

COMPUTER-AIDED CNC PROGRAMMING FOR THE MACHINING OF NON-TYPICAL PARTS

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Summary

In this paper the CNC programming techniques for the machining operation planning of parts about non-typical shape and requirements are introduced. Especially, if the Group Technology approach is used. A short review of programming methods for the group part programs was presented. Based on the examples from industry different approaches for solving this problem are presented. The tools of Computer Aided CNC programming was discussed as a indispensable element of the manufacturing processes planning.

Keywords: Machining, CAD/CAM, Group Technology, CNC machine tools.

Komputerowo wspomagane projektowanie programów CNC do obróbki nietypowych elementów maszyn

Streszczenie

W pracy omówiono wybrane rodzaje projektowania programów sterujących (CNC) do obróbki elementów maszyn o nietypowych kształtach i wymaganiach, w szczególności w warunkach stosowania technologii grupowej. Przedstawiono ogólny opis metod projektowania grupowych programów sterujących. W oparciu o przykłady pokazano różne sposoby rozwiązania tego problemu. Uwagę szczególną zwrócono na narzędzia do komputerowego wspomaganie projektowania programów sterujących jako niezbędnego elementu projektowania procesów wytwarzania.

Słowa kluczowe: obróbka skrawaniem, CAD/CAM, technologia grupowa, obrabiarki CNC.

1. Introduction

Many manufacturing firms, especially medium and small, has to solve problem of production development and search of new customers. In many cases this leads to the assortment enlarging of already manufactured products. Often this is joined with implementation of the new manufacturing processes. In conditions of market competition it demands high flexibility which is often got in way replacing of conventional manufacturing resources by the modern CNC tool machines [1]. This is essentials condition for more efficient development, higher quality and faster adoption to new requirements [2]. For maintenance of the low costs of manufacturing for production of small and medium batches very

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often the Group Technology is applied [3]. With help of grouping of the manufactured components into families more efficient the machines, devices, workers are used.

In the processes planning one from most important tasks is the CNC machine tool programming [4, 5]. Very often the CAD/CAM systems are used from reason their possibility of flexible programming. In the case of typical components such approach the positive results gives, though it demands an efficient co-operations between constructors and technologist.

Sometimes from different reasons it is impossible, especially when the Group Technology is applied. Usually the part programs for machining of single components are created, but the modern CNC controllers offer some methods of programming, which to machining of some similar components can be used. Such methods are:

1. **Cycles** [6]. The cycles are design for machining of typical surfaces (the holes, threads, slots etc.). Usually a parametric description of machined surfaces is applied which enable the easy and fast changes of their geometry. Unfortunately they be characterized by small flexibility and small influence onto strategy of machining, dependent only from the parameters of cycle. In the modern controllers it permit onto a Workshop Oriented Programming (WOP), i.e. programming directly by the operators, often aided by a dialog programming (sometimes a conversational programming called). Therefore this is relative simple programming method, very often used in industrial practice.
2. **Parametric programming** [5, 6]. A typical part program is executed from beginning to end in one run. In parametric programming the execution of part program can run into different way (e.g. by conditional instruction *IF.. THEN..* use). In addition, a multiple repetition of the part program fragment is accessible (*REPEAT* loop, *WHILE* loop etc.). Furthermore, the arithmetical functions and other advanced functions are possible. The axis positions, feed and speed functions, etc. can be specified by a parametric expressions (by R-parameters use). Into this way it was been possible to create own machining cycles also. This approach demands high skills of programming and is very labour-consuming also. Exact verification of the program is necessary, in this its immunity in the dangerous situations (e.g. joined with application of incorrect value of the input parameters). Therefore in view of above mentioned defects it is infrequently used in industrial practice.
3. **Programming based on the freely defined contours**. The task depends on defining of machined contour and its automatic conversion to the CNC codes. If the automatic cutter radius compensation (the G41 and G42 functions) is not used then additionally a equidistant has to be generated. This sub-task is easy to realization if mentioned contour is represented in a CAD system – with help of the *Offset* function. Second sub-task often is

realized in way of export of graphic form of the tool path to the typical formats of data exchange (DXF, HPGL etc.). In next step by the suitable postprocessors use (for example the solution given in [7]) conversion of tool path onto the CNC codes is performed. From practical regards this approach in generality for the simple operations is applied, e.g. a laser cutting, a water jet cutting etc. A solution integrating both sub-tasks in one application program are applied also – the AutoCUT is the best example [8]. In practice this solution is not applied too often although it possesses many advantages.

In the conditions of small batch production a process planning to the CNC programming is often restricted [9]. In this situation large meaning has integration of the CAD/CAM systems with omission of CAPP stage. The *Features* idea is then a effective method of data exchange [10, 11, 12]. When the Group Technology is used, after supplement by appropriate data bases and knowledge bases, it can be best solution for production of typical elements [13, 14]. In case of non-typical parts such approach generally is ineffective. Mainly in view of the widely applied methods of *Features* recognizing which limit number of the *Feature* types [10, 12]. Maybe in future a solution will bring integration of CAD/CAM/CNC systems based on the STEP-NC standards (ISO 14649, ISO 10303:238) [15, 16] which will replace traditionally applied CNC programming with G-codes onto thing of the neutral format of data exchange.

2. Analysis of the examples

Presented below examples of the group CNC machining are a fragment of production program from the small firm. Generally this components have non-typical shapes, they are manufactured from hard materials (e.g. austenitic stainless steel), usually needed the special jigs and fixtures, in the conditions of small batch production. The planning processes in this case demand a participation of technologists with large experience. A specific character of accessible tool machines for defining of the method of CNC programming should to consider also.

After execution of detailed analysis onto subject of the discussed methods the following conclusions were formulated:

- The machined shapes exclude applying of the standard cycles. Most of the programs is design for the complicated profiles machining. From here description of these profiles is largest problem. Moreover, machining of the components is performed on the different tool machines, equipped in different controller.

- For most of machined components the exact drawing documentation is not made. In a production order the general drawings are included, often

described by parametric dimensions. Then current values of this parameters are given also.

- Short series and large variety of the components demands fast modifying of current production program. Fast CNC programming and the programs implementation is necessary, best directly at tool machine (WOP).

- Often the operators of tool machines possess large knowledge and experience in the area of manufacturing technology, sufficient for preparation of simple program (in range of the technology). Fast preparation of the tool path is limitation only.

General conclusion is such, that in presented case use of the universal CAD/CAM systems for CNC programming is very difficult. Moreover, it joins with high costs of shopping and trainings for the workers. Low flexibility of this method is expected also, especially time of programming can be a great problem. In this situation a parametric programming as the best solution was considered. But, as it was shew on the examples, the parametric programming can be realized in different way.

2.1. Example I – the grooved rollers finish machining

Finish machining of the grooved rollers family was subject of research (Fig. 1). Basic changing dimensions for rollers were external diameter d , working profile length L and profile angle α . The profile of co-operate roller is moved by half pitch. Finish machining is performed by turning with use of tool with the V type rhombic insert (nose angle equal 35°), where the nose radius r_ϵ is equal 0,4 mm (Fig. 1). The tool reference point is located in the insert nose center. For each pair of rollers their profile is designed in a CAD environment according to the dimensions of rolling elements.

A fast method of tool path generation was the main subject of performed research. First of all generating of the tool path (only finishing, without rough machining which is programmed in a manual mode) and forming it in accordance with requirements of appropriate language. As has been mentioned above the use of parametric program was considered. With help of the advanced programming methods (e.g. transformations of co-ordinate system, sub-programs etc.) it was been possible to achievement the aim of this study. However, number of the machined rollers is very small (some per year).

Therefore another approach was accepted. Because for each roller a exact CAD model is prepared (2D model), it was used to CNC programming. For achievement of this aim the following activities was considered:

- For each used CNC controller the framework of part program is created, including program header, technological functions, tool functions and program end (without tool path).

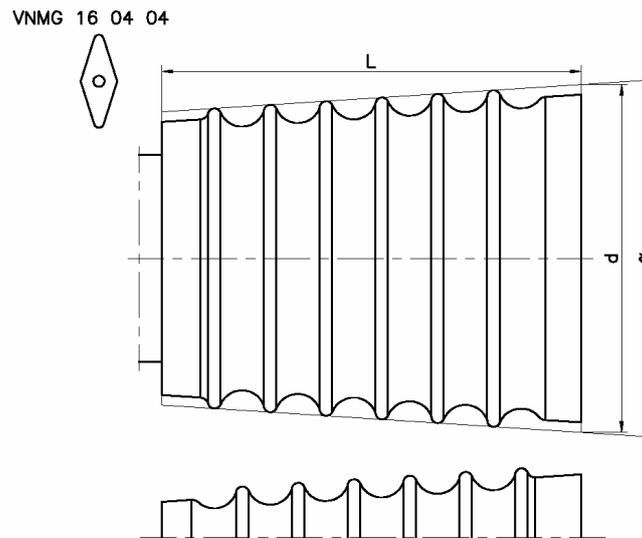


Fig. 1. A representative component of the rollers family

- In a CAD environment the model co-ordinate system is assigned to the workpiece co-ordinate system.
- In the semi-automatic mode from the model of working surface a tool path is extracted with use the *Offset* function.
- Manually the run-in path and the run-out path is added. For different elements of tool path (with working interpolation or with rapid interpolation) different attributes of line were applied.
- The designed tool path is converted to a numerical form in semi-automatic mode by special program (written in LISP language) and inserted to the part program (created previously). User has to show only first element of the tool path, further analysis is worked out on basis of the drawing data base (Fig. 2).
- Finally the part program is verified, the cutting parameters values are corrected and a graphical simulation of machining is executed (Fig. 3).

Total time of program planning (without preparing of CAD model) then about some minutes. An universal postprocessor was not applied (e.g. [7]) because format of the CNC program can be easily adapt to requirements of controller. Furthermore time of designing became significantly shortened.

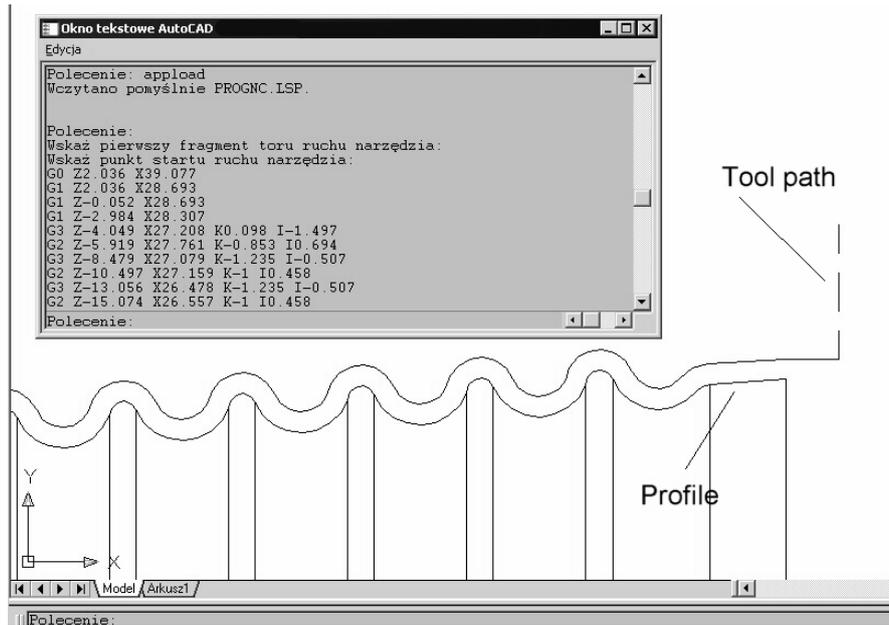


Fig. 2. A tool path and the suitable CNC program

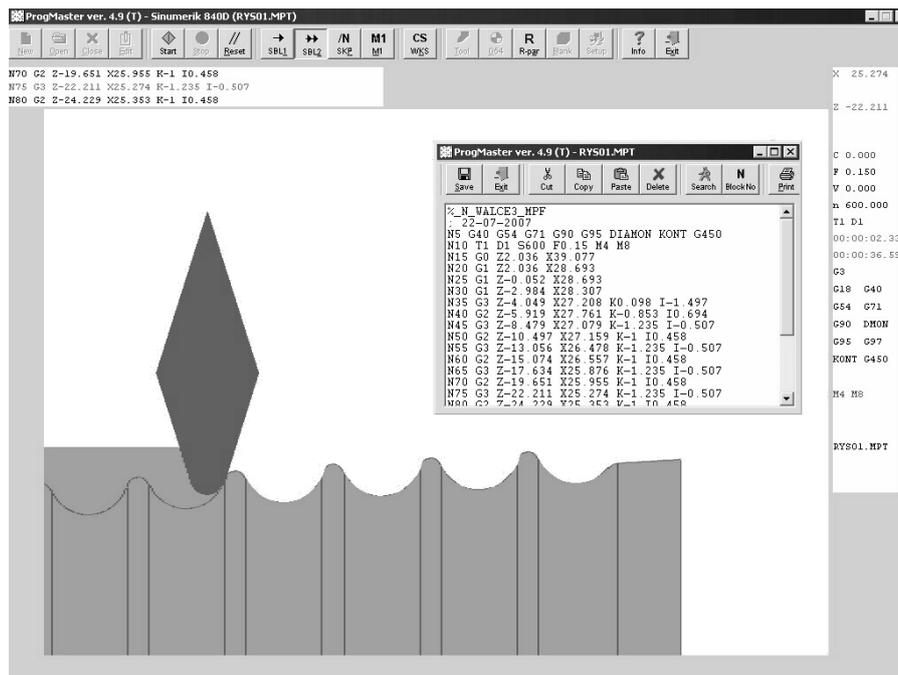


Fig. 3. A graphical simulation of the rollers machining

2.2. Example II – the multi-edge rings profile machining

The multi-edge rings profile machining was subject of the research (Fig. 4). On the face three zones of grooves are machined. Number of grooves (n_1 , n_2 , n_3) results from companies' recommendations. In every zone the constant value of pitch S is kept. The grooves dimensions (S , F , G) and the chamfer dimension w are changing and they have to be contain in the recommended limits. Their values are calculated for the constant diameters D_1 and D_2 (given in a production order). Just after complete determining of grooves geometrical form the machining operation can be designed. The rings are machined by tool with square insert (S type) – Fig. 4. The tool reference point is located in the insert nose center.

In order to clearly determine of the remaining ring dimensions the following dependences were accepted (according to the recommendations):

$$\left. \begin{array}{l} S \in (S_{\min}, S_{\max}) \\ w \in (w_{\min}, w_{\max}) \\ F \in (F_{\min}, F_{\max}) \\ G = f(S) \end{array} \right\} \quad (1)$$

and the geometrical dependences are described as follows (Fig. 4):

$$\left. \begin{array}{l} L = \frac{D_2 - D_1}{2} - 2 \cdot w \\ n = \frac{L - F}{S} \\ ROUND(n) = n_1 + n_2 + n_3 \\ n - ROUND(n) \rightarrow 0 \end{array} \right\} \quad (2)$$

what causes that the S , w and F dimensions in given ranges have to be changed until total number of grooves will not be a natural number. The above task as a optimization problem has treated where three decision values are given (S , w and F) and the constrains is given according to equation (1). The criterion function is calculated according to equation (2). The problem of optimization has solved by the Hooke-Jeves method use [17].

When ring geometry is finally determined then calculations of tool path elements is very simple – tool is moved along equidistant. Therefore was assumed that this two tasks will be solved by means of one program (Fig. 5), a similar approach was showed in [18]. After introduction of value of well-known dimensions (e.g. from production order) the value of remaining

dimensions are automatically calculated. If user accepts this values then the part program is generated automatically (in non-parametric form). In opposite case user can improve values of dimensions and their correctness is checked by program. After execution of simulation (Fig. 6) the part program can be transmitted to CNC controller.

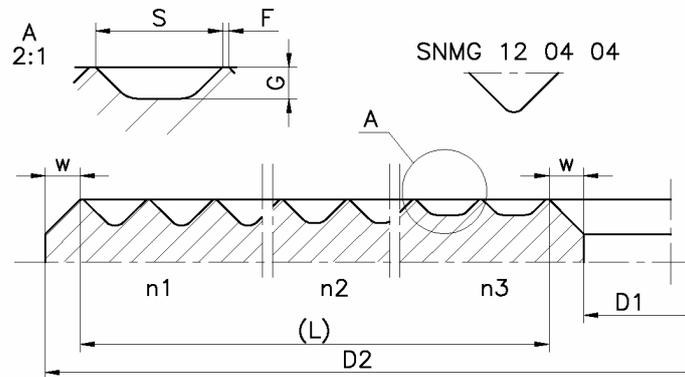


Fig. 4. A representative component of the multi-edge rings family

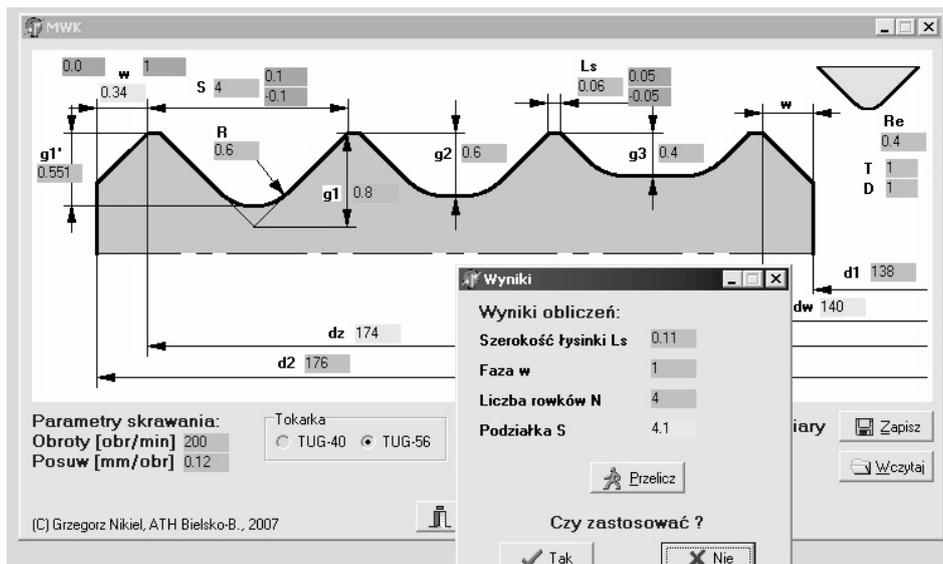


Fig. 5. Main window of the application program for data entering and tool path calculations

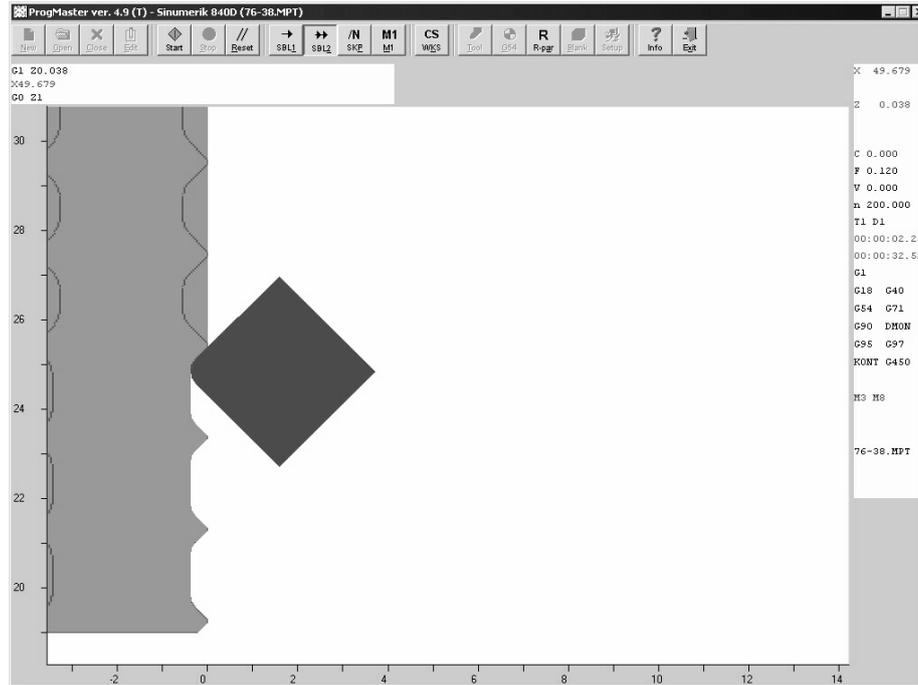


Fig. 6. A graphical simulation of the multi-edge rings machining

2.3. Example III – the eccentric seal rings machining

The eccentric seal rings machining was subject of the research. The external surface of ring which have shape of cone, is machined in analyzed operation. (Fig. 7). A machining datum is located on the internal cylindrical surface (with diameter D) and on the face surface. The groove with diameter dr is made as option. Steel cylindrical ring is a semi-product (from acid-resistant steel or from stainless steel). Described operation comprise two stages: the roughing machining (removal of considerable allowance on part of ring) and finish machining (for obtainment of the exact shape). The shape accuracy has larger importance than the surface roughness (the exploational requirements) [19].

The operation is executed by use of typical tool with rhombic insert (C type). In the part program a linear position of tool (linear co-ordinates Z and X) and an angular position of spindle (angular co-ordinate C) have to be joint.

Initially a 3D parametric model making was analyzed (e.g. in AutoDesk Inventor environment) and use it for generating of the part program (e.g. in EdgeCAM environment [20, 21]). Finally another approach was accepted – a parametric program was used for rings machining. This decision is justified by following premises:

- larger influence onto machining strategy, especially due to the machined materials;
- possibility of program set-up directly at the machine tool, even by machine operators;
- easy and fast changes of part program execution;
- considerably smaller size of program;
- high cost of the CAM systems.

Nevertheless this solution own one important disadvantage – the group program has to work in accordance to very complicated algorithm. Especially, where calculations of co-ordinate points on the cone have to be carried out. Moreover, cutter radius compensation is performed (automatic cutter radius compensation is impossible). In this situation efficiency of a CNC controller can to make significant limitation. It was checked that time of calculation at full implementation of mentioned algorithm on the CNC controller is too long in relation to required speed of machining. Simplifying of the program was indispensable for correct realization of this operation.

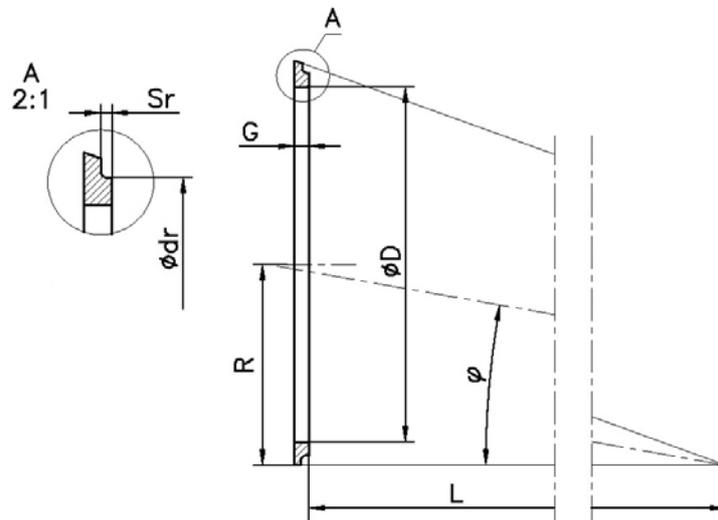


Fig. 7. A representative component of the eccentric rings family

The final form of proposed CNC program is showed in Fig. 8. The main program (*PIERSCIEN.MPF*) is fixed for the rings family, where the machining in a parametric form is described. A subprogram (*DANE.SPF*) is a data set (in the R-parameters form) which dimensions of the concrete ring define (from

a design documentation). Moreover, mentioned subprogram contains the technological parameters (a speed, a feed, etc.) and co-ordinates of the selected points on the machined surface. These points are required to calculation other remaining coordinates in the part program. Mentioned coordinates are determined by use of an additional program, working in the external computer [19]. To tasks of this program should help user at data introducing (Fig. 9), the necessary calculations and the subprogram saving in accordance with requirements of given CNC controller. In next step the part program simulation can be performed (Fig. 10). In last step the part program is sent to a CNC controller.

In proposed form the main program contains about 190 blocks, the subprogram – about 150 blocks. If it was accepted first from considered solutions then part program is considerably longer. Presented part program generates about 80÷100 thousands of the tool movements.

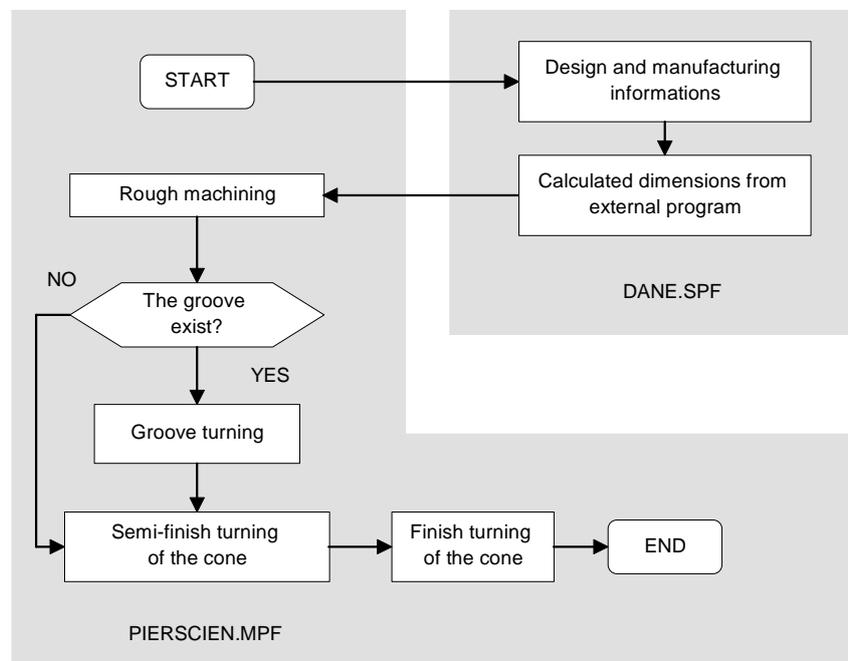


Fig. 8. An architecture of the group control program for the machining of eccentric seal rings

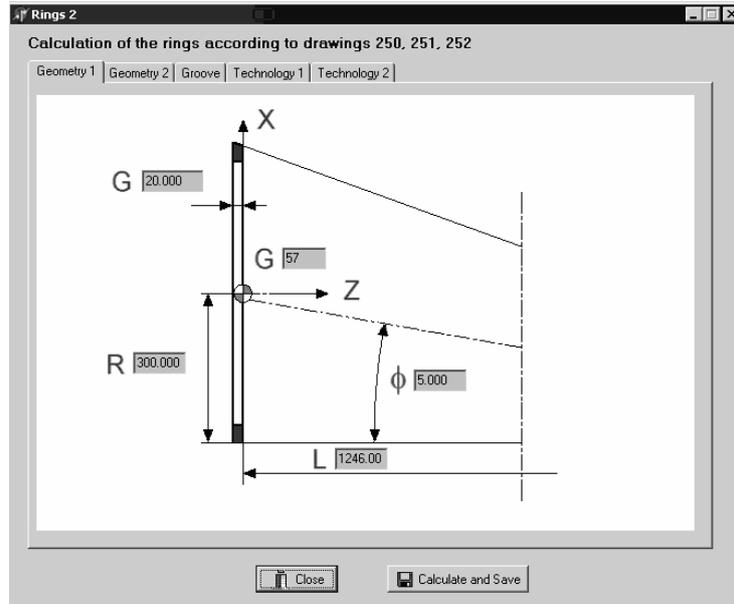


Fig. 9. Main window of the application program for tool path calculations

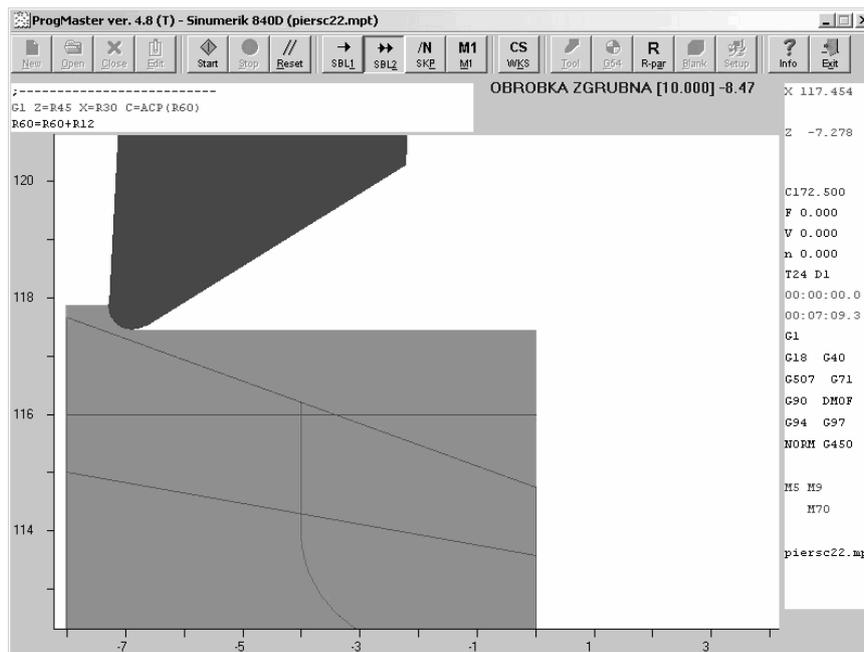


Fig. 10. A graphical simulation of the eccentric rings machining

3. A CNC programming in *off-line* mode

A CNC programming directly on the machine tools (in *on-line* mode) is very difficult, even sometime impossible. Advanced methods of parametric programming (calculation on the parameters, the structural functions, the jumps etc.) demand exact verification of the algorithm. Exclude this functions usually such part programs use simple methods for the co-ordinates giving. A graphical simulation of parametric programs was not been possible to execute in wide applied popular CAM systems (from reason of the rules of their work). Moreover, often in industrial practice fast conversion a NC program to other language is required. From this in practice sometimes one should to create specialized software [22].

Therefore the original system for NC programs analysis and simulation was realized [23] – Fig. 3, Fig. 6,

Fig. 10. Acceleration and facilitation of programming in *off-line* mode, especially for parametric programs is main purpose. Discussed system contains typical modules – specialized editor, graphical simulation module, offset registers, parameters table, programs database, serial transmission module, etc. As base language was accepted Sinumerik 840D/810D (Siemens) because largest set of functions it contains. Onto its basis was created original, internal programming language (where work philosophy is based on the APT system idea). Therefore the work of this system runes in accordance with presented architecture – Fig. 11.

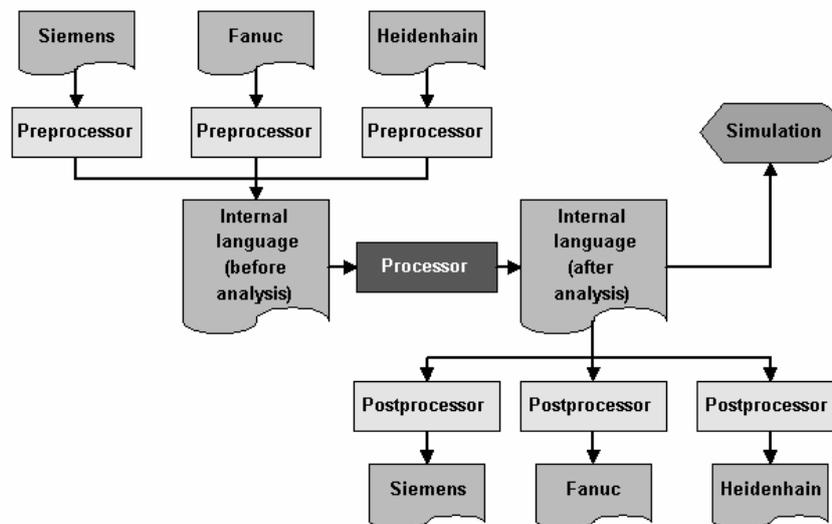


Fig. 11. Architecture of the system for analysis and simulation of NC programs

A preprocessor translates the part program written in language of concrete controller (Siemens, Fanuc, Heidenhain) onto its internal language. Simultaneously syntactic correctness of the part program is checked. In this form the CNC program is analyzed and executed through processor and in analogical form is remembered. In next step this program can be simulated or translated by postprocessor onto CNC program for other controllers. If necessary is including a new language then should to make only new postprocessor or preprocessor, without necessity of changes in the processor. Common procedures for analyses and simulation, included in the processor, simplify adaptation of the system to new tasks.

4. Conclusion

In all presented above examples the typical CNC programming methods use was analyzed. Both cycles as programming with help of the Computer Aided Manufacturing systems (CAM) based on parametric solid models were ineffective. For all analyzed surfaces their geometry is significantly different from geometry of the standard cycles. If CAM software is used then has to be prepared exact model of the machined part (by CAD software). In conditions of small batch production no always this is possible. Use of described methods of programming can be often one real solution.

Presented approach possesses many advantages. Firstly, significantly reduce the part programming time (to some minutes). The CNC programs can be generated by operators directly at tool machine. Possession of the exact drawings of machined parts is not required (with except of first presented example). Correctness of the generated programs is very high, applying of additional verification (e.g. graphical simulation) usually does not join from modification (except changes of machining parameter values). Significantly is decreased time and cost of the programs start. More expensive CAM software are not necessary. This approach could reduce the number of program changeovers and decrease programs length.

The disadvantages of presented approach are naturally also. Firstly, is necessary additional time onto analysis of problem, solution proposing and often additional software preparing. Formulating of the complex geometric dependences for a tool path calculation demands large knowledge from area of mathematics and geometry. Moreover, a user should to know to write this formulas in the form of computer programs. Such approach does not have to generate additional costs onto shopping of the commercial programming systems because are accessible their free non-commercial versions (e.g. used by author Borland Turbo Delphi, AutoLISP or Visual Basic for Application available as the programming interfaces for AutoCAD, Inventor, etc.).

In opinion of author in situation of process planning for the parts about non-typical shapes, especially when Group Technology is used, applying of non-typical methods of CNC programming is required also. Then use of unconventional tools of computer aid is necessary. Described in this paper solutions are the best example of this approach.

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