University of Banja Luka
Faculty of Mechanical Engineering
DEMI 2017
13th International Conference on Accomplishments in Mechanical and Industrial Engineering

FUNCTIONS FOR PROCESSING OF WOKPIECE CAD MODEL FOR PREDICTION AND OPTIMIZATION OF MILLING PROCESS

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Summary: *This paper deals with specific presentation of wokpiece volume and with functions for manipulating them in order to extract necessary data for various functions in virtual manufacturing environment. Basic idea was to use standard STL output of created model of blank material and convert to Z-map model. Functions for simulation of material removal process and extracting of geometry of instant tool immersion conditions are developed in Matlab environment. Exacting of engaging (tool immersion) map along discretized tool path is of great importance for application of model for instant cutting forces, based on simulation of discetized cutting geometry of the tool. Such simulation algorithm provides a solid base for prediction of cutting forces along tool path and for optimization of NC part program via feedrate scheduling. Presented methodology is tested in milling operations for machining of planar contours with flat end-mills, and some illustrative results are shown.*
Key words: machining simulation, CAD/CAM, milling, NC program optimization, Z/map

1. INTRODUCTION

Almost ten last year great improvements were made in commercial CAM software in order to take in account physicality of the cutting process. Such improvements are recognized as strategies for adaptive roughing and feedrate scheduling [1,2]. The first one assumes specific tool path (morphing spiral, trochoidal path, corner slicing etc.) that ensures constant immersion angle and further constant cutting force along such path. The second one assumes rediscretization of the programmed tool path and redistribution of the feedrate along such path in order to guarantee constant level of cutting forces. Applied algorithms for such strategies work with partial success. Representative cutting forces in execution of generated NC part programs will be almost constant but their level cannot be guaranteed. This is the reason for development of various algorithms for prediction of cutting forces. Many of research activities, in this field, use various presentations of work piece volume (voxel, Z-map, dexel, octree, CSG, etc. [5,6]) more or less suitable for processing and storing in typical

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functions of virtual manufacturing (predictions of: surface roughness, cutting forces and chattering and also for optimization of the NC part program). In our laboratory a set of functions for processing of workpiece model according to given NC program, based on its Z-map presentation were developed [3,4]. Functions that are described in this paper are: creating of Z-map of the blank, functions for discretization of the programmed tool path, functions for updating of workpiece model according to NC-program propagation and functions for extracting area of the workpiece engaged with the tool in points of tool path.

2. Z-MAP MODEL OF THE BLANK AND WORKPIECE

Z-map presentation of the workpiece volume is well known. It has matrix form containing linear elements of the finite length (Fig 1a) [5,6]. Such matrix can be generated easily in many programs for simple geometry of blanks. For more complex blank geometries, using of power of CAD modellers is desirable.

For this reason function *stl2zmap* is developed in Matlab. It uses standard ASCII STL output of software for solid modelling. Basic steps of the procedure implemented in this program function are: convert triangles of the STL model in Matlab patches, their manipulation (translate, rotate, flip) selection of the base and eliminating of patches perpendicular to the base.

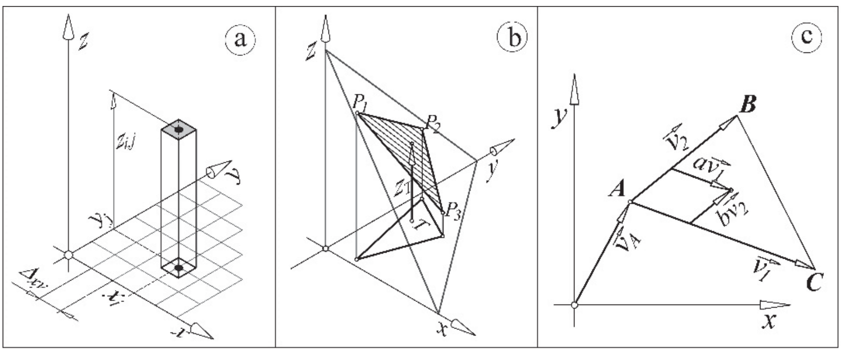

Fig. 1 *Element of the Z-map (a) identification by patch of the hull (b) definition of the point in triangle (c)*

Further, this function calculates elements of Z-map (Z-coordinates of the hull) for each point of the grid in selected base plane. Each point of the base (x_i, y_j) should be checked if it belongs to projection of the certain patch. After that, distance (z_{ij}) along z-direction between point in the base and intersection with identified patch should be calculated. Condition for checking if point T belongs to the triangle ABC in the base of the Z-map is formulated as:

$\overrightarrow{AT} = a\vec{v}_1 + b\vec{v}_2$ and $\overrightarrow{AT} = a\overrightarrow{AC} + b\overrightarrow{AB}$, with condition: $a \geq 0 \wedge b \geq 0$.

element $Z_M(i, j) = z_T$, of the Z-map, corresponding to such point *T*can be obtained using equation of the plane of actual patch of the workpiece hull:

$$A x_1 + B y_1 + C z_1 = D,\ A x_2 + B y_2 + C z_2 = D,\ A x_3 + B y_3 + C z_3 = D.$$

After substitutions: $A1 = -A/D$, $B1 = -B/D$, $C1 = -C/D$ and

$R = \begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ x_3 & y_3 & z_3 \end{bmatrix}$, $Z_M(i,j)$ can be obtained as:

$Z_M(i,j) = z_T = (1 - A1 x_T - B1 y_T)/C1$. One example of Z-map creating, starting from solid model of the part (a) via STL and patch-model (b) to Z-map model (c) is shown in Fig 2.

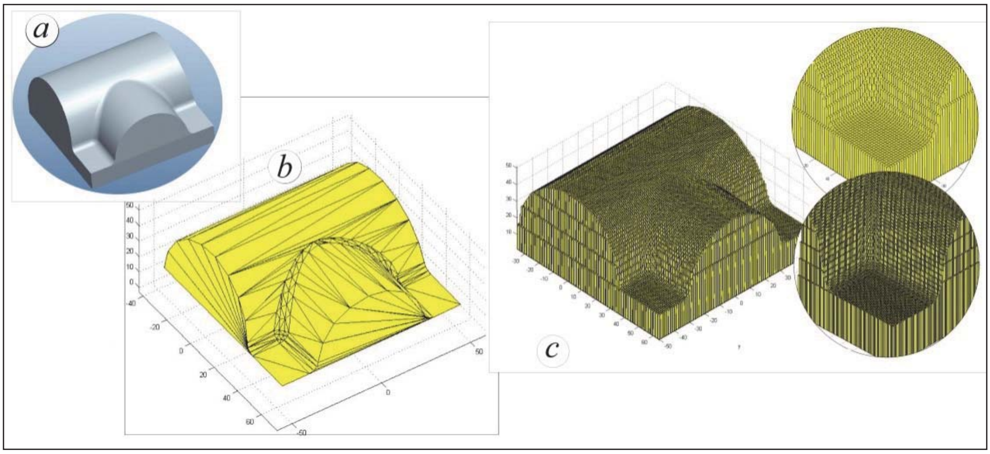

Fig. 2 *An example of creating the Z-map model*

3 . DISCRETIZATION OF THE TOOL PATH

Coordinates of toolpath points are required for most of the mentioned functions of virtual machining environment. Regarding this, specific Matlab function (*fragmented)* is created. It uses postprocessed part program (created in CAM) in standard G-code format (ISO 6983). This functions is capable to extract toolpaths for milling of planar contours. As a criterion for this extracting the change G0 (G1) Z... to G1(G2,G3) X... Y...F... and vice versa, was used. Process of disretization can be applied for all programmed planar contours. First step in this process is reconstruction of the toolpath elements (lines G1, or arcs G2/G3) and storing of toolpath in specific matrix form useful for further processing. One example of tool path in G-code format and its proposed matrix presentation is shown in Fig. 3. Each part program line is presented by the frame with following attributes: Local number, Label No. in original program, associated feed and speed and path shape (G1/G2/G3). Any arc (G2/G3) is decomposed in its quadrants (called segments). Frame also includes coordinates of starting (X_S,Y_S,Z_S) and end point (X_E,Y_E,Z_E) of segment as well as direction of feed vector in start and end point (*Ang_S*, *Ang_E*), centre of the arc segment (X_C,Y_C) and its radius (*Rad*).

(a)

```
%
:8200(DEMO_PATH.TAP)
….
N150 G0 X-5.75 Y4.75
N160 G1 Z4.F1600
N170 G1 Z-8. F300
N180 G3 X-10.5 Y0. R4.75 F200
N190 Y-19.
N200 X0.
N210 G3 Y19. R19.
N220 G1 X-10.5
N230 Y0.
N240 G3 X-5.5 Y-5. R5.
N250 G0 Z30.….
```

(b)

LinNo	*LinLab*	*Seg*	*Segs*	*LinType*	*Feed*	*Speed*	*Quad*
1	180	1	1	3	200	1100	2
2	190	1	1	1	200	1100	0
3	200	1	1	1	200	1100	0
4	210	1	2	3	200	1100	4
5	210	2	2	3	200	1100	1
6	220	1	1	1	200	1100	0
7	230	1	1	1	200	1100	0
8	240	1	1	3	200	1100	0

■ ■ ■

Xs	*Ys*	*Zs*	*Dirf_s*	*XE*	*YE*	*ZE*	*Dirf_E*	*XC*	*YC*	*Rad*	*Ang_S*	*Ang_E*
-5.750	4.750	-8.000	180.000	-10.500	0	-8.000	-90.000	-5.750	0	4.750	90.000	180.000
-10.500	0	-8.000	-90.000	-10.500	-19.000	-8.000	-90.000	0	0	0	0	0
-10.500	-19.000	-8.000	0	0	-19.000	-8.000	0	0	0	0	0	0
0	-19.000	-8.000	0	19.000	0	-8.000	90.000	0	0	19.000	-90.000	0
19.000	0	-8.000	90.000	0	19.000	-8.000	180.000	0	0	19.000	0	90.000
0	19.000	-8.000	180.000	-10.500	19.000	-8.000	180.000	0	0	0	0	0
-10.500	19.000	-8.000	-90.000	-10.500	0	-8.000	-90.000	0	0	0	0	0
-10.500	0	-8.000	-90.000	-5.500	-5.000	-8.000	0	-5.500	0	5.000	180.000	-90.000

Fig. 3 *An example of frames (b) for particular tool path (a)*

The next step is disretization of the tool path according to the specified increment. As a result one matrix will be created. Each row in this matrix consists from coordinates of the specific point of the tool path with value of angle which specifies inclination of corresponding feed speed vector, in this point, to the positive side of x-axis of WP-coordinate system. Each point is referenced to its segment (matrix in Fig. 2).

4. SIMULATION OF MATERIAL REMOVAL

Functions that ensure vizualization of material removal process according to propagation of the simulated NC part-program are implemented in the most of commercial CAM software. Its high resolution, rendering performances and high speed of workpiece geometry updating [1,2] are not so important for functions of predicting effects of process (forces, chattering). Specific updating of wokpiece model in this functions [5,6] is required in cases of milling in multiple passes, closely distributed or intersecting toolpaths. For this purpose, in our case, Matlab function *sim_path* is created. This function uses following inputs: (1) Z-map of the blank, (2) parameters of the cutter profiler and (3) discretized tool path in matrix form, discussed in the previous section. Updating of the Z-map model of the wokpiece according part program is achieved by using of 2 subroutines: *plunger* (applicable in the points of discretized path) and *digger* (between 2 subsequent points of the path), as shown in Fig. 4

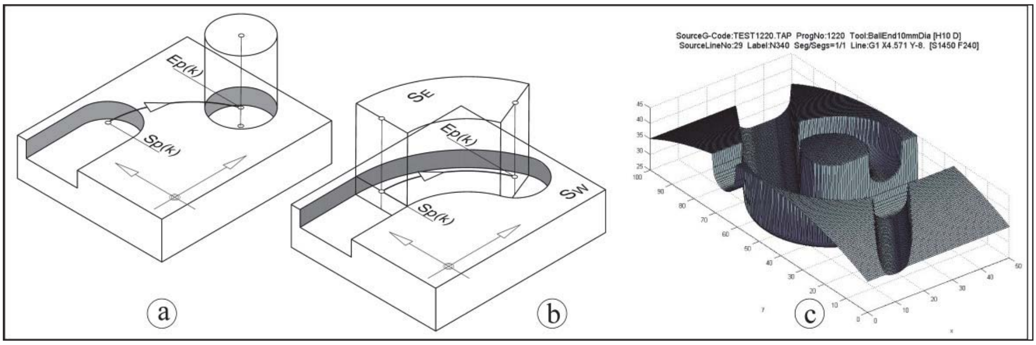

Fig. 4 *Functions for updating of Z-map model of the workpiece: plunger (a), digger (b) and example of their use (c)*

5. EXTRACTION OF THE TOOL ENGAGEMENT MAP

Figure which presents area of engagement of cutting tool into workpiece material here is denoted as engagement map. Reconstruction of this area in each point of the discetized tool path is very important, as input for different algorithms for prediction of cutting forces and for feedrate scheduling [4].In certain point of discretized tool path this reconstruction assumes identification of the elements of the workpiece Z-map distributed along half-cylinder defined with coordinates of the tool tip, cutter profile and oriented according to the instant vector of the feed speed (Fig. 5)

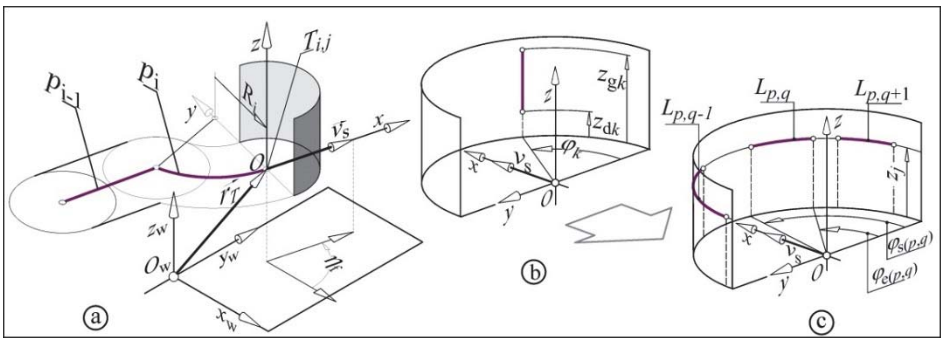

Fig. 5 *Engagement map: problem formulation (a), data structures: z(φ) (b) and φ (z) (c)*

Engagement map, obtained by function *explorer,* has a matrix structure. Each row has an angular coordinate φ_K and corresponding lower and upper limit (z_{dk}, z_{gk}) of engaged element of the Z-map. Such structure is appropriate for calculation of engaged area (A) or its projection (A_X), as well as for obtaining coordinates (y_T, z_T) of the center of gravity of such projection. This area and coordinates (y_T, z_T) are used in some CAM systems for feedrate scheduling based on criterion of constant material removal rate. Algorithms [4,7] that use simulation of one revolution of the cutter with discretized (slices) geometry (mechanistic approach) require another data structure which describes engagement map. Function *zfi2fiz* performs transformation from described form (φ_{K}, z_{dk}, z_{gk}) into matrix form with rows which describe start and end angle of up to 2 arcs on each z-level (corresponding to slices of the cutter). One example of application of functions described in this work is shown in Fig. 6.

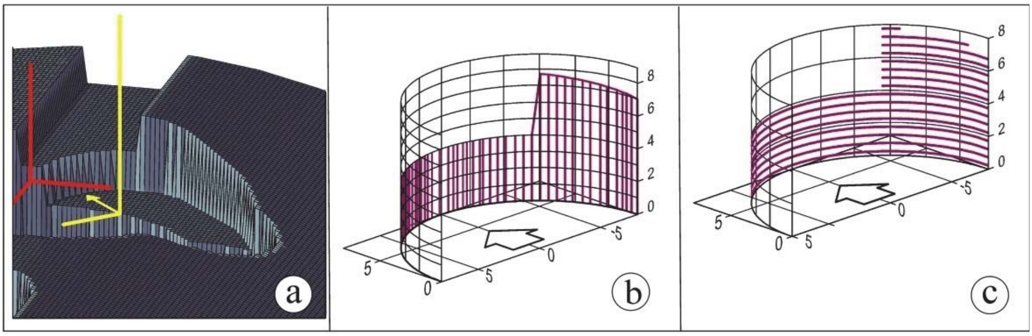

Fig. 6 *One example with updated Z-map of the workpiece (a) and reconstructed engagement map (b,c) in certain point of the discretized tool path*

6. CONCLUSION

A set of programs, developed in Matlab, for manipulating of workpiece model during simulation of NC-program is shown in this paper. They use STL model of the blank and postprocessed NC program in G-code. As a result, these programs enable identification of the engagement map in each point of discretized tool path. This is necessary condition for use of various algorithms for predicting of cutting forces and chattering, as well as for optimization of the NC program, based on feedrate scheduling.

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