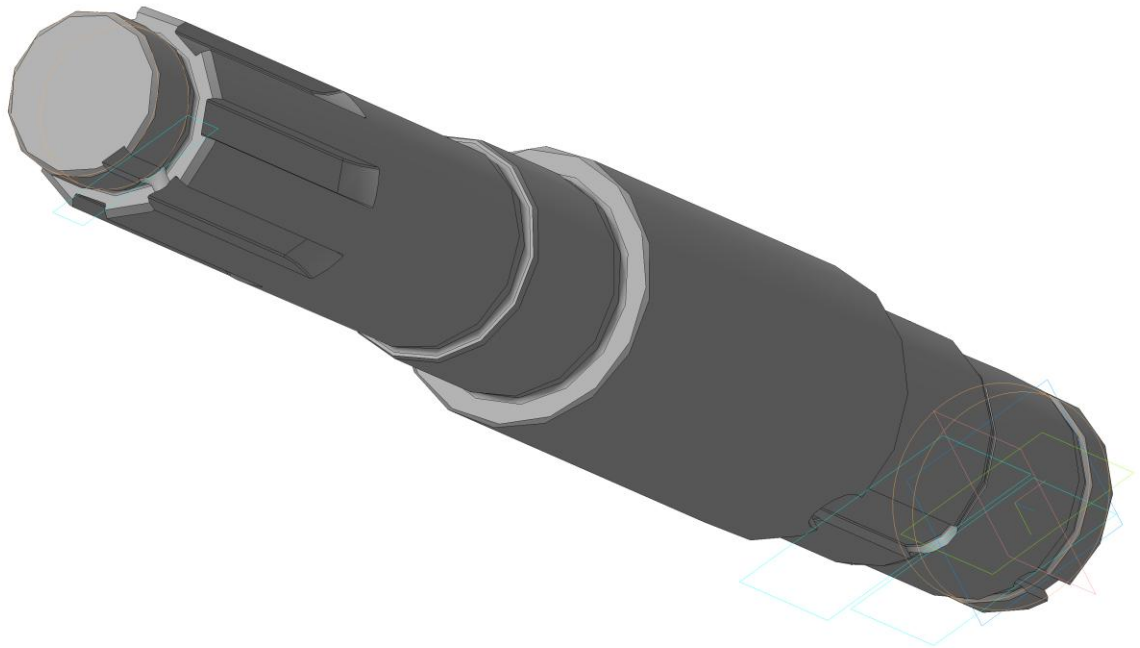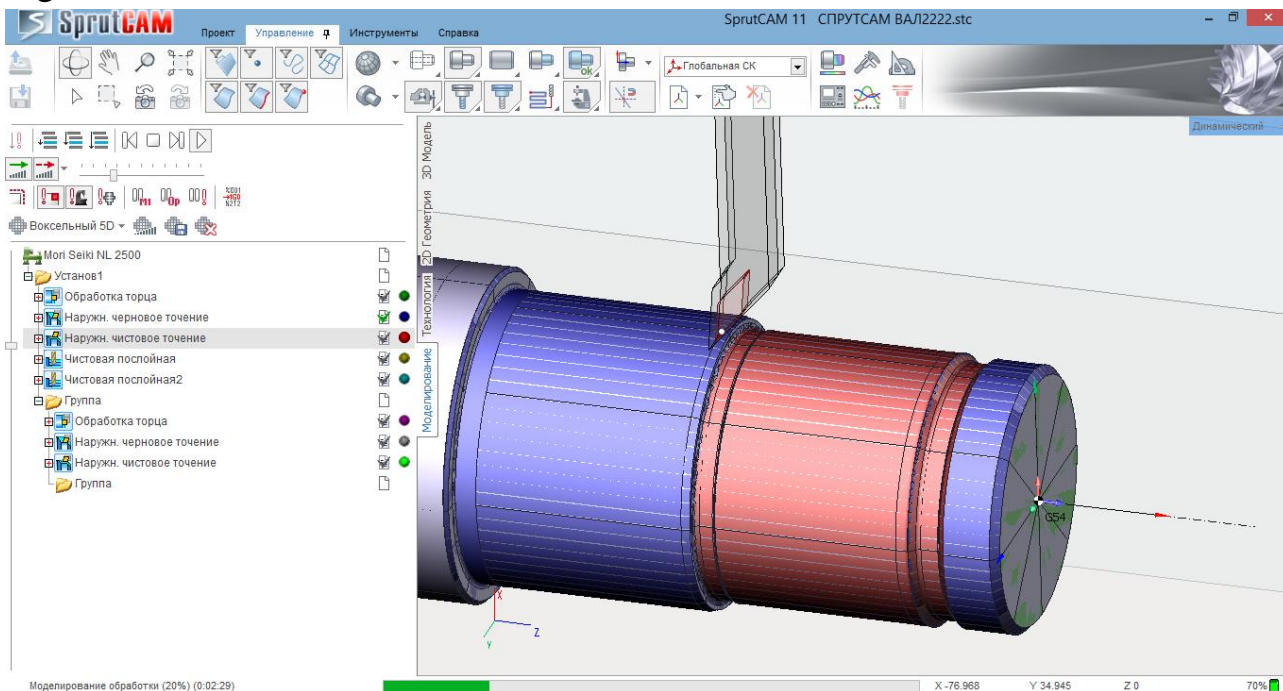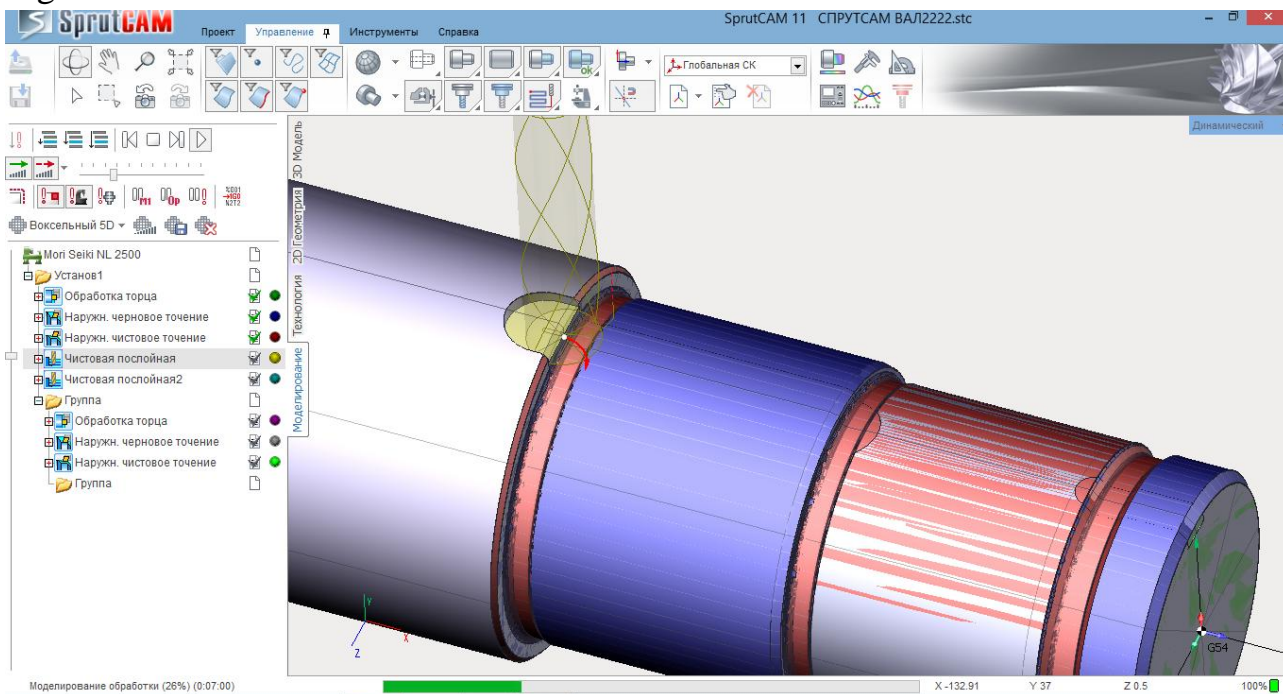
Supplement C.
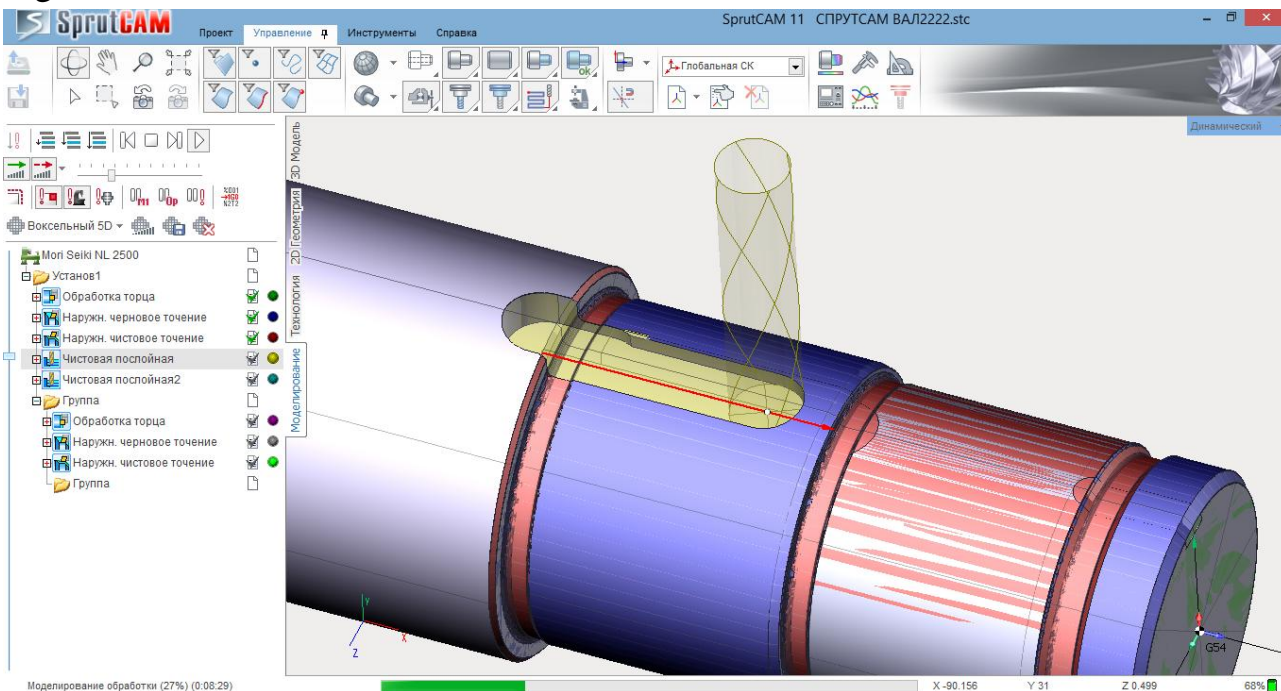
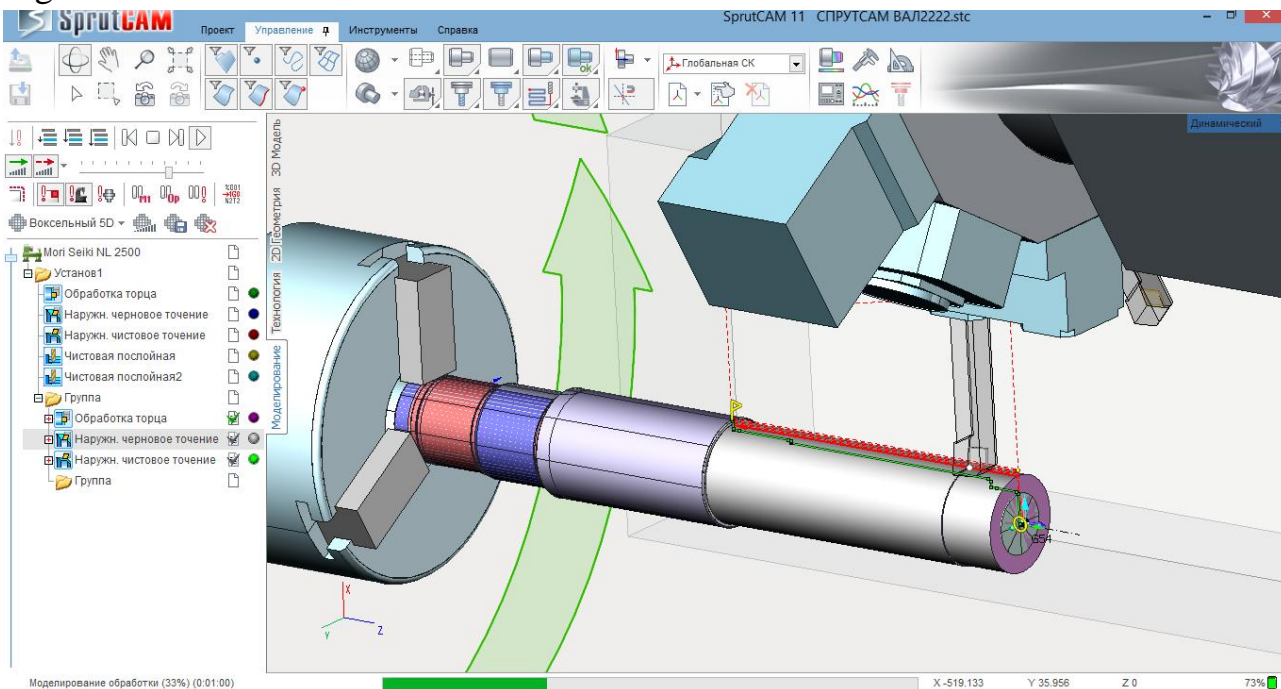*Figure C-1.*
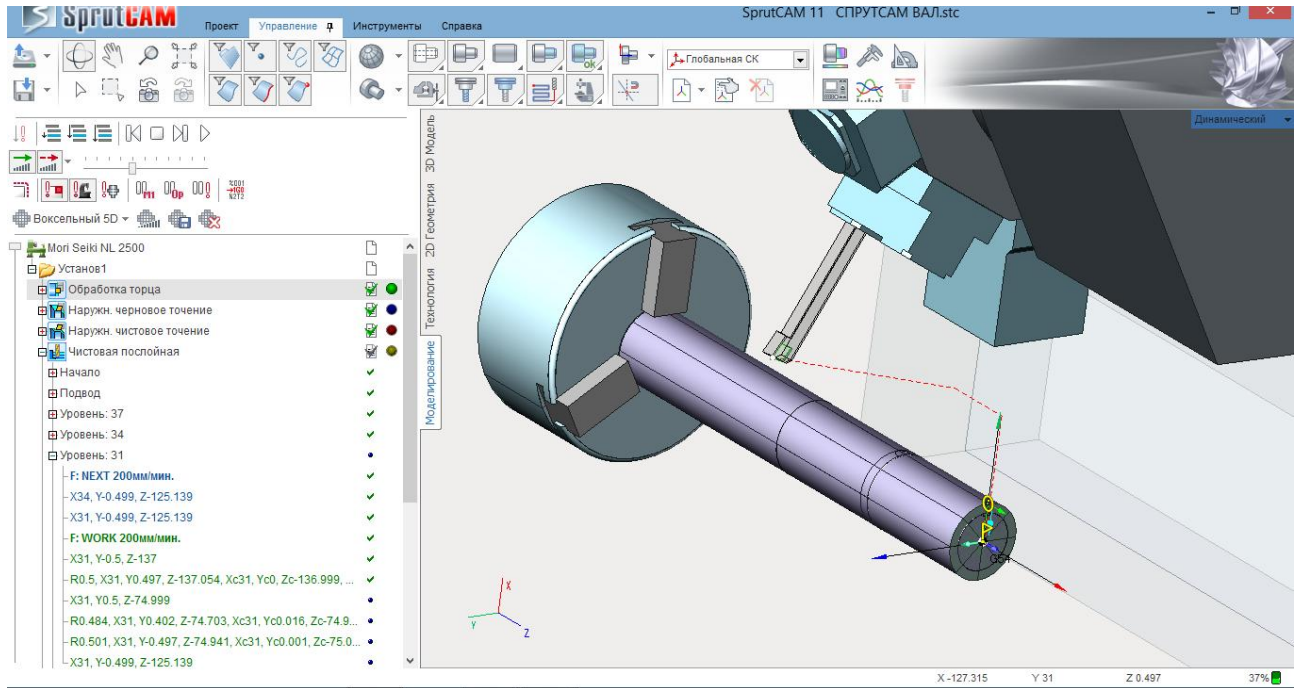
Figure C-2.
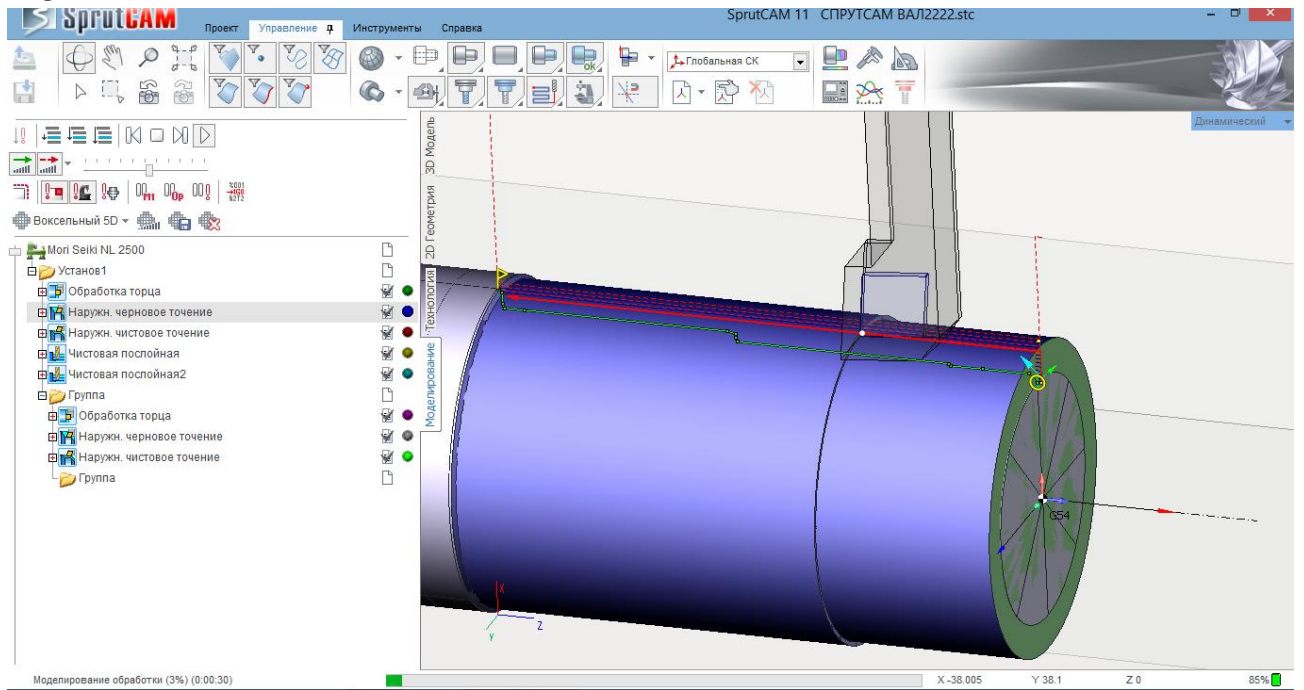
Figure C-3.

Figure C-4.

Figure C-5.

Figure C-6.

Figure C-7.