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"Features-based approach to CAD/CAM/CNC/CAC Integration" - Dr A. Sharmazanashvili, L.Megrelishvili

Dear Chair, Ladies and Gentleman, dear colleagues!

I am Dr Alexander Sharmazanashvili from Georgian Technical University. The aim of my report is to represent those investigations which are carrying out in Georgian Technical University at the ParametricCAD CAD/CAM division.

My report is 20min duration and finally, if chair kindly agree, I would like to represent Demo of our latest Software.

We are working in field of CAD/CAM/CNC integration and develop the original methodologies with corresponding Software tool kit.

I prefer to continue reading my report and I beg you pardon in this case.

The main problem recently exists in manufacturing industry is the provision of workability and reliability of technological processes of machining and corresponding Numerical Control (NC) programs for CNC machines. The importance of this problem was caused by the requirements of increase of operationability and minimise operator involvement, which are the main trends in state-of the-art manufacturing system development.

Usually, NC programs often contains errors (fig.1), which are corrected before the machining. It make necessity to do time consuming (fig.1) and uneconomical prove out procedures in the workshop. There is lot of investigations which gives quantitative analyse in this case. We have our own results of observation of manufacturing processes in some Russian military organisations. All of these sources confirm conclusions mentioned above.

Unfortunately, the simulation modelling CA tools could not remove problem, while the range of error detection is still limited.

More detailed analyse of problem showed that the majority of decisions which are made on the stage of the part and technological process designing (PTPD) are usually formed via determinate models, while the manufacturing processes of machining has stochastic character (fig.1). Stochastizm of machining process is expressed through the substantial dependence of some decisions on the non-stable values of workpiece and cutting tools geometrical (fig.1), physical and chemical quality parameters (fig.1); kinematic and rigidity parameters of machines, etc.

Thus, from one point we have manufacturing processes which are substantially depended on the disturbances, and from another point we have CA tools with determinate models of decision making.

Therefore, on the different levels of PTPD, formation of inadequate decisions is take place and while all of inaccuracies are summarised in NC programs, it demands necessity of NC programs correction according to actual manufacturing conditions.

Nowadays it is possible to solve this task by:

1. Stabilising the parameters of machine tools, workpiece and tools (allowance, physical and chemical quality, etc.). However, its sensitivity increases machining cost.

2. Application of adaptive control systems. Nowadays this systems are used in very specific cases. Enlarging of range is requiring controllers with high computing power to process feedback in real time. This is still an important consideration.
3. Implementation of statistical models of optimisation, which are beneficial only for that cases, where disturbances have "long time" action.

In this case we suggest to move some synthesis tasks (fig.2), which are substantially depended on the disturbances, and corresponding decision making models from the PTPD stage to the machine control stage. It gives opportunity to work out on PTPD error-free macro descriptions of NC programs and realise full synthesis on the machine control level in workshop via CNC, take into account information from CAC system.

Our research showed that disturbances have the most substantial influence on the machining conditions and geometric parameters of tool path. Machining conditions includes three parameters: V - machining speed, S - feedrate and t - depth of machining. Geometric parameters of tool path we can represent as G vector, which includes the sequence of support points and their coordinates in the machine axis. Quantitative analysis showed that in some cases fluctuation of workpiece hardness on 30% have changed value of feedrate up to 80% (fig.3), and value of machining speed up to 25% (fig.3); fluctuation of workpiece geometrical parameters on 30% have changed feedrate up to 60% (fig.3), and machining speed - up to 30% (fig.3); calculation of geometrical parameters of tool path accordingly the workpiece actual geometry enlarge range of compensation of fluctuation (fig.4) and receive the best results of rough pass optimisation (fig.4).

Therefore it is necessary to realise on machine control level machining conditions and tool path geometry calculation procedures. However realisation of full models is not preferable (fig.5), because it requires the special hardware foe CNC. We can separate relatively simple models, called Worker Models (WM) from the full model (fig.5). In this case definition of WM will be carried out on the PTPD (fig.5) and calculation of (V,S,T,G) (fig.5) will take place in CNC via WM (fig.5).

Conjunction machining condition WM's with WM's of tool path geometry creation, gives original features. We call it Constructive-Technological Features (CTF). Features-based approach in designing and modelling tasks is state-of-the-art. The results of a literature survey describe the meanings of features within different areas. In some cases features defined as geometrical elements for part designing, suggested by Bandyopadhyay et al. (1986), by Bazrov B.M. (1989), by Kapustin N.M. (1989); in other case as element for manufacturing process planing, suggested by Ssemakula et al. (1990); in different case as element for manufacturing process planing, suggested by Tsvetkov V.D. (1980), by Shah et al. (1988), in other case as integration element between CAD-CAPP-CAM systems, suggested by Gornev V.F. (1989), by ElMaraghy H.A. (1990), by Lenau T. et al. (1993), etc. Yesterday we have listened to new approach in features-based design presented by Prof. R.Gadh, and I highly respect him in this presentation.

By the meaning feature we express the basic integration element between CAD-CAM-CNC-CAC system, which should become a combined description of the WM's of machining condition calculation, WM's of tool path geometry creation, NC data formation and CAC procedures.

Generally, calculation of machining conditions is based on the following concept: values of V,S,t have to provide all geometrical and quality (accuracy and asperity) requirements of surfaces and support quality machining processes, as well as.

During V,S,t definition it is necessary to take into account wear of cutting instrument. In spite of much work, the existing understanding of physical nature of wear, is still limited and it is impossible to formulate exact equation. Therefore, the mathematical models of cutting tool, are built on the basis of empirical equations. More preferable in this case is Taylor's empirical equation (fig.5) which is supported by a large number of experimental data and manufacturing experience.

Usually, cutting process is conjugated with dynamical functioning of technological system - Machine-Appliance-Instrument-Part. Therefore, values of V,S,t could not exceed limitations expressing the possibilities of machining tool elements behaviour. This limitations are represented by boundary conditions and generally will be written in the form of following equation (fig.5).

Nowadays, there is much work where theoretical and empirical equations and classification of boundary conditions are given. The most completely approach is described by Valikov V. (1989), who suggests to group majority of boundary conditions according to the character of restriction (fig.6) and by that, to which element of the technological system this restriction belongs (fig.6).

Our research showed, that the majority of boundary conditions which are separated according to given classification, restricts values [V], [S] and cutting force [P]. Cutting force will be described by the following empirical equation (fig.6). On the base of this equation we can define other force parameters: cutting power (fig.6) and cutting moment (fig.6).

Geometrical interpretation of given restrictions is described on figure (fig.6). Surfaces, which are concerning to various restrictions have different orientation (fig.6). It means that for each fixed value of t (fig.6), the field of admitting values (V,S) (fig.6) will be changed - some restrictions become to be active, while others remove as inactive. The aim function which is reflecting to process productivity and cost (fig.6), for Taylor's empirical equation have not unconditional optimum and conditional extremum is always lie on the boundary condition (fig.6). Determination of this extreme is possible by simultaneous solving of equations of two curves, crossing each other in that point (fig.6). Such equations pair envisage the worker model of (V,S) calculation.

In common case, all equations belong to WM's will be joined to the system with two following group (fig.6).

Gornev V.F. (1980) suggests to joint in the first group [H] (fig.6), equations which are relatively substantially depended on feedrate (S), and in the second group [F] (fig.6), equations which are rather depended on cutting speed (V). Results of our analysis of existing boundary conditions have showed that to the [H] group we can concern:

restrictions by force (fig.6), restrictions by feedrate (fig.6). To the [F] group we can concern: restrictions by cutting speed (fig.6) and restrictions by optimal value of tool life (fig.6).

Thus. we have composed nine WM's which describe the most common cases of machining (fig.6).

Generally tool path is calculated for given machining stock (fig.7), cutting tool geometry and tool movement scheme (fig.7). While in such cases stock will remove with different tools and scheme, for each typical stock must be existed various alternatives of typical solutions. Such solutions have hierarchical structure (fig.7).

It means that solutions at any higher level involves several new solutions at lower level. For each WM the concrete combination on the hierarchical diagram have been existed. For example A-B-C branch describe the separate WM. However, often stock will be removed by typical sequences of tool and scheme. Therefore, in addition we can separate on hierarchical diagram horizontal levels too (fig.7), which are corresponded to the typical sequences of tool-scheme combination.

Thus, each vertical and horizontal branches (fig.7) describe particular WM's of tool path calculation.

Therefore, CTF formalism unify four kinds of description:
Constructive (fig.8) - include formal representation, in parametric form, stock geometry and intended to construct the full stock;
Technological (fig.8) - unify for each stock WM's of calculation of tool path and machining conditions;
Control (fig.8) - contain typical procedures for CAC processes realisation;
NC macros (fig.8) - describes calls of corresponding CNC subroutines.
Example of CTF is given below (fig.8).

CTF formalism summarise typical decisions which are usually made on the different levels of PTPD. Several CA tools are involved in this process of decision making. Therefore with the view of the functioning, CTF join the decision making models of those systems and become common knowledge base intended for system integration, in common designing system.

System integration approach on the base of CTF is described on figure (fig.8). Information network in this case contain 3 vertical levels (fig.8) with corresponding horizontal networks (fig.8).

1-st level - Part analysis and formation of CTF library (fig.8). Horizontal networks are supported by CTF library (fig.8) and provide information flows about:

- part surfaces (fig.8)
- typical processes of machining (fig.8)
- NC macro's in ISO format and CNC subroutines (fig.8)
- procedures of entry control (fig.8).

2-nd level - Stock design and technological operation structure synthesis (fig.8). Horizontal networks provide execution of stock designing (fig.8), synthesis of structure of the technological operation (fig.8) and NC macro program preparation (fig.8). Networks are supported by technological frame (fig.8).

3-d level - Technological operation parametric synthesis (fig.8). Horizontal networks provide execution of CAC (fig.8) and procedures of calculation of tool path and parameters of machining conditions (fig.8). Networks are supported by NC macro program (fig.8).

An Object-oriented technological engine named Turbo T (fig.9), realised first and second stages of synthesis is currently being developed at Georgian Technical University. Synthesis procedures is made within three separate modules (fig.9):

1. Object system developer (fig.9) - which provides preparation of CTF library. Three classes of object have been worked out: Geometrical, includes six objects of surface

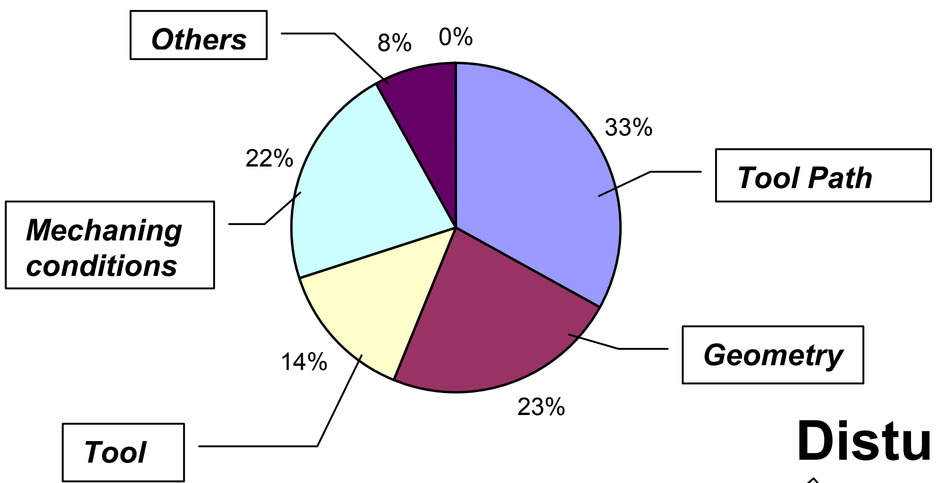
processing; technological - five objects of machining conditions synthesis and tool movement objects with its nine objects for calculation of tool path support points. At this moment, the system is limited to turned parts, but the approach can be used to the other mechanical processes, as well.

2. CAM engine (fig.9) - realise following basic functions

- Stock designing - process DXF part surfaces files and currying out feature recognition procedures for stock identification;
- Debugging of programs with fixation errors and step-by-step interpretation mode realisation;
- Preliminary evaluation of cost effectiveness of designed technological decisions, taking into account wear of cutting tools and current manufacturing conditions;
- 2D simulation of tool path with representation of tool and detailed contours images;
- 3D simulation animation, with realistic representation of the machining workstation and displaying the material removal process;
- NC program preparation and setting up on any CNC machines.

3. X-system (fig.9) - represent user oriented program modules which are developed according to separate WM's from the given CTF library.

Error Rate



- ***Expensive procedures of NC programs prove-out***
- ***Long standstill of machine tools***

Disturbanses

Fluctuation of Stock

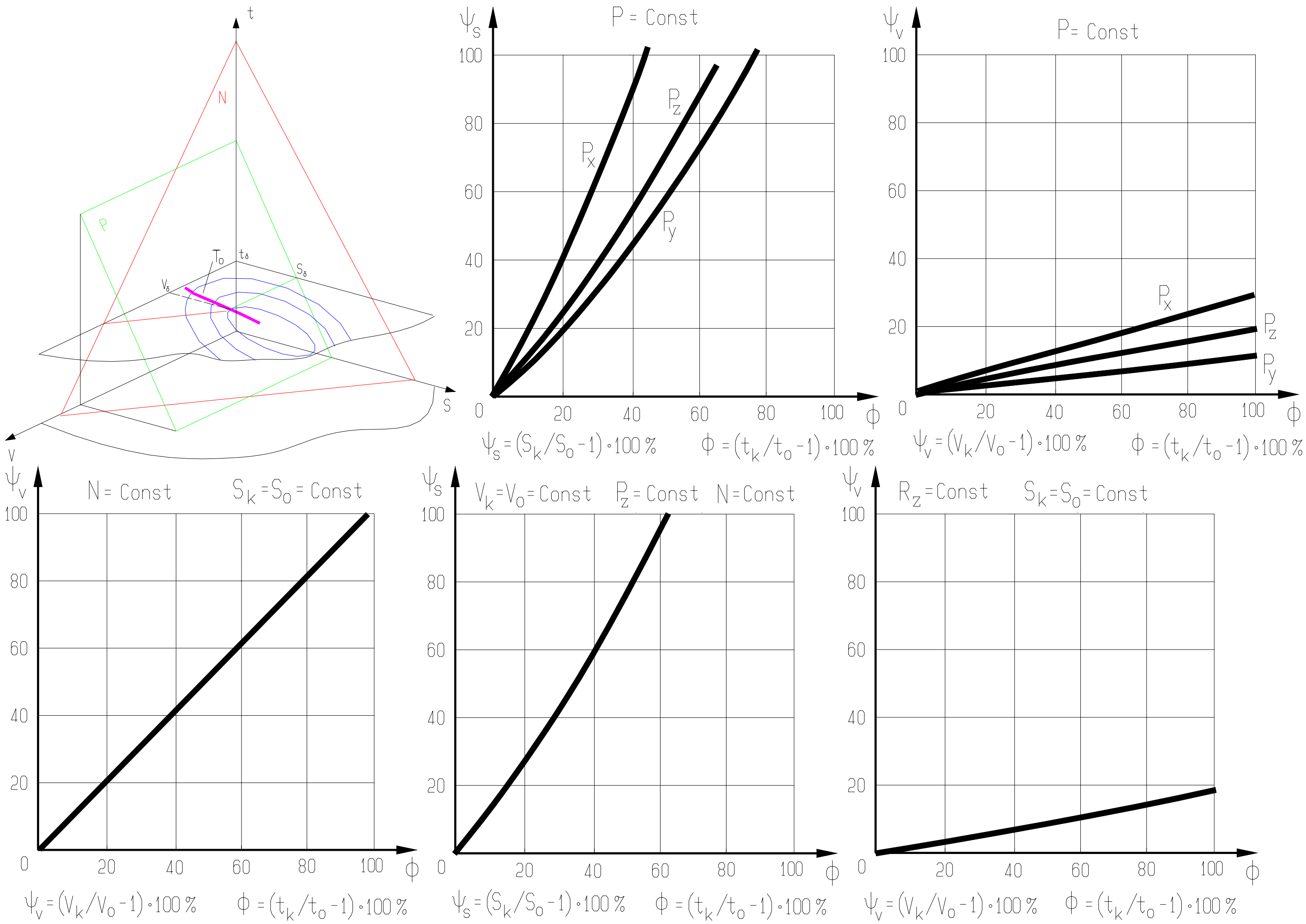
$$2Z_1=2(Rz+h)_{i-1}+2(\Delta_{\Sigma})_{i-1}+2\sigma_1+Td_{i-1}+Tdi$$

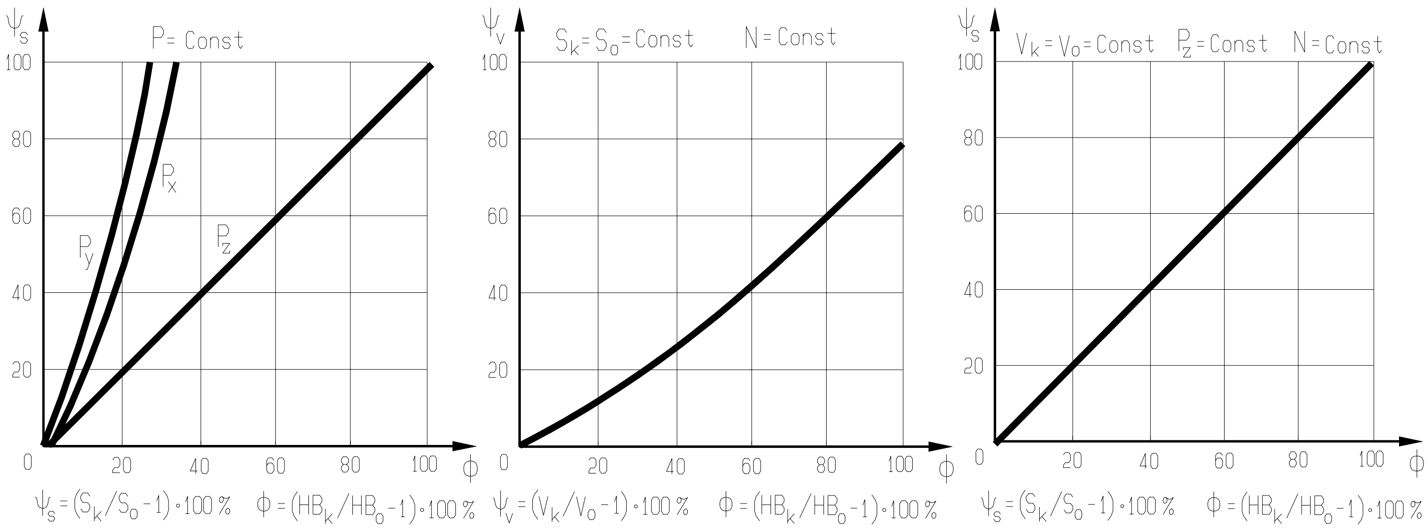
Diameter=100*mm* l=200*mm* Δ_{Σ}=1 Δ_K ** - for (R_Z+h)

Casting	0.8 **	-	0.6	5.5	4.15	-	10	-	6.0	13.6
Cogging	3.5 **	-	1.2	14	11.7	-	6	-	16	15.2
Pressing	0.4	0.4	0.8	4.5	3.85	-	1.5	-	5.8	5.6
Rolled Stock	1.2	1.2	0.8	1.8	4.1	-	1	-	-	3.9

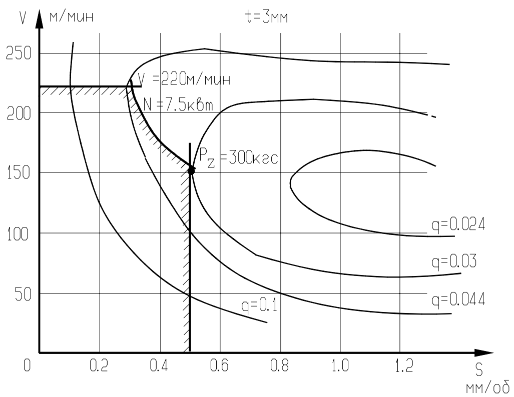
Fluctuation of Hardness

	Conditions	Physical characteristics of rigidity					
		Medium		Toleramce		Percentage	
		CT45	AL45	CT45	AL45	CT45	AL45
1	Warming-up 810-840 ^{0}C	154.1	147.2	12.2	12.5	2.9%	3.8%
2	Warming-up 860-880 ^{0}C, Cooling 20min	169.5	158.5	6.2	9.5	1.9%	3.4%
3	Warming-up 840-860 ^{0}C, Cooling water 680 ^{0}C	190.6	182.4	25.8	27.3	8.1%	9.3%
4	Warming-up 840-860 ^{0}C, Cooling water 630 ^{0}C	216.3	218.1	41.3	51.1	9.6%	10.8%
5	Warming-up 840-860 ^{0}C, Cooling water 600 ^{0}C	233.5	-	53.5	-	20.0%	-
6	Warming-up 840-860 ^{0}C, Cooling water 600 ^{0}C	265.7	253.8	82.0	116.5	22.8%	45.2%
7	Warming-up 840-860 ^{0}C, Cooling water 440 ^{0}C	329.1	248.4	148.3	121.0	43.0%	43.4%

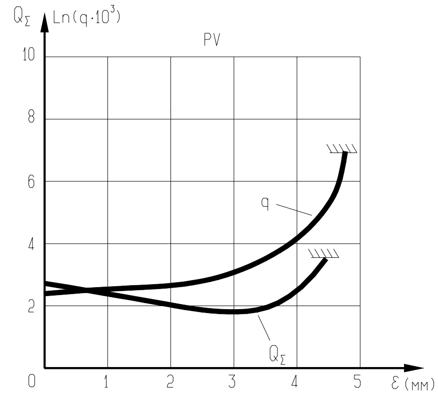

t
N
P
T_o
t_o
S_o
V_o
S
V
ψ_s
P = Const
P_x
P_z
P_y
$\psi_s = (S_k/S_o - 1) \cdot 100\,\%$
$\phi = (t_k/t_o - 1) \cdot 100\,\%$
ψ_v
P= Const
$\psi_v = (V_k/V_o - 1) \cdot 100\,\%$
$\phi = (t_k/t_o - 1) \cdot 100\,\%$
N= Const
$S_k = S_o$ = Const
$\psi_v = (V_k/V_o - 1) \cdot 100\,\%$
$\phi = (t_k/t_o - 1) \cdot 100\,\%$
$V_k = V_o$ = Const
P_z = Const
N=Const
$\psi_s = (S_k/S_o - 1) \cdot 100\,\%$
$\phi = (t_k/t_o - 1) \cdot 100\,\%$
R_z=Const
$S_k = S_o$= Const
$\psi_v = (V_k/V_o - 1) \cdot 100\,\%$
$\phi = (t_k/t_o - 1) \cdot 100\,\%$
0
20
40
60
80
100
ϕ



P= Const
Py
Px
Pz
ψs = (Sk/So - 1)∙100 %
ϕ = (HBk/HBo - 1)∙100 %
Sk = So = Const
N = Const
ψv = (Vk/Vo - 1)∙100 %
ϕ = (HBk/HBo - 1)∙100 %
Vk = Vo = Const
Pz = Const
N = Const
ψs = (Sk/So - 1)∙100 %
ϕ = (HBk/HBo - 1)∙100 %



а)



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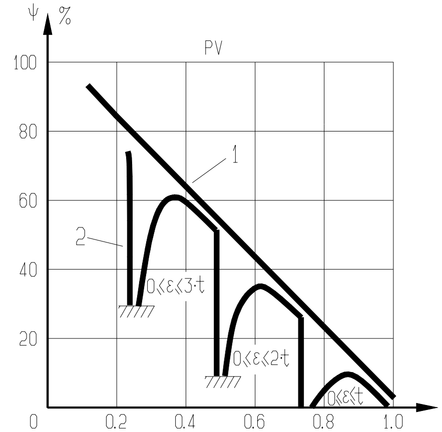

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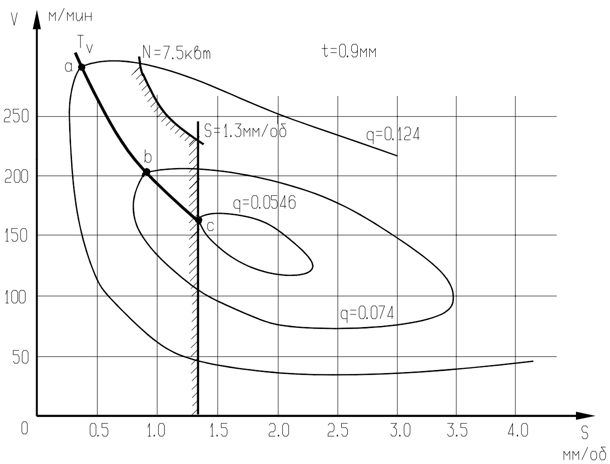

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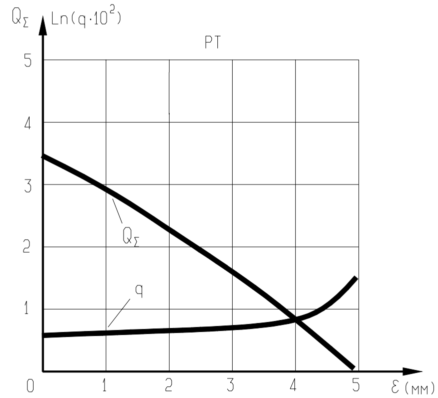
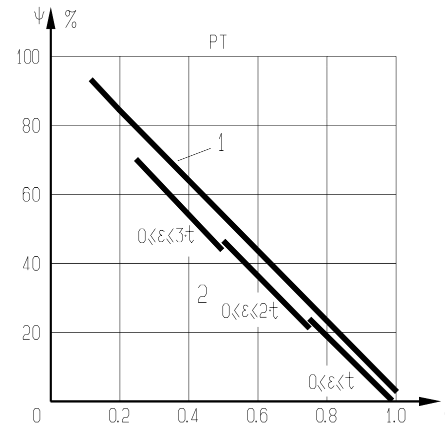


б)

Заготовка ЭИ437Б НВ260 ø100мм
Инструмент ВК8, $\tau_{см}$=2мин. γ_n=4.5 E_C=6.7коп,
P_Z=300кгс V=150м/мин t=5мм 0≤ε≤t



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