FEATURE-BASED APPROACH IN CAD/CAM/CNC INTEGRATION

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ABSTRACT

This paper reports the Manufacturing System Integration methodology based on the Constructive-Technological Features, which permits to increase workability and reliability of Numerical Control programs and reduce volume of prove-out procedures on the machine tools. Conjunction of stock form features, and machining and quality control processes features are described. In this case methodical aspects of synthesis procedures realization on the different levels of decision making are discussed. An object-oriented technological engine called Turbo T, which currently are being developed at the Georgian Technical University, are presented.

KEYWORDS

NC program, reliability, worker models, features

1. INTRODUCTION

Providing information links between the several Computer Aided tools, as CAD, CAPP, CAM, CNC, CAC, etc., and development entire information environment is the mainstream in manufacturing systems integration (MSI). Whereas the investigation in conceptual aspects of integration are still limited. In each case MSI must solve concrete manufacturing problem and its demand to develop particular methodological approach of integration primarily.

Provision of workability and reliability of technological processes of machining and corresponding numerical control (NC) programs for CNC machines, is one of the oldest problem in the domain on manufacturing. Traditionally, NC programs often contain errors, which are corrected before the machines are used to cut metal. Therefore it brings necessity to make prove out procedures in the workshop directly. This procedures in most cases are time consuming and reduced economical effectiveness of machining. According to data of Dun & Bread research firm, US manufacturers spend about $1.8 billion per year on NC programs testing, using hundred thousand dollar machines, people and machinery to find errors; the results of observation of the 800 processes of machines settings in 4 different industries of Germany showed that the NC programs prove out procedures demands the most long standstill of machines.

At present, to solve this task, many Firms use the several simulation modeling software. Chrysler, Boeing, McDonnell Douglas and Ingersoll Milling Machines Co. use NC verification approach for simulation tool path and material removal; Black & Decker Co. use *VERICUT* to display the material removal processes of NC tool path and simulate the wear of the machine tool; realistic representation of the machining workstation and 3D simulation of CLDATA instructions, etc. However this software inspected NC programs after when errors have already occurred. Furthermore, the range of error detection is still limited. So many of errors are slipped on and necessity in prove out procedures is not removed.

Another traditionally existing task in manufacturing, is ensuring high quality of machining processes on CNC machines. Usually, technological parameters are premeditatedly diminished in order to remove the high risk of process violation (e.g. tool breakage and etc.) and to ensure the quality of part surface, e.g. reduce value of machining conditions 2-3 or more time; calculation of tool path geometry for workpiece maximal allowances, etc. However, it is not cost beneficial for CNC machine tools. Nowadays it is possible to solve this tasks by:

1. Stabilizing the parameters of machine tools, workpiece and tools (allowance, physical and chemical quality, etc.). However, its sensitivity increase 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 optimization, which are beneficial only for that cases where the disturbances have "long time" action.

2. THE MAIN CONCEPT

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. Stochastizm of machining process is expressed through the substantial dependence of some decisions, relate to technological process of machining (TPM) on non-stable values of workpiece and cutting tools geometrical, physical and chemical quality parameters; kinematic and rigidity parameters of machines, etc.

Thus, formation of inadequate decisions on the different levels of PTPD is take place, and while all of inaccuracies are summarized in NC programs, it demands necessity of NC programs adaptation on actual production conditions. Implementation of determinate models for realization of synthesis procedures is possible after determination of actual values of technological disturbances, which is possible on the machine control stage via computer aided control (CAC) systems by usage of both entry and real-time control methods.

In this case it is preferable to move some models and corresponding synthesis tasks, which are substantially depended on the disturbances, from the PTPD to the machine control stage, while it gives opportunity to work out on PTPD error-free macro descriptions of NC programs and realize full synthesis on the machine control level in workshop via CNC, take into account information from CAC system. Therefore the NC programs adaptation on the actual production conditions is considerably simplified. Thus, it is due requirement for creation of special approach for system integration.

Our research works 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%, and value of machining speed up to 25%.; fluctuation of workpiece geometrical parameters on 30% have changed feedrate up to 60%, and machining speed - up to 30%. Sharmazanashvili (1994) showed that calculation of geometrical parameters of tool path accordingly the workpiece actual geometry enlarge range of compensation of fluctuation and receive best results of rough pass optimization.

$$T = \frac{C_T}{V^{\mu} \cdot S^{\nu} \cdot t^{\rho}}$$

Therefore it is necessary to realize on machine control level machining conditions and tool path geometry calculation procedures. However realization of full models is not preferable [fig.1], because it requires the special hardware for CNC, and except of this it is not necessary. We can separate relatively simple models, called

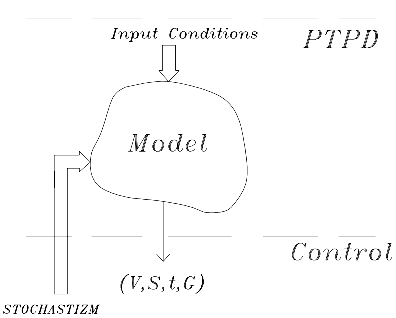


Figure 1. Decisions making model-1

worker models (*WM*) from the full model. In this case definition of *WM* will be carried out on PTPD and calculation of *(V,S,t,G)* will take place in CNC via *WM* [fig. 2].

3. CTF FORMALISM

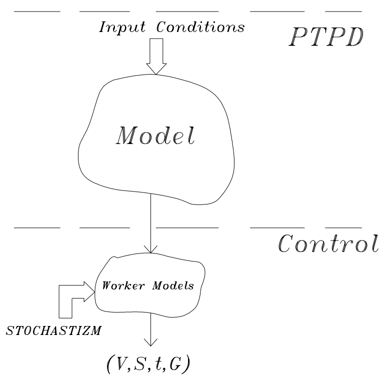


Figure 2. Decisions making model-2

Feature-based approach in designing and modeling tasks is state-of-the-art. The worldwide known companies as Parametric Technology Corp., with its Pro/Engineering, Dassault Systems - *CATIA/CADAM*, Computervision - *CADDS,* etc., use parametric designing technique. This enables to generate designs and manufacturing processes with unprecedented ease, faster and at a lower cost.

Generally, investigations in this case are going into two main directions - Features-based design and Feature recognition. The results of a literature survey describe the meanings of features within different areas. In some cases features defined as geometric elements for part designing (Bandyopadhyay et al., 1986; Bazrov B.M., 1989; Kapustin N.M., 1989), as elements for manufacturing process planing (Ssemakula et al., 1990) and technological design (Tsvetkov V.D., 1980; Shah et al., 1988), as integration elements between CAD-CAPP-CAM (Gornev V.F., 1989; ElMaraghy H.A.,1990; Lenau T. et al., 1993), etc.

By the meaning feature we express the basic integration element between CAD-CAM-CNC-CAC systems, 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.

3.1 WM's for Calculation of Machining conditions.

Machining conditions describe the working conditions of function elements of machine tools. For turning processes, machining conditions include: V - cutting speed, S - feedrate and t - depth of cut. Calculation of machining conditions is based on the following concept: values of the V,S,t have to provide all geometrical and quality (accuracy and asperity) requirements of surfaces and support quality of machining processes, as well as. Usually, process quality is described by two generalized parameters - productivity and cost.

In V,S,t definition it is necessary to take into account joint equations of machining, which describe the changing of process parameter in time. As it known, such parameter of process is 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 (1) which is supported by a large number of experimental data and manufacturing experience. (Tverskoi M.M. - 1982; Wiebach M.G. - 1988).

(1)

where *T* - tool life, period between tool adjustments by reason of wear; C_T, μ, ν, ρ - coefficient, which depends on workpiece and cutting tools properties.

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 behavior. This limitations are represented by boundary conditions and generally will be written in the form of following equation.

(2)

where M_i - parameter of boundary condition, C_m - coefficient Π_i - restricted value of boundary

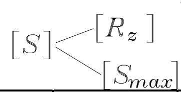
$$C_{m_i} \cdot V^{\alpha} \cdot S^{\beta} \cdot t^{\gamma} = M_i \lesseqgtr \left[\Pi_i\right] \quad i = 1,2,\ldots,n$$

condition parameter.

Nowadays, there is much work where theoretical and empirical equations and classification of b

oundary 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 and by that, to which element of the technological system this restriction belongs (Table 1). For example group B_{R-M} includes all

Character of restriction	Technological system element			
	Machin.	Applian.	Instrum.	Part
Geometrical,	B_{G-M}	B_{G-A}	B_{G-I}	B_{G-P}



Kinematic				
Force	B_{F-M}	B_{F-A}	B_{F-I}	B_{F-P}
Wear	B_{W-M}	B_{W-A}	B_{W-I}	B_{W-P}
Rigidity	B_{R-M}	B_{R-A}	B_{R-I}	B_{R-P}

Table 1. Groups of restriction

the boundary conditions related to limitations by rigidity and machine tools, like - rigidity of the feedrate mechanism in X-axis direction; rigidity of the feedrate mechanism in Z-axis direction; dynamical forces on the bearing of spindle; dynamical forces on the ball bearing and back center of lathe, etc.

Our research showed, that the majority of boundary conditions restricts values [V], [S] and cutting force [P]. According to the numerous investigations, cutting force insignificantly depends on the cutting speed and is often described by the following empirical equation

$$P_{\varpi} = C_P \cdot S^{\beta_{\varpi}} \cdot t^{\gamma_{\varpi}} \cdot HB^{n_{\varpi}} \quad (3)$$

where ϖ э *(X,Y,Z - axis), Cp* - coefficient, *HB* - workpiece hardness.

Geometrically, in 3 dimensional space (V,S,t), (3) equation is interpreted by surface which is parallel to V-axis and which limits cross-sectional area (Sxt). On the base of (3) equation we can define other force parameters:

- cutting power

$$N = \frac{1}{6120} \cdot V \cdot C_{P_Z} \cdot S^{\beta_Z} \cdot t^{\gamma_Z} \cdot HB^{n_Z} \quad (4)$$

In (VxSxt) space (4) equation is represented by surface, which is crossing with all (VxSxt) axis.

- Cutting moment

$$M = 0.5 \cdot 10^{-3} \cdot D \cdot C_{P_Z} \cdot S^{\beta_Z} \cdot t^{\gamma_Z} \cdot HB^{n} \quad (5)$$

where *D* - workpiece diameter.
In (VxSxt) space corresponding surface is parallel with V-axis.

Therefore in (VxSxt) coordinate system the space of machining conditions admitting values is formed (fig.3). Surfaces, which are concerning to

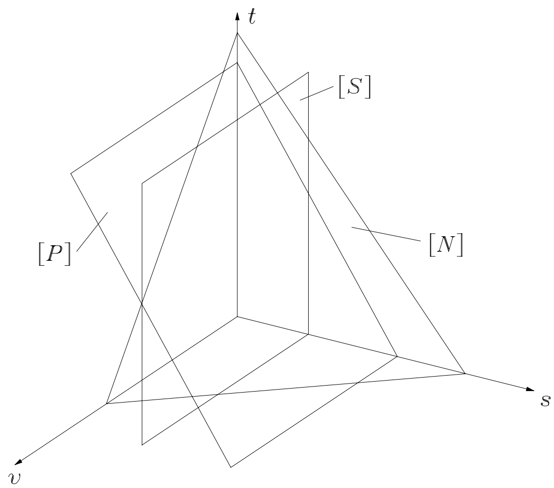


Figure 3. Geometrical interpretation of restrictions

various restrictions have different orientation. It means that for each fixed value of t, the field of admitting values (V,S) will be changed - some restrictions become to be active, while others remove as inactive. The aim function which is reflecting process productivity and cost mentioned above, for Taylor's empirical equation (1) have not unconditional optimum and conditional extremum is always lie on the boundary condition. Determination of this extreme is possible by simultaneous solving of equations of two curves, crossing each other in those point. Such equations pair envisage the worker model of optimization.

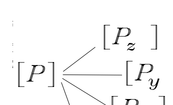
In common case, all equations belong to WM's will be joined to the system with two following group

$$\begin{cases} H = C_H \cdot V^{\alpha_H} \cdot S^{\beta_H} \cdot t^{\gamma_H} \\ \Phi = C_{\Phi} \cdot V^{\alpha_{\Phi}} \cdot S^{\beta_{\Phi}} \cdot t^{\gamma_{\Phi}} \end{cases} \quad (6)$$

C_H, C_{Φ} - coefficients.

Gornev V.F. (1980) suggest to joint in the first group [H], equations which are relatively substantially depended on feedrate (S), and in the second group [Φ], 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



- restrictions by [M]

feedrate

R_Z - asperity of surface.

To the [Φ] group we can concern:

- restrictions by cutting speed

$$[V] \begin{cases} [N] \\ [n_{max}] \end{cases}$$

n_{max} - maximal value of spindle rotational speed.

- restriction by $[T_v]$ - optimal value of tool life

$T_v=(\mu-1)\,\delta$. δ - coefficient; μ - parameter from the (1) equation.

Thus, we have composed *nine* WM's which describe the most common cases of machining - [PV], [SV], [ST], [PT], [SN], [PN], [MV], [MN], [MT].

3.2 WM's for Calculation of tool path geometry

Generally, tool path is calculated for given machining stock, cutting tool geometry and tool movement scheme.

Machining stock is formed on one side by part surface, and on another side by surface of workpiece. For example fig.4 describes the turning stock. Usually, full stock is divided on the simple stocks - fig.5. In each case, stock

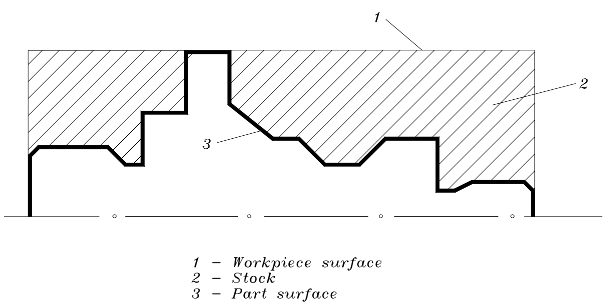


Figure 4. Full stock

formalization require description of surfaces in the parametric form. Full stock will be constructed by

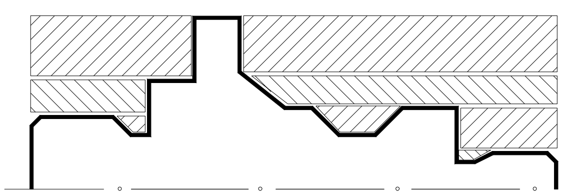


Figure 5. Separate stocks

definition of the values of surface geometric parameters. Sharmazanashvili A. (1991) offers *five* typical stocks which permits to construct the majority of the turning stocks.

Tool movement scheme describes the strategy of tool movement - e.g. longitudinal, diametrical or parallel to surface movement, etc. (fig. 6).
Thus, tool path geometry calculation WM contain algorithm which is made according the stock and

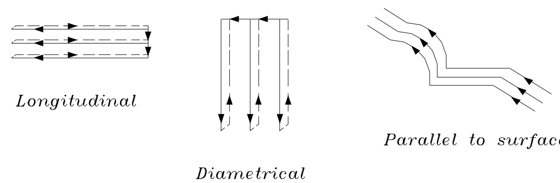
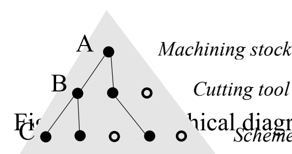


Figure 6. Tool movement schemes

typical combination of required cutting tools and tool movement scheme. 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).



Fi… hical diagram

It means that a solution at any higher level involves several new solutions at the 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

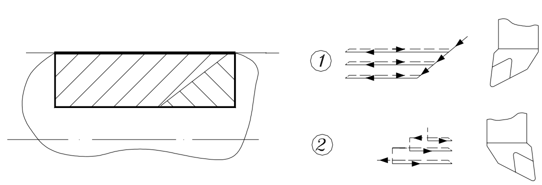


Figure 8.

typical sequences of tool and scheme. For example, main part of the stock described on fig.8, will be removed by left-hand tool, and the rest part by right-hand tool. Therefore, in addition we can separate on hierarchical diagram horizontal levels, too, which are corresponded to the typical sequences of tool-scheme combination (fig.9).

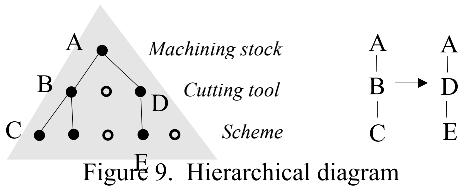


Figure 9. Hierarchical diagram

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

Therefore CTF formalism unify *four* kinds of descriptions:
constructive - include formal representation, in parametric form, stock geometry and intended to construct full stock;
technological - unify for each stock WM's of calculation tool path and machining conditions;
control - contain typical procedures for CAC processes realization;
NC macros - described calls of corresponding CNC subroutines.
Example of CTF is given below on fig. 10.

4. CTF-BASED INTEGRATION APPROACH

CTF formalism summarize typical decisions which are usually made on the different levels of PTPD. Several CA tools are involved in this process of decision making. Stock identification and selection of WM's are carrying out via computer aided technological process designing system; calculation of tool path geometry and machining conditions is made by CNC system; realization of control procedures is carried out by CAC system.

Therefore, with the view of the system functioning, CTF join the decision making models of those systems mentioned above and becomes common knowledge base intended for system integration in common designing system.

In this case there are separated three stages of synthesis:

1. Part analysis and formation of *CTF* library
2. Stock design and technological operation structure synthesis
3. Technological operation parametric synthesis.

First and second stages are take place on PTPD, while third stage is realized on machine control stage.

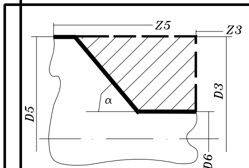
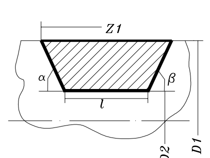
Construction	Tool Pass			NC Macros	CAC	
	Tool	Scheme	M.Condit.		Method	Parmt.
			[PV] [SN] [PT] [ST]	N... R01... R02... R03... R04... R05... R06... R07... R08... R09... R10... R11... L71	Entry: L93 Marpos Real-time: Promec	D3; HB P_z; P_x; N
			[PV] [SN] [PT] [ST]	N... R01... R02... R03... R04... R05... R06... R07... R08... R09... R10... R11... L72	Entry: L93 Marpos Real-time: Promec	D3; HB P_z; P_y; N
			[PV] [ST] [SV]	N... R01... R02... R03... R04... R05... R06... R07... R08... R09... R10... R11... R12... R13... L73	Entry: L93 Marpos Real-time: Promec	D3; HB P_z; P_y
	① ②		[PT] [ST]	N... R01... R02... R03... R04... R05... R06... R07... R08... R09... R10... R11... L81	Entry: Real-time: Promec	HB P_y
	① ② ③ ④		[PN] [MT] [SV]	N... R01... R02... R03... R04... R05... R06... R07... R08... R09... R10... R11... R12... L82	Entry: Real-time: Promec	HB P_z; P_y; M

Figure 10. Constructive-technological features. (Sinumeric 3T)

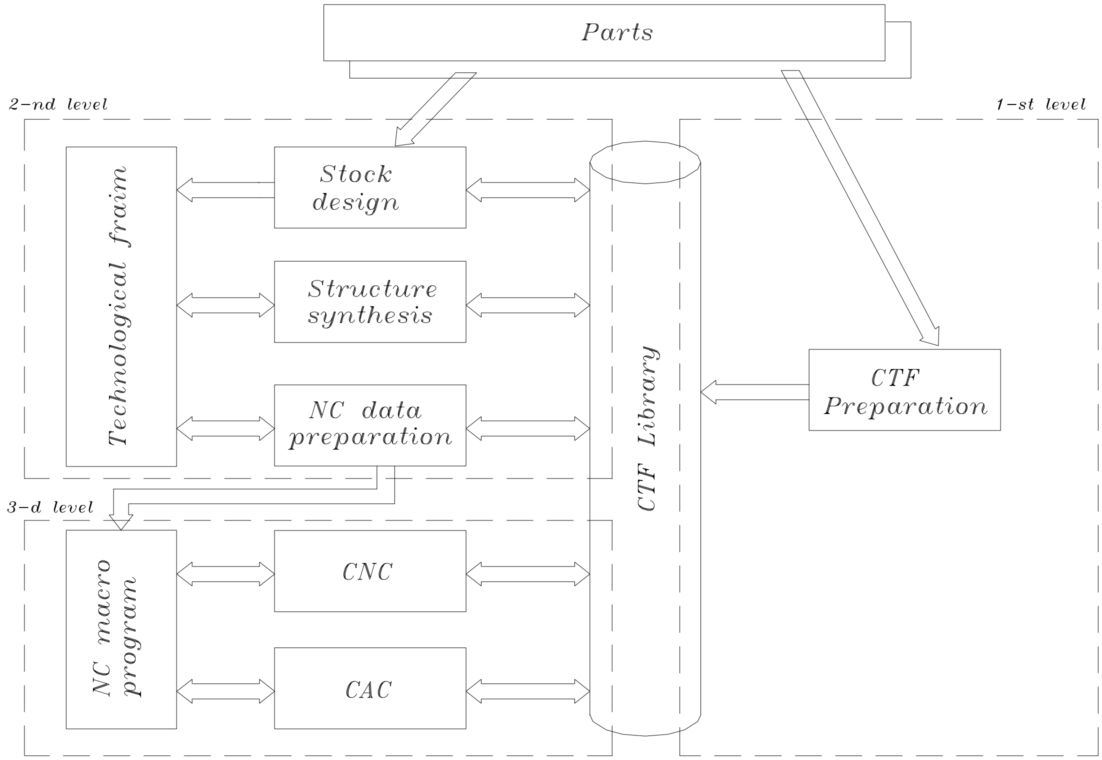


Figure 11. System integration via CTF

CAD-CAM-CNC-CAC information network in this case will contain the following vertical levels with corresponding horizontal networks described on fig. 11.

1 level - Part analysis and formation of *CTF* library. Horizontal networks are supported by *CTF* library and provide information flows about:

- parts surfaces
- typical processes of machining
- *NC macros's* in *ISO* format and *CNC* subroutines
- procedures of entry control.

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

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

For typical parts "Perehodnik", "Vtulka", "Flanec", "Nakonechnik", produced at some military enterprises of Russia the *CTF* library has been developed. The corresponding *CAD-CAM* software tool kit was also built. In Moscow "**TEMP**" organization it was approved for turning center *STR-25* with new generation *CNC* - *MC2106*. The following results for future benefit has been received: the volume of tool path prove out procedures cutdown on 70%; it gives cost benefit on 28%. Cutting condition prove out procedures cutdown on 73%; cost benefit - 72%.

5. TURBO T

An object-oriented technological engine named *Turbo T*, realized first and second stages of synthesis is currently being developed at Georgian Technical University. Synthesis procedures is made within three separate modules:

Object system developer - which provides preparation of CTF library. Three classes of objects have been worked out: *geometrical*, includes *six* objects of surfaces 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.

Stock designer - process DXF part surfaces files and currying out feature recognition procedures for stock identification.

Process designer - intended for technological process structure synthesis and corresponding NC macro programs formation. This module realize following basic functions:

- Debugging of programs with fixation errors and step-by-step interpretation mode realization.
- 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 detail contours images.
- 3D simulation animation, with realistic representation of the machining workstation and displaying the material removal process.
- Setting up on any CNC machines.

6. Conclusion

This paper described investigations concerning to workability and reliability of numerical control programs. It was formed CTF formalism, which permits to decrease influence of mechanical process stochastizm on NC programs. The main components of CTF are stock, cutting tool, WM's for calculation of machining conditions and tool path geometry, NC macros and control procedures. *Nine* WM's for calculation of machining conditions have been formed, which are representing the common cases of machining.

Three stages of synthesis according to CTF, where proposed.

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