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## GENERATING PARAMETERS FROM THE NC CODE NEEDED FOR DEFINING THE OPTIMAL TOOL PATH

**Abstract:** CAM packages are able to generate several different tool paths for multi-axis NC machining of one pocket or contour. Using the optimal toolpath a minimum cutting force, the maximum dynamic stability of the process and minimum tool wear are achieved or some other technological requirements are met. To determine the optimum tool path it is necessary to establish analytical dependence between optimization criteria and machining elements that are determined by specific tool path. In the NC program the basic technological, kinematic and geometric data are contained but not the elements that depend on the tool path, such as cutting depth, width of cut and engagement angle of the cutting tool. This paper presents a NC code transformation methodology and generation of tool path parameters necessary for calculating all elements of contour milling machining process.

**Key words:** milling, tool path, NC code transformation

### 1. INTRODUCTION

Most of mechanical parts consist of faces parallel or normal to a single plane and free form objects require a 2.5D rough milling operation of the raw work piece, making 2.5 D pocketing one of the most important milling operations [1]. Using CAM programs for creating tool path for pocket milling, technology designers faces some choices which determine the final shape of tool path. Fig. 1. shows an example of different tool paths generated with the same CAM program for pocket machining.

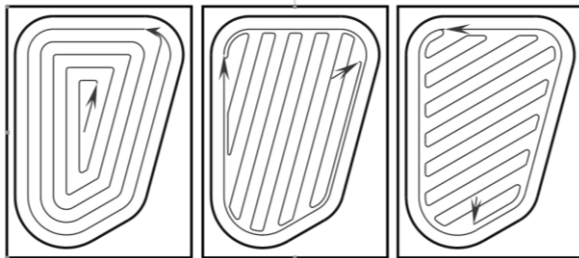


Fig.1. Examples of typical tool paths generated by CAM program

Using the optimal toolpath a minimum cutting force, the maximum dynamic stability of the process and minimum tool wear are achieved or some other technological requirements are met.

The NC program contains basic technological data (specified speed and feed rate), kinematic and geometric data (mode of tool movement and coordinates of points on the tool path). However, cutting process elements, such as engagement angle, depth and width of cut are not contained in the NC programs. Knowledge of these machining elements along the tool path is necessary for checking the adequacy of the generated tool paths from different aspects.

Required elements of the cutting process can be calculated if, in addition to data contained in the generated NC programs, geometric characteristics of blank and geometric and technological characteristics of the tool are defined.

In this paper, NC code transformation methodology and generation of tool path parameters necessary for calculating all elements of contour milling process is presented.

### 2. NC PROGRAM DATA ANALYSIS

In order to create tool paths database for a given NC programs, transformation of technological, kinematic and geometric tool path data contained in the NC programs into database tables is needed.

#### 3.1 Tehnological data

Used tool data are determined according to NC program blocks which contain program word beginning with T and contain function M06.

$$a_{obr} = f('T'), 'T' \in b_i^{NC}, 'M06' \in b_i^{NC}$$

$$i_1 = i, 'M06' \in b_i^{NC}$$

$$i_0 = i - 1, 'M06' \in b_i^{NC} \quad (1)$$

$$i_0 = i, f(m) \in b_i^{NC}, f(m) = \{M00, M19, M30\}$$

where:

$f('T')$  - is evaluation of tool no.

Value of spindle speed  $n_{obr}$  or value of cutting feed  $s_{obr}$  is determined according to NC program blocks which contain program word beginning with S or with F [2]:

$$n_{obr} = f('S'), 'S' \in b_i^{NC} \quad (2)$$

$$s_{obr} = f('F'), 'F' \in b_i^{NC} \quad (3)$$

where:

-  $f('S')$  is evaluation of spindle speed

-  $f('F')$  is evaluation of cutting feed

Spindle speed is changing value in program blocks which contain M-functions:

$$n = \begin{cases} n_{obr}, f(m) \exists b_i^{NC}, i_1 = i, f(m) = \{M03, M04\} \\ 0, f(m) \exists b_i^{NC}, i_0 = i, f(m) = \{M00, M30\} \\ 0, f(m) \exists b_i^{NC}, i_0 = i+1, f(m) = \{M05\} \end{cases} \quad (4)$$

Cutting feed is changing value in program blocks that contain G-functions:

$$s_g = \begin{cases} s_{obr}, f(g) \exists b_i^{NC}, \\ f(g) = \{G01 - G03, G81, G82, \dots\} \\ 0, f(g) \exists b_i^{NC}, f(g) = \{G00, G80\} \end{cases} \quad (5)$$

### 3.2 Kinematic and geometric data

Kinematic and geometric data, based on coordinates given in current and previous block, are calculated in absolute coordinates for each program block:

$x_1, y_1, z_1$  - coordinates of start point,

$x_2, y_2, z_2$  - coordinates of end point,

for functions G00, G01, G02, G03, G81, G82, ..., G89, G98 and G99 (Table 1);

for G90	for G91
$x = \begin{cases} f('X'), 'X' \in b_i^{NC} \\ x_1, 'X' \notin b_i^{NC} \end{cases}$	$x = \begin{cases} f('X'), 'X' \in b_i^{NC} \\ 0, 'X' \notin b_i^{NC} \end{cases}$
$y = \begin{cases} f('Y'), 'Y' \in b_i^{NC} \\ y_1, 'Y' \notin b_i^{NC} \end{cases}$	$y = \begin{cases} f('Y'), 'Y' \in b_i^{NC} \\ 0, 'Y' \notin b_i^{NC} \end{cases}$
$z = \begin{cases} f('Z'), 'Z' \in b_i^{NC} \\ z_1, 'Z' \notin b_i^{NC} \end{cases}$	$z = \begin{cases} f('Z'), 'Z' \in b_i^{NC} \\ 0, 'Z' \notin b_i^{NC} \end{cases}$
$x_2 = x; \quad y_2 = y; \quad z_2 = z$	$x_2 = x_1 + x; \quad y_2 = y_1 + y; \quad z_2 = z_1 - z$
<p>where:</p> <p><math>x, y, z</math> - are coordinates given in current block;</p> <p><math>f('X'), f('Y'), f('Z')</math> - is coordinate evaluation according to G20 and G21</p> <p><math>f(g) = \{G00, G01\}</math></p>	

Table 1 - Coordinates for functions G00 and G01

and:

$x_c, y_c, z_c$  - circular interpolation center coordinates,

$r$  - circular interpolation radius,

$\alpha_0$  - circular interpolation start angle,

$\alpha$  - circular interpolation angle,

for functions: G02 and G03.

Calculation of circular interpolation parameters for given interpolation center coordinates, for one case is presented in Table 2.

for G02 and G17	for G03 and G17
$i = \begin{cases} f('I'), 'I' \in b_i^{NC} \\ 0, 'I' \notin b_i^{NC} \end{cases}; \quad j = \begin{cases} f('J'), 'J' \in b_i^{NC} \\ 0, 'J' \notin b_i^{NC} \end{cases};$ $r = \sqrt{i^2 + j^2}$	
$x_c = x_1 + i; \quad y_c = y_1 + j; \quad \alpha_0 = \left  \arctg \left( \frac{y_1 - y_c}{x_1 - x_c} \right) \right $ $\alpha_0 = \begin{cases} \alpha_0, y_1 - y_c \geq 0 \wedge x_1 - x_c \geq 0 \\ 180 - \alpha_0, y_1 - y_c \geq 0 \wedge x_1 - x_c < 0 \\ 180 + \alpha_0, y_1 - y_c < 0 \wedge x_1 - x_c < 0 \\ 360 - \alpha_0, y_1 - y_c < 0 \wedge x_1 - x_c \geq 0 \end{cases}$ $\alpha_1 = \left  \arctg \left( \frac{y_2 - y_c}{x_2 - x_c} \right) \right $ $\alpha_1 = \begin{cases} \alpha_1, y_2 - y_c \geq 0 \wedge x_2 - x_c \geq 0 \\ 180 - \alpha_1, y_2 - y_c \geq 0 \wedge x_2 - x_c < 0 \\ 180 + \alpha_1, y_2 - y_c < 0 \wedge x_2 - x_c < 0 \\ 360 - \alpha_1, y_2 - y_c < 0 \wedge x_2 - x_c \geq 0 \end{cases}$	

Table 2. - Circular interpolation parameters ( $r, \alpha_0, \alpha$ ) for given interpolation center coordinates  $x_c, y_c, z_c$

If circular interpolation is defined by its radius  $r$ , interpolation center coordinates  $x_c, y_c, z_c$ , circular interpolation angle  $\alpha$  and start angle  $\alpha_0$  have to be calculated. Generally, for given coordinates  $x_1, y_1, z_1$  and  $x_2, y_2, z_2$  and radius  $r$  for same type of circular interpolation, there are two possible tool paths (circular arcs corresponding two different center points presented at Fig.2a). For determination of circular interpolation center coordinates  $x_c, y_c, z_c$ , rhombus with side  $r$  and diagonal corresponding arc chord  $t$  is observed (Fig.2b).

For circular interpolations G02 and G03, sign of radius  $r$ , and thereby arc center coordinates, is determined by

arc of interpolation (Table 3).

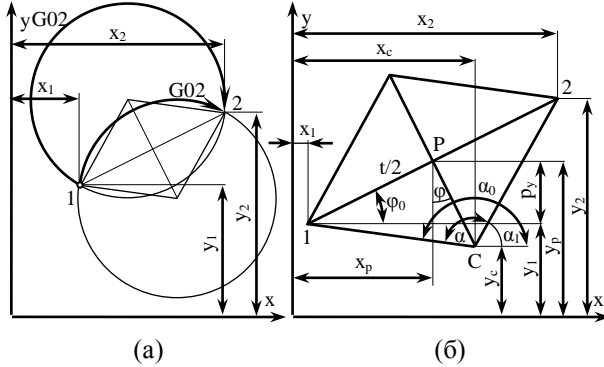


Figure 2. Determination of circular interpolation center coordinates  $x_c, y_c, z_c$ ,

Circular interpolation radius  $r$  in NC program is positive ( $r > 0$ ) for angle  $\alpha \leq 180^\circ$ , and negative for angle  $180^\circ < \alpha \leq 360^\circ$ .

In Table 3, one case of determination of circular interpolation center coordinates is presented.

Case: G17; G02, $r > 0$ and G17; G03, $r < 0$	
$0 \leq \varphi \leq 90^\circ, \varphi = \varphi_0$ $x_c = x_p + p_x; y_c = y_p - p_y$	$90^\circ < \varphi \leq 180^\circ; \varphi = 180 - \varphi_0$ $x_c = x_p + p_x; y_c = y_p + p_y$
$180^\circ < \varphi \leq 270^\circ; \varphi = 180 + \varphi_0$ $x_c = x_p - p_x; y_c = y_p + p_y$	$270^\circ < \varphi \leq 360^\circ; \varphi = 360 - \varphi_0$ $x_c = x_p - p_x; y_c = y_p - p_y$

Table 3. Circular interpolation center coordinates

By introducing the coefficients:

$$k_g = \begin{cases} 1, & \text{for G02} \\ -1, & \text{for G03} \end{cases} \quad (6)$$

and

$$k_r = \begin{cases} 1, & r > 0 \\ -1, & r < 0 \end{cases} \quad (7)$$

circular interpolation center coordinates  $x_c, y_c, z_c$ , are calculated (for G17):

$$\begin{aligned} x_c &= x_p + k_g \cdot k_r \cdot p \cdot \sin \varphi \\ y_c &= y_p - k_g \cdot k_r \cdot p \cdot \cos \varphi \end{aligned} \quad (8)$$

Start angle  $\alpha_0$  is determined as (for G17):

$$\alpha_0 = \left| \arctg \left( \frac{y_1 - y_c}{x_1 - x_c} \right) \right| \quad (9)$$

$$\alpha_0 = \begin{cases} \alpha_0, & y_1 - y_c \geq 0 \wedge x_1 - x_c \geq 0 \\ 180 - \alpha_0, & y_1 - y_c \geq 0 \wedge x_1 - x_c < 0 \\ 180 + \alpha_0, & y_1 - y_c < 0 \wedge x_1 - x_c < 0 \\ 360 - \alpha_0, & y_1 - y_c < 0 \wedge x_1 - x_c \geq 0 \end{cases} \quad (10)$$

Angle  $\alpha$  is calculated:

$$\alpha = \begin{cases} 2 \cdot \left| \arccos \frac{p}{r} \right|, & k_r = 1 \\ 360 - 2 \cdot \left| \arccos \frac{p}{r} \right|, & k_r = -1 \end{cases}$$

### 3. USING OF DATA FROM NC PROGRAMS

Every single NC program block  $b_i^{NC}$

**N G X Y Z I J K R F S T M**

can be transformed into one record of database table with structure shown as [3]:

NCtabel1(N, G, X, Y, Z, ...)																		
N	G	X	Y	Z	I	J	K	R	F	S	T	M	Tool	interpolation	direction	feed rate f	spindle speed s	...
													mm/	o/min				
...	$x_1$	$y_1$	$z_1$	$x_2$	$y_2$	$z_2$	$x_c$	$y_c$	$z_c$	$r$	$\alpha_0$	$\alpha$						
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	°	°						

Table 4. Database table record

In every record (row) of table NCtabel1(N, G, X, Y, Z, ...) according to fields obtained by transformation of data from NC program block (G, X, Y, Z, ...) corresponding fields (feed rate, spindle speed, ...) are calculating. According to this table, records in database tables are created with following structures:

NCprogrami(nazivncprg, ...)				
NC program name	no G01	no G02	no G03	no G8x

Table 4. Structure of database table kinematic records

Alati(nazivncprg, oznalncprg,...)						
NC program name	Tool no	Diametar	Number of flutes	Tool life	Cost index	Shape of tool
		mm		min		

Table 5. Structure of database table technological records

Every record of the table [NCprogrami\(nazivncprg,...\)](#) corresponds to one NC program, with addition of fields related to number of interpolations. One record of the table [Alati\(nazivncprg, oznalncprg, ...\)](#) corresponds to one tool, one cutting feed and one spindle speed in one NC program.

Therefore, NC programs placed in ASCII files are transforming into database tables. First, every NC program block converts into corresponding record of NC table, then in accordance with fields obtained by transformation of data from NC program block (G, X, Y, Z, ...) corresponding fields are calculated (Fig. 3).

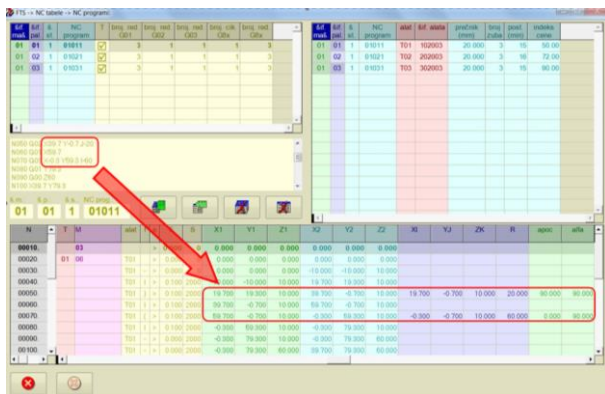


Figure 3. Program blocks transfer and calculation of corresponding fields

For each NC program a single NC database table is created. NC blocks are transferred by decomposition on program words. Firstly, program block no („Nxxxx“) is transferred, and then the block is checked for existence of G function. After G functions, kinematic (X, Y, Z, I, J, K and R) and technological parameters (F and S) are transferred. Then, tool no (T) in tool storage is transferred. Finally, program block is checked for existence of M functions. Based on M functions, tool no (T) is assigned to each record.

#### 4. CONCLUSION

According to the processed data from the NC program and blank geometry, tool path and the cutter location relative to the workpiece can be generated at appropriate spatial intervals along a path, using Matlab program.

The program is developed to track changes in depth and width of the cut and engagement angle along the tool path. On the basis of these variations, cutting force during the milling process can be monitored. Based on the analysis of the cutting force diagram for the different tool paths, a methodology for assessing the tool path and selection of the most appropriate path from the point of minimum cutting force variations can be developed. The analysis can also include other criteria such as tool wear, the total processing time and process stability.

#### 5. REFERENCES

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