

CEPP CONVERSION AND EXECUTION OF PROCESS PLANS

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Abstract

This paper deals with a method to produce a program in Numerical Control (NC) language from a part drawing in a CAD system. This method is applied to any piece with revolution axis that can be machined in a CNC - Lathe. The method was developed with the goal of being integrated in the control software of the flexible manufacturing system existent in the CIM center of ISEP. The proposed method involves three phases, which are presented and explained.

Keywords: Process Plan, CAD/CAM(Computer Aided Design/Computer Aided Manufacturing), CNC (Computer Numerical Control)

1. Introduction

The Manufacturing Systems have been developing in the sense of a growing automation and integration of processes, creating a new concept, Computer Integrated Manufacturing or as it is more well known CIM. However it does not only embrace the aspects related with the design and manufacturing of the product, but also all the marketing subjects, sales, finances, etc.

The modernisation process is hard, slow and it involves many subjects, it implies automation, use of flexible cells, use of computerised systems for manufacturing planning and control, CAD/CAM (design and manufacturing aided by computer). Finally, the factory of the future, involving the CIM concept, it intends to make easier the simultaneous accomplishment of the automation of tasks and the centralised administration through automated and computerised systems.

The possibility to use the new technological solutions becomes a factor of essential success. So there is the growing of new concepts, like Reengineering, Flexible Manufacturing, Lean Manufacturing, Intelligent Manufacturing, Concurrent Engineering, Design for Manufacturing, etc.

The introduction of these new solutions provides the increase of the profits and the productivity at the

same time that assures to the company achieving essential strategic positions to its survival. One of the main goals is the increase of flexibility in terms of manufacturing periods, reducing the time period to answer changes and the conception period of new products.

As we previously said one of the fundamental aspects in the actual Manufacturing systems is the need of a fast answer in terms of new products face to the market's flotation. The decrease period of introduction of new products depends essentially on the time of conception, specification and process planning, being of enhancing the communication between the design and manufacturing phases.

Literature shows that there are a lot of systems for process planning. The first ones appeared in the seventies APPAS[1], CAPP[2], and AUTAP[3], but most of the progress have been made with in the last 15 years. The existing process planning systems differ from each other in their domain of application, and in the methods they employ. For example TOM[4], focuses on drilling processes. PROPLAN[5] and EXCAP[6] addresses turned parts. CUTTECH[7] is an operation planning system which determines the operations sequence, the necessary tools, speeds, etc. SIPS[8] focuses on selecting the lowest cost operation for individual features created in a process plan, which differs a lot from finding the over all lowest cost plan. Two systems for assembly sequence generation for a product were developed by Borjault[9] and Homem de Mello[10]. The first uses liaison graphs representing part connections and the second uses AND/OR graphs, however none of these systems has inference capabilities concerning geometric knowledge about assembly. AMRF[11] and XCUT[12] are systems that create plans for parts having only one *setup* because they have features in just one side.

The systems GARY[13], Hi.MAPP[14], QTC[15], Das[16] and MACHINIST[17] are good examples of process planners that construct multiple *setup* plans for prismatic parts machined on CNC machines.

As we referred before there are a lot of systems for process planning, but the bridge between process planning and part manufacturing it is usually not considered. To automate this process is necessary to consider machine parameters and related process constraints. Our system considers the existence of a manufacturing system that will

operate over the part, so manufacturing parameters and constraints are considered allowing the automation of the transfer process of information from design to manufacturing.

The aim of the work presented in this paper is the development of a method of Conversion and Execution of Process Plans. Using a part drawing created CAD tool, and knowing the processes constraints related to the machine the proposed method generates a program in NC language for manufacturing in a lathe the part geometrically specified in a CAD drawing.

2. Developed method

The goal of the proposed method, *CEPP - Conversion and Execution of Process Plans* [18], is the automatic generation of a file with the NC language for machines CNC-lathe, adapted for the execution of any piece with revolution axis. This method involves three phases:

Phase 1 – Interpretation and treatment of the file generated by CAD software with information about the geometry of the piece

Phase 2 – Process Planning

Phase 3 - Generation of a file containing the NC language adapted for the machining of the work piece.

2.1. Phase 1 - Interpretation and treatment of the file generated by CAD software

The first step of this phase is the interpretation of a file with IGES or DXF format generated by the CAD software, creating an interface among the conception and design aided by computer and the functions of production engineering (CAD/CAM).

To produce this interface without mistakes the part drawing must have certain requirements. The drawing will have to contain different levels (*layers*) where it is represented the work piece (*stock*), the final piece to produce and the different areas to remove. The levels are also good to indicate the precedence that exists among the removal areas. For example, supposing that it intends to execute a piece starting from a certain stock, as represented in the figure 1.

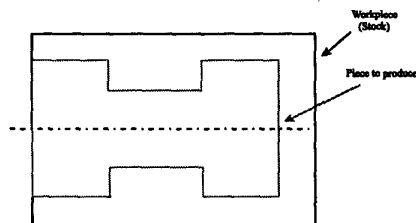


Figure 1 - Geometric model of the piece and the stock

The corresponding drawing in CAD is represented in the figure 2. Because is a piece with revolution axis with symmetry of the contour, it will just be necessary to represent half of the contour.

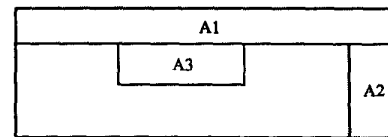


Figure 2 - Representation of the different removal areas

To remove area A2 it will be necessary to remove first area A1, therefore in the CAD drawing the level in which the removal area A1 will be is inferior than the level of the removal area A2. Of noticing that in the case of no removal precedence between two different areas they should be represented in the same level, as it happens with the areas A2 and A3. The decision of choosing which the area will be removed in first place is determined in the phase of process planning.

The levels 0 and 1 were reserved to represent the geometry of the stock and the piece to produce respectively.

The figure 3 presents the different levels that should be composing the drawing of the piece in CAD;

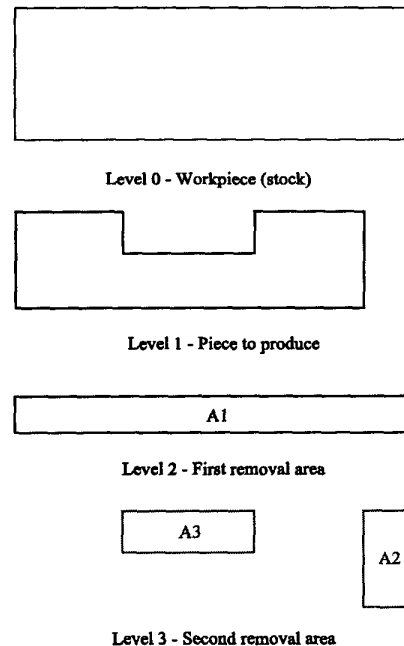


Figure 3 - Levels constitution of the drawing

The determination of the removal areas is executed by another method called *generation and automatic sequencing of machining areas geometry* developed by Ferreira [19]. This method has the goal of generation and automatic sequencing of the removal areas according to

the basic areas defined. There are four basic areas as we can see in figure 4:

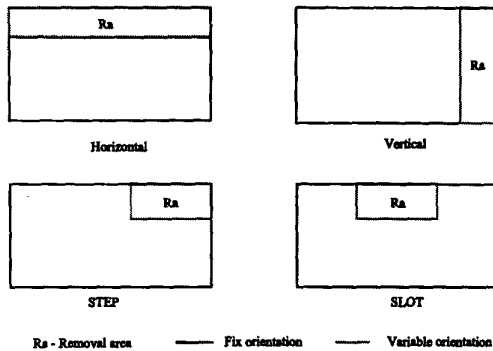


Figure 4 – Basic areas

In each one of the different basic areas there are some straight lines whose orientation cannot be modified, as it is the case of the fix orientation segments represented in the previous figure. This happens because the method use the machining cycles defined by the manufacturer of CNC machines to remove the areas.

All the other straight lines or arches that constitute the geometry of the piece, may have a variable orientation.

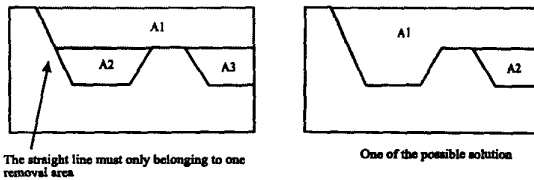


Figure 5 -Removal area restriction

A straight line or arch that represents the final geometry of the piece should be integrated inside of the same removal area as we can observe in the figure 5. This means, the same straight line or arch cannot have a part belonging to a removal area and remain belonging to the other. This happens because when the lathe execute the referred elements, they will be executed in two different machining cycles and could originate a finish surface of inferior quality than if they were executed in the same cycle.

After the storage of all the important information picked up through the analysis of the CAD file in DXF or IGES format, the next step is the treatment of the information through routines to make easier the treatment of these areas in the phase of process planning.

2.2. Phase 2 – Process Planning

In this phase it is created a plan where it is determined:

- The type of areas to remove,
- the necessary tools,
- the operations for removal the areas,
- the sequence of areas to remove.

The recognition of the removal areas is the first step of this phase. As it was referred previously there are four basic areas represented in the figure 4. The recognition algorithm is based on a group of rules that allow determining the area type in subject.

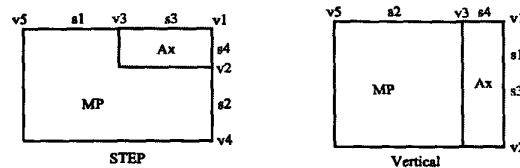


Figure 6 - Removal Areas

Considering the example of two removal areas, the step and vertical thinning represented in the figure 6.

The corresponding rules are explained below:

Rule for step recognition

IF vertex v1 of area Ax is the same vertex v1 of area MP
 AND decline segment of line s1 is the same decline segment of line s3
 AND decline segment of line s2 is the same decline segment of line s4
 AND coordinate x of v3 is larger than coordinate x of v5
 AND coordinate y of v2 is larger than coordinate y of v4
 THEN the area Ax is of the type step

Rule for vertical recognition

IF vertex v1 of area Ax is the same vertex v1 of area MP
 AND vertex v2 of area Ax is the same vertex v2 of area MP
 AND decline segment of line s1 is the same decline segment of line s3
 AND decline segment of line s2 is the same decline segment of lines 4
 AND coordinate x of v3 is larger than coordinate x of v5
 THEN the area Ax is of the type vertical

For removal each one of the basic areas is chosen a more appropriate machining cycle and tool. Factors as removal area type, machining type (turning, facing, grooving, cut, etc) and the geometric restrictions of the toolholder determine that choice. However, there are certain removal areas in which just a machining cycle and a tool are not enough to machine the removal area, as it can be observed in the following examples.

2.3.1. Example 1

To remove an area of the type slot rectangle there are two possibilities of machining, grooving or turning in two stages, as we can see in figure 7. The determination of which of the machining types to choose is one of the decisions that the NC programmer can take during the phase of process planning. If the programmer does not choose any of the available options it is chosen the one that have a smaller machining time. In this case it will be grooving, because for turning in two stages it is needed a tool change, what should be avoided whenever possible because it implies non-productive times.

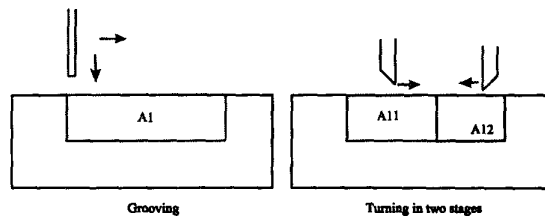


Figure 7 - Grooving and Turning in two stages

2.3.2. Example 2

To remove an area of the type slot represented in the figure 8, only the operation of turning can be executed. However, due to the characteristic of the area it is not possible to find at the tools library any toolholder able to execute this operation in just one machining cycle. For this case and in similar cases the removal area is divided in two stages, being create two removal areas for which will be attributed the machining cycle and the toolholder more appropriate.

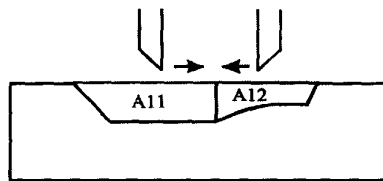


Figure 8 - Removal area type slot in two stages

The removal sequence will be first the area A11 and after the area A12, or vice-versa, with a tool change between the two machining cycles.

However, there are situations in which just one toolholder and a machining cycle are enough for turning the removal area of the type slot, as it is the case represented in the figure 9:

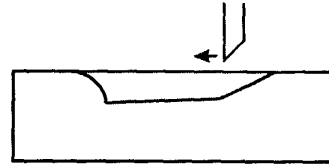


Figure 9 - Removal area type slot turning in a single stage

The procedures exemplified for treatment of the type slot areas will also be applied for the case of the step areas type, whenever a machining cycle and a toolholder are not enough for turning the removal area.

The choice of the most appropriate tool is made through the consult of a database (library of tools) where it is stored information about the geometric characteristics of the toolholder and cutting parameters. If the selected tool does not exist at the library, an appropriate tool can be specified by the NC programmer. This choice will be stored in the library for future use.

The last step of this phase is the establishment of precedences between the removal areas represented in the same level. These precedences are made through an ordering algorithm that has the function to minimise the number of tool changes, allowing minimising the time for the execution of the piece.

2.4. Phase 3 - Generation of a file containing the NC language adapted for the execution of the piece

The last phase of the method is the generation of a file with the NC program. So that it is possible its integration with the control software of the Flexible Manufacturing System from the CIM center of ISEP, the generated file must have the following requirements:

- have an ASCII format with extension FNC,

- be composed by commands interpreted for the machine tool GE FANUC SERIES OT,

- have in the beginning and in the end the following sequence of commands.

```
M62 (AUX 1 ON)
M39 (close the door)
.....
```

```
Code NC generated by the method for
machining the removal areas
.....
```

```
M38 (open the door)
M64 (AUX 1 OFF)
M15 (special function control)
% (end of program)
```

The code NC generated is commented properly, allowing to the NC programmer a faster and efficient validation. The comments appear in the beginning of each code block

3. Example of application of the developed method

Supposing we want to machine, in a CNC lathe, a work piece with revolution axis whose geometric model is represented in figure 10;

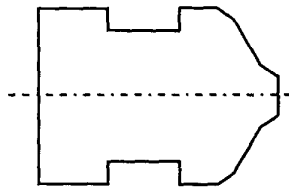


Figure 10 – geometric model of the piece

With base in the drawing of the piece to produce, in the characteristics of the stock and assisting to the requirements described in the point 2.1, the method developed by Ferreira will elaborate a new drawing where will be defined the removal areas and the respective removal sequence (see figure 11) [2].

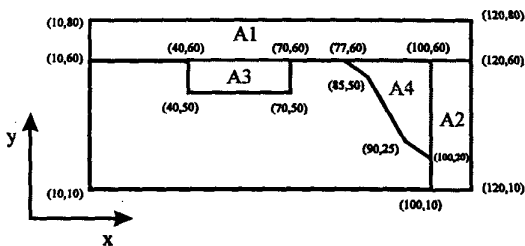


Figure 11 - Geometric model of the piece and the different removal areas

Phase 1

The first step of this phase is the interpretation of the file in format DXF or IGES generated by Ferreira method. This interpretation consists in a detailed analysis of the file allowing the store of information about the geometry and identification of each one of the areas of the drawing. In a second step is performed the vertex organisation of a same area. This organisation begins from the vertex with larger X coordinate. In the case where there is more than one vertex with equal X coordinate, the representation of the area will begin with the one that has larger Y coordinate.

For example, the direct interpretation of the file for the area A3 is obtained the following sequence of vertexes:

(40,60) (70,60) (70,50) (40,50) (40,60)

After the application of the vertexes organisation algorithm the new sequence will be:

(70,60) (70,50) (40,50) (40,60) (70,60)

After having concluded the application of the organisation algorithm of vertexes to all the removal areas, the stored information is prepared for the phase of process planning.

Phase 2

In this phase a recognition algorithm is applied to know which is the type of defined removal areas. The result of the algorithm application for this case is the following:

the area A1 is of the type horizontal

the area A2 is of the type vertical

the area A3 is of the type slot,

the area A4 is of the type step.

The following step is the choice of the tool type to use to machine each one of the defined areas. It is assigned to each area type a tool that is already defined at the tool library as being the appropriate for that area type. However, and depending on the characteristics of each area, the chosen tool may not be the most appropriate. To solve this situation it is verified if there is some geometric restriction that prevents the selected tool of removing the intended area, if that happen another tool is chosen to machine the removal area. If even so there is not any tool which allows removing that area, it is proceeded to the division of the area until tools adapted for the removal of each one of the parts in which the area was divided are found.

For each one of the areas of the example of the figure 11 the selected tools are:

area A1 - toolholder type L0

area A2 - toolholder type L3

area A3 - toolholder type C2

area A4 - toolholder type L3

The definition of the machining cycles is dependent on the type area that we intend to remove. So to execute the area A1 the operation is turning and the machining cycle is G71. For the areas A2 and A4 the operation will be facing that corresponds to the machining cycle G72, and for the area A3 the operation is grooving, what corresponds to the machining cycle G74.

The last step of this phase is the determination of the sequence of removal areas represented in the same level. The sequence is obtained respecting the rule of minimising the number of tool changes. The result obtained for the example in subject is A1, A3, A2 and A4.

Phase 3

In this phase it is performed the generation of the file with the NC program. For the case in subject the result of this phase is the NC file represented.

(initial sequence for integration in control software)

O0001;
N5 M62;
N10 M39;

(machine Preparation for machining a type K work piece)

N15 G99 G21 G96 G00 X145.00 Z0.00;

(tool change for an operation type M)

(in area A1 of the type horizontal in the layer 2 with a type L 0 toolholder)

(depth of cut 3.70 feedrate 0.35 cutting speed 170)
(acceptable tolerances are: dc 0.4-6.0, fr 0.15-0.60, cs 215-140)
N20 MO6 T0101;
N25 MO3 S170;
N30 MO8;

(for the following operation it is not necessary to change the tool)

(turning cycle to remove the area A1 in the layer 2)

N35 G00 X140.00 Z0.00;
N40 G71 U3.70 R0.1;
N45 G71 P50 Q60 U4.00 W2.00 F0.35 S170;
N50 G00 X100.00 Z0.00 F0.20 S215;
N55 G01 X100.00 Z-110.00;
N60 G01 X140.00 Z-110.00;
N65 G70 P50 Q60;
N70 G00 X145.00 Z0.00;

(tool change for an operation type R)

(in area A3 of the type slot in the layer 3 with a type C 2 toolholder)

(depth of cut 3.70 feedrate 0.18 and cutting speed 175)
(acceptable tolerances are: dc 0.4-6.0, fr 0.05-0.15, cs 270-130)
N75 MO6 T0202;

(turning cycle to remove the area A3 in the layer 3)

N80 G00 X100.00 Z-50.00;
N85 G74 R0.50;
N90 G74 X80.00 Z-80.00 P3.5 Q3.5 R1.0 F0.18;

N95 G00 X145.00 Z0.00;

(tool change for an operation type M)

(in the area A2 of the type vertical in the layer 3 with a type L 3 toolholder)

(depth of cut 3.70 feedrate 0.35 and cutting speed 170)
(acceptable tolerances are: dc 0.4-6.0, fr 0.15-0.60, cs 215-140)

N100 MO6 T0303;

(facing cycle to remove the area A2 in the layer 3)

N115 G00 X100.00 Z0.00;
N120 G72 U3.70 R0.1;
N125 G72 P130 Q140 U4.00 W2.00 F0.35 S170;
N130 G00 X100.00 Z-20.00 F0.20 S215;
N135 G01 X0.00 Z-20.00;
N140 G01 X0.00 Z0.00;
N145 G70 P130 Q140;
N150 G00 X145.00 Z0.00;

(for the following operation is not necessary to change the tool)

(facing cycle to remove the area A4 in the layer 4)

N155 G00 X100.00 Z-20.00;
N160 G72 U3.70 R0.1;
N165 G72 P170 Q185 U4.00 W2.00 F0.35 S170;
N170 G00 X100.00 Z-43.00 F0.20 S215;
N175 G01 X80.00 Z-35.00;
N180 G01 X30.00 Z-30.00;
N185 G01 X20.00 Z-20.00;
N190 G70 P170 Q185;
N195 G00 X145.00 Z0.00;

(tool change for an operation type C)

(with a type C 2toolholder)

(depth of cut 3.70 feedrate 0.15 and cutting speed 115)
(acceptable tolerances are: dc 0.4-6.0, fr 0.10-0.30, cs 140-100)
N100 MO6 T0404;

(cycle for chip breaking)

N200 G00 X140.00 Z-110.00;
N205 G75 R0.50;
N210 G75 X-1.00 P3.50 R1.00 F0.15;

(come back for safety position)

N215 G00 X145.00 Z-30.00;

(final sequence of commands for integration in control software)

N220 M05;
N225 M38;
N230 M64;
N235 M15;
%

4. Conclusions

In this paper CEPP method (Conversion and Execution of Process Plans) was described and illustrated. The integration of this method with the method developed by Ferreira (generation and automatic sequencing of machining areas geometry) can produce automatic plans with minimal production time for pieces with revolution axis that can be manufactured in a CNC – Lathe.

The Ferreira method generates high level plans with the minimal removal areas and it is precedences according to the basic areas defined. The CEPP generated an

execution plan according to the machine cycles available in the tool machine, through the more appropriate tool choice and minimising the number of tool changes by ordering the removal areas.

We think to have contributed with one more method to aid always in the difficult task of process planning. One of the contributions of CEPP is the automatic tool choice. However, the main contribute of the method corresponds to the fact of negotiating with larger depth the problem of the execution planning. Because it is not only important the elaboration of good plans but also the possibility of fast reconfiguration of the productive system, through the re-programming of the machines involved in the process.

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