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Tool Path Generation for Pocket Machining Operations with Island

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Abstract

A new method, in which suitable tool paths are generated in order to manufacture pockets in CNC milling machines, was developed in this study. For this purpose, a new algorithm was developed in order to offset pocket profiles with or without the island. In addition, errors that may arise as a result of offsetting were also eliminated. The tool path was generated by using the offset components obtained through this offsetting process. The acquired tool paths were tried after being sent to CNC milling machine. The success of the developed method was proved without any hollow or residue.

1. INTRODUCTION

One of the most frequently used methods in tool-path generation process is the tool path generation method through repetition of profiles. An accurately-working offsetting method is required for repetition of profiles. According to the literature researches, various studies have been conducted for solving the offsetting problem.

Although there have been numerous studies aimed at the offsetting problem, they can generally be collected under a few main titles. The first of them is the method of offsetting process through “voronoi curves”. These curves are used in order to prevent the errors that may arise during the intersection of offset components that are formed in the offsetting process [1-3].

Another commonly used method is the invalid loop elimination method. In this method, closed sub-profiles that form by the offsetting of the closed profile are evaluated independently. These profiles are classified as valid and invalid, and those that are invalid are eliminated. Valid profiles constitute the correct offsetting result. There are various approaches to determine whether the profiles are valid or not. In one of these studies, the profile’s direction was taken as a reference [4]. In another study, the validity of one of the formed profiles was determined through mathematical functions. Afterwards, other profiles were evaluated and their validities were determined according to this profile [5].

In another common method, the circle with a radius that is equal to the offsetting distance is dragged in a tangent line with the profile to be offset. Offsetting result is achieved by using the orbit where the circle’s center moves [5-7].

In the process of offsetting the pocket profiles with islands, the border components that form island profiles are also subject to the same processes together with the components of the main profile. Unlike the main profile components, island profiles are offset outwardly [1, 8-10].

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In the studies conducted by Dilipak et al., the components forming the profile were individually offset at first and then according to the condition of the profile, offset components were extended or clipped and interconnected [11,12]. In the subsequent studies of the researchers, junction points of components have also been included in the offsetting process, and extensions and clippings have been eliminated [13]. While offsetting the profiles with islands, components that belong to the main profile and island profile have been offset together and have been subjected to the same error debugging processes [14].

In this study, a reliable offsetting process was used. The errors that may arise in the offsetting process were eliminated with a more practical and applicable error debugging approach. The tool paths to process the pocket were generated by using the offset components that were obtained through the error debugging. While generating tool paths, proper G and M codes were also generated according to the features of the offsetting component. After the tool path generation process, the NC file including and M codes was transferred to the CNC machine. Pocket machining experiments were conducted by using suitable work parts. When experimental samples were examined, it was observed that there was a successful machining without residue or hollow. Developed software generates CNC codes accordance with FANUC operating system. In addition, it is possible that this program can generate CNC code for other operating systems by adding code to the program. This program are suitable to generate CNC code.

2. RETRIEVING THE DATA OF POCKET PROFILE FROM DXF FILE

The method developed in this study was performed with software prepared in Delphi environment. This software is able to read the data of the pocket profile from a DXF file that was created by any cad-cam software. The data of components of the pocket profile and island profile were read through the developed software, and the pocket and island components were recognised. Component data were converted into different formats to be processed more easily after being recognised. An example of DXF file and content of new file derived from first one are shown in Figure 1.

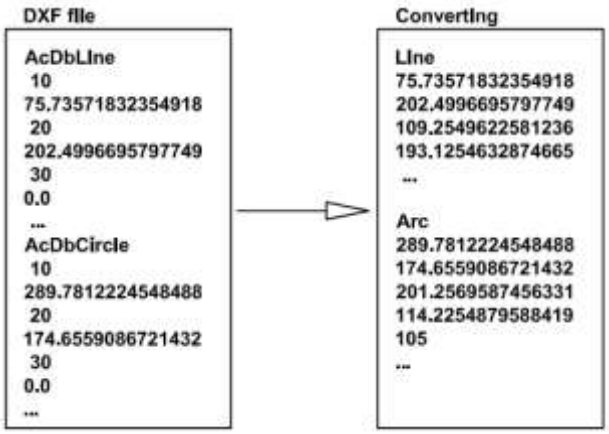

Figure 1. *Converting DXF file to new data format*

3. DETERMINATION OF COMPONENT SEQUENCES AND SEQUENCE DIRECTIONS

While processing the pocket, the cutter moves by following a certain path continuously. Therefore, the components forming the profiles should also be lined in a chain. With the help of the developed software, components were rearranged where the starting point of every component was the ending point of the previous component (Figure 2).

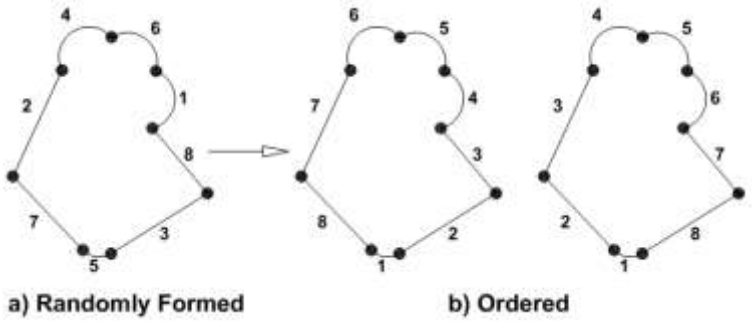

Figure 2. *Randomly formed and ordered profile components*

Offsetting each of the components, forming the pocket or island profile, to the left or right may lead the pocket profile to offset inwardly or outwardly. In order to determine to which direction the profile is offset when components are offset to certain directions, sequence directions of components are required to be determined. A point outside of the profile was detected with the help of the developed software. The sequence direction of the profile was determined by controlling direction of the component that was closest to this point (Figure 3).

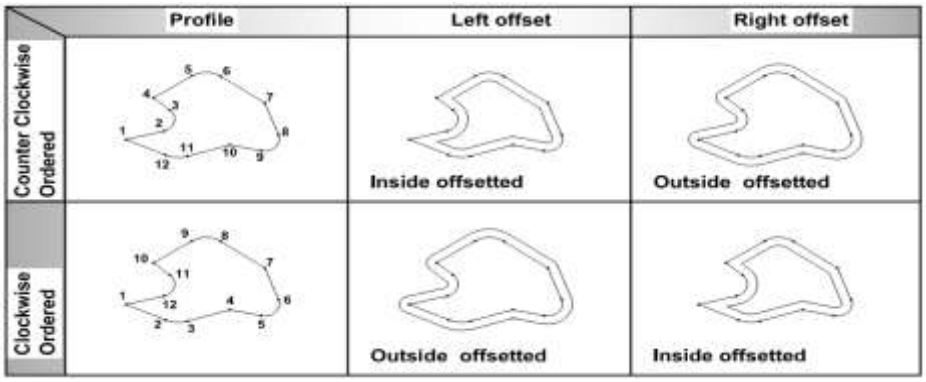

Figure 3. *Left and right offsetting of components that formed the profile*

4. OFFSETTING OF THE COMPONENTS

Each of the components that formed the island and pocket profiles was primarily offset individually. Beginning and ending coordinates were used while the lines on pocket profiles were being offset (Figure 4). Beginning and ending points of offset line were extended to the offset direction as far as offset distance.

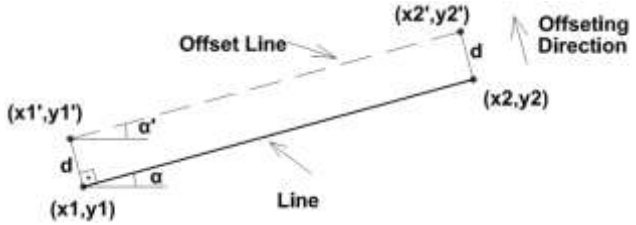

Figure 4. *Offsetting of a line*

Begining and ending coordinates of offset line were obtained by using the values of line, which are going to be offset, with the equations at the equality 1-4.

$$x_1' = x_1 + \cos(90 + a) \cdot d \quad (1)$$

$$y_1' = y_1 + \sin(90 + a) \cdot d \quad (2)$$
$$x_2' = x_2 + \cos(90 + a) \cdot d \quad (3)$$
$$y_2' = y_2 + \sin(90 + a) \cdot d \quad (4)$$

At the offsetting of arches on pocket profile, coordinates of arch center does not change. During offset beginning and ending angles of the arch also does not change. But at the offsetting of arch inwards, enormity of offsetting distance upon arch radius is an exception. In this case beginning and ending angles of the arch increases 180°. If offsetting distance and arch radius is equal, offset arch does not occur (figure 5).

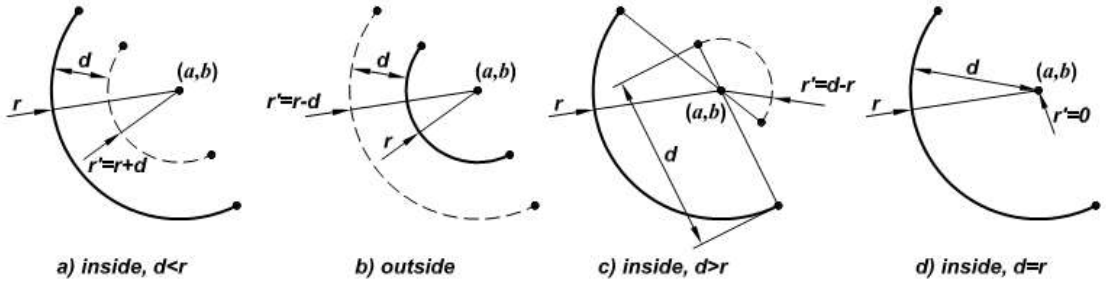

Figure 5. *Ofsetting of arches*

Radius, beginning and ending angles of offset arch were obtained by using the values of arches, which are going to be offset, with the equations at the Equality 5-8.

$$r' = r + d \quad (5)$$
$$r' = r - d \quad (6)$$
$$\alpha_s' = \alpha_s + 180 \quad (7)$$
$$\beta_s' = \beta_s + 180 \quad (8)$$

During these offsetting processes, not only the components forming the profiles, but also the junction points of these components were offset.While the components of the pocket profile were offset inwardly, the components forming the island profiles were offset outwardly. The errors that may arise through offsetting were ignored in this phase (Figure 6).

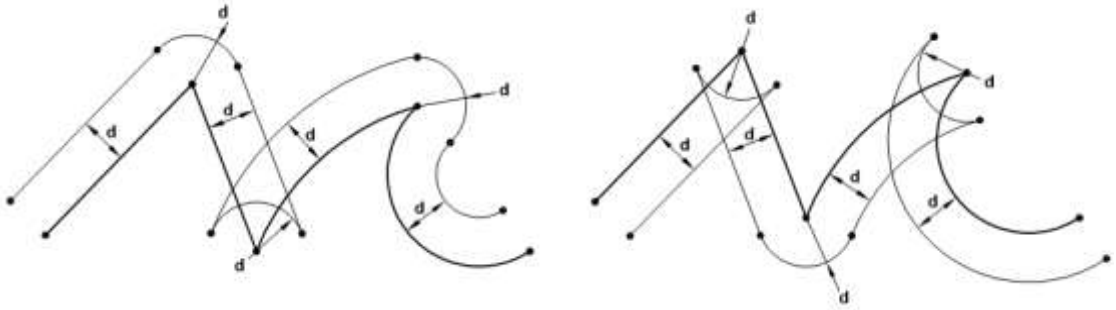

Figure 6. *Individually offsetting of the components forming the profile*

Island and pocket profiles were offset after all components forming island and pocket profiles were offset (Figure 7).

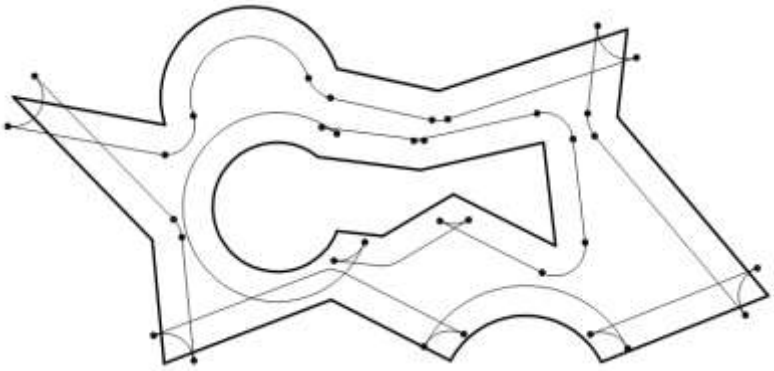

Figure 7. *Offsetting of pocket and island profiles*

5. BREAKING OF OFFSET COMPONENTS AND ELIMINATION OF ERRORS

Component breaking process was conducted in order to eliminate the defective parts while offsetting the offset components. The purpose of the breaking process is to eliminate the defective excesses that formed during offsetting while preventing the defect-free parts from being discarded. All offset components forming through offsetting of profile components were broken from the points they intersected with each other. Each part forming as a result of the breaking process was assessed as independent components (Figure-8).

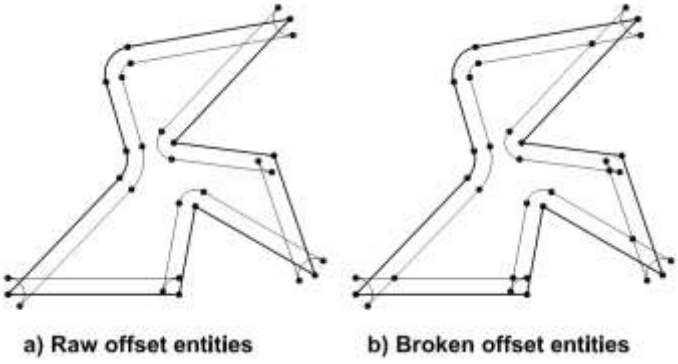

Figure 8. *Breaking of offset components*

While performing the breaking processes, offset components were evaluated two by two and intersection points of these two offset components were found by using analytical equations. During intersection points of offsetting lines were being found respectively for line-line, arch-arch and line-arch pairs, equations at the Equality 9-11 which were obtained by mutual solution of analytical equations were used.

$$x = ([(y_2'-y_1')/(x_2'-x_1')]x_1-[(y_4'-y_3')/(x_4'-x_3')]x_3'+y_3'-y_1')/([(y_2'-y_1')/(x_2'-x_1')]-[(y_4'-y_3')/(x_4'-x_3')]) \quad (9)$$

$$4x^2[(a_1-a_2)^2+(b_1-b_2)^2]+x[4(a_1-a_2)(a_2^2-a_1^2+r_1^2-r_2^2+(b_1-b_2)^2)-8a_1(b_1-b_2)^2]+(a_2^2-a_1^2+r_1^2-r_2^2+(b_1-b_2)^2)^2-4(b_1-b_2)^2(r_1^2-a_1^2)=0 \quad (10)$$

$$x^2(1+m^2)+x(-2a+2m(-mx_1+y_1-b))+(a^2+(-mx_1+y_1-b)^2-r^2)=0 \quad (11)$$

x: X axis coordinate of junction point.
(x_1, y_1), (x_2, y_2): Beginning and ending coordinates of first line.
(x_3, y_3), (x_4, y_4): Beginning and ending coordinates of second line.
(a_1,b_1): Central coordinates or first arch.

r_1: Radius of first arch.
m: Slop of line

After the breaking process, errors wererendered to be eliminated by discarding the unnecessary offset components. In the subsequent phase, unnecessary offset components weredetermined and eliminated. The following three rules were taken as reference in order to determine whether an offset component was valid or not [12].

- Offset components intersecting with the pocket profile and/or island profile were invalid.
- Offset components that were closer to the pocket profile and/or island profile than offsetting distance were invalid.
- Offset components inside of the island profile or outside of the pocket profile were invalid.
- Offsetting errors were eliminated by discarding the invalid components determined according to these three rules that were taken as reference (Figure 9).

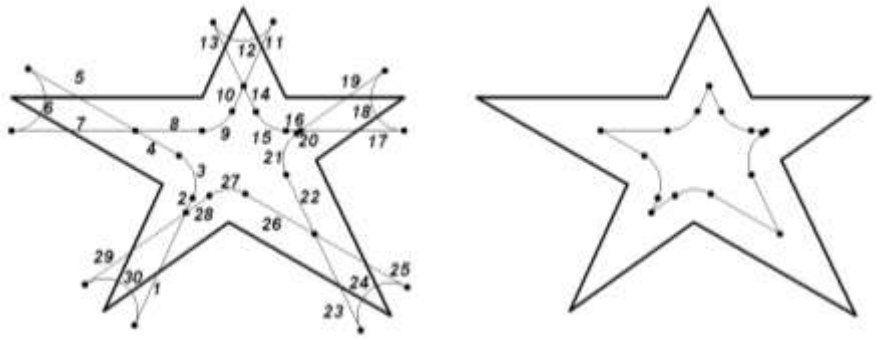

Figure 9. *Elimination of offsetting errors*

After achieving a defect-free offsetting process, the tool path generation phase was started.

6. GENERATION OF THE TOOL PATHS

While processing the pocket profile, the side-slip distance identified for the cutting tools wasused as the offsetting distance in the offsetting process. Offsetting process was repeated in order to machine the pocket profile thoroughly. In the first offsetting of the pocket profile and island profile, the offsetting distance was identified as the total of the radius of the cutting tool and the finishing cutting depth amount to be left on side walls. In every new offsetting, the offsetting distance was increased as much as the side-slip distance. Offsetting process was repeated until no valid offsetting result was obtained (Figure 10).

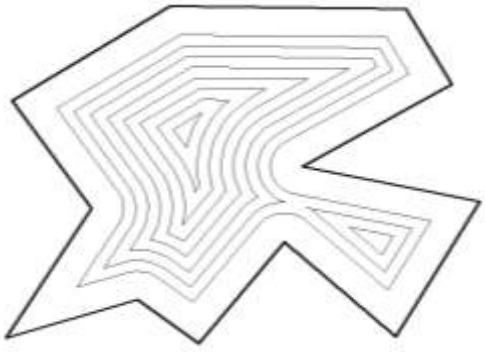

Figure 10. *Repetition of offsetting process*

The offsetting results obtained after the offsetting processes formed the new sub-profiles. When the cutting tool moves on these profiles, the pocket profile would thoroughly be processed (Figure 11).

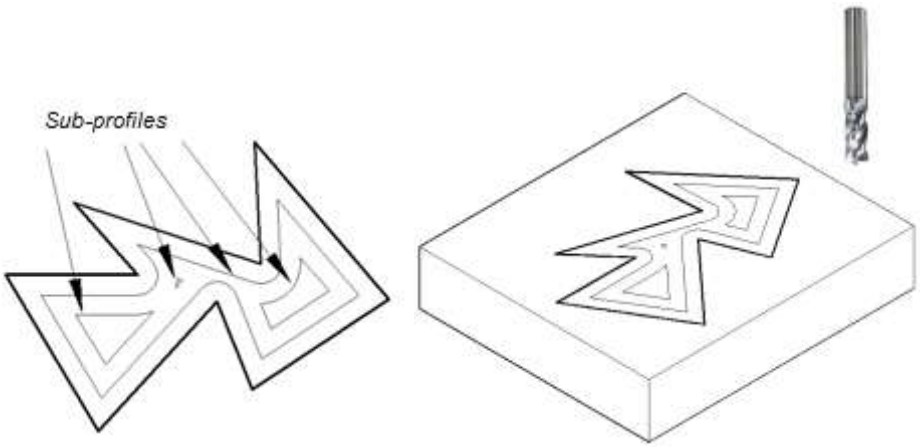

Figure 11. *Sub-profiles formed through the repetition of offsetting process*

However, the profiles where the cutting tool would be moving on should be lined according to a certain sequence. Additionally, the transition moves from one profile to another should also be determined. Offset profiles were associated with each other through the software developed in Delphi environment. The obtained offset profiles were lined hierarchically from outward to inward. The profiles with the same hierarchical sequences were also grouped among themselves in order to minimise the processing time (Figure-12).

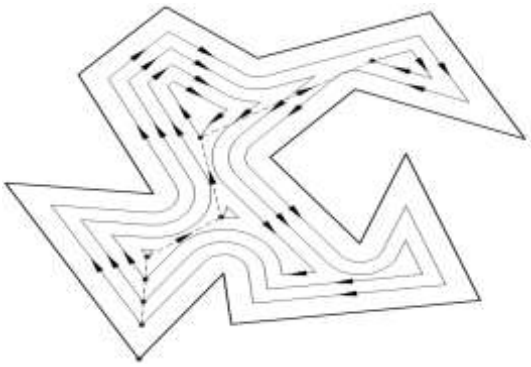

Figure 12. *Closed profiles with specified processing hierarchies*

7. GENERATION OF NC CODES

After determining the tool paths, they have been converted into required NC code for CNC machine. Than, this codes have been generated as accordance with FANUC oparating system. As showns figure 13, Lines ans arc forming offset the profile have been converted G codes corresponding to cutting tool's linear and circular movements.

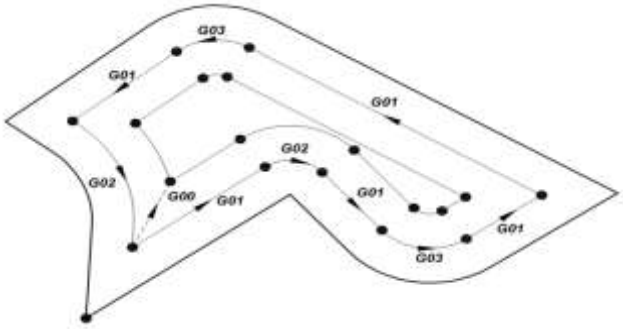

Figure 13. *NC codes that are obtained from profile components*

Besides, developed software wants to speed and feed rate values from user. As shown Figure 14 and Figure 15, developed software generates NC codes according to cutter locations obtained from DXF files and cutting parameters that are achieved from developed program interface.

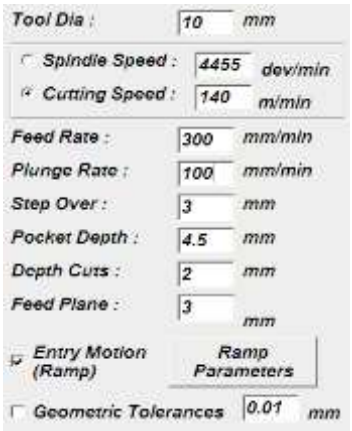

Figure 14. *Entering cutting parameters to program*

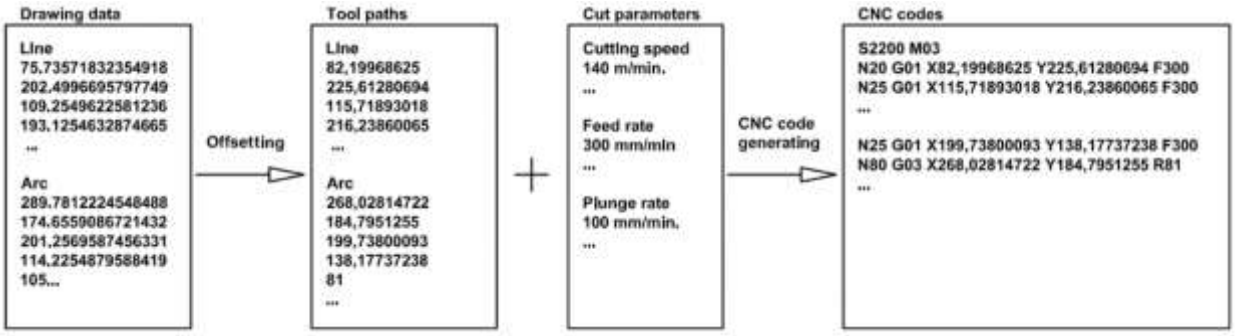

Figure 15. *Generating CNC codes*

Then, this codes are saved as the extension of "*.nc" and this codes are transferred to the CNC machine. Therefore, machining of workpiece havign island profile and having extension of *.dxf file has been performed. In order to reability of program under study, different profile shown in Figure 16 have been denied and NC codes have been succesfully derived.

Figure 16. *Some machined pockets*

Then this codes have transfered to CNC machine and manufacture of this parts have been performed with high accuracy.

8. CONCLUSION

In this study which serves as the continuation of a series of studies, a tool path was generated for pockets with islands by using the data obtained through the developed offsetting method. The used offsetting method is a method with high applicability where errors could easily be defined and eliminated. Pockets with complicated shapes and with or without islands wereenabled to be processed in CNC milling machines in a short term.

The developed methods were applied through the software developed in Delphi environment, and offsetting and tool path generation results could be visually followed.

In the offsetting process, analytical equations of profile components were used in order to determine the intersection states of profile components and perform breaking processes. While offsetting the profiles with curves, successful results were obtained compared to the current CAD software [11].

The developed methods were applied through software developed in Delphi environment. The tool path data obtained from the applications were tried on suitable billet pieces in the CNC machine. Pockets with and without islands were successfully machined as a result of the conducted experiments. Machining errors caused byresidue and hollow on experimental specimens did not occur.

Developed sotfware has been prepared for Fanuc opereating system. However, it is possible that suitable for the other operating systems through new arrangements to be made.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

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