Management and Production Engineering Review
Volume 4 • Number 4 • December 2013 • pp. 50–58
DOI: 10.2478/mper-2013-0037

ALGORITHM FOR ISO 14649 (STEP-NC) FEATURE RECOGNITION

Janusz Pobożniak

Cracow University of Technology, Production Engineering Institute, Poland

Corresponding author:
Janusz Pobożniak
Cracow University of Technology
Production Engineering Institute
Jana Pawła II 37, 31-864 Kraków, Poland
phone: +48 12 3743266
e-mail: pobozniak@mech.pk.edu.pl

Received: 30 September 2013
Accepted: 5 November 2013

Abstract

The paper focuses on the algorithm for the recognition of manufacturing features defined in ISO 14649 (STEP-NC). First, the features defined in STEP-NC standard are discussed and then commonly used feature recognition methods are presented. Then the developed algorithm for recognition is presented in details starting with the discussion of STEP-NC features from the point of view of their recognition. The steps of the algorithm responsible for the recognition of profile based, transition and group features are presented. The software developed to verify the algorithm is also described. The final part includes the directions for the future research works. This paper adds to the works aimed to strengthen the position and use the full benefits of this new ISO 14649 standard.

Keywords

ISO 14649, ISO 10303, machining feature recognition, STEP-NC, CNC machine tool programming, computer aided process planning, CAD/CAPP/CAM integration.

New ISO 14639 standard (STEP-NC)

The CNC machine tool programming standard ISO 6983 [1] used for more than 50 years has many disadvantages and restrictions [2]. To change this situation, the new programming standard, namely ISO 14649 (STEP-NC) [3, 4] was introduced. This standard allows to include the full information about the machining tasks, set-ups, part to be machined, tools and the manufacturing features [2] in the control program. Thus it supports the integration of the several engineering application, which is required to implement the concurrent engineering approach [5]. Because of these characteristics, it should be considered during the implementation of technical aspects of Lean philosophy [6]. The set of information contained in STEP-NC format can also be used for some management tasks, as for example for effective management of technological machines system in a production company [7] or multiple-criteria approach to machine-tool selection [8, 9].

This standard uses manufacturing features. According to commonly used definitions, the manufacturing feature is the set of information about the part, containing both the geometrical and non-geometrical information, significant from the point of view of manufacturing process planning. As the examples of manufacturing features, the closed pocket, through slot or counterbored holes can be given. Three methods are commonly used to create feature based model (Fig. 1). In the first method, the user interactively defines the features by selecting the geometric elements. The obvious weakness of this methods is its time-consumption and no possibility to automate this process. The second method is the manufacturing feature oriented design. In this method, the part is created as the result of the operations on the manufacturing features stored in the library. This method requires changing the traditional design procedures and approaches. Because of this, it was not accepted by the industry. The third method is the recognition of manufacturing features based on the low-level entities saved in the drawing databases of commercial CAD systems. To increase the versatility of such approach, the recognition procedure can use the very popular STEP standard (ISO 10303) [10].

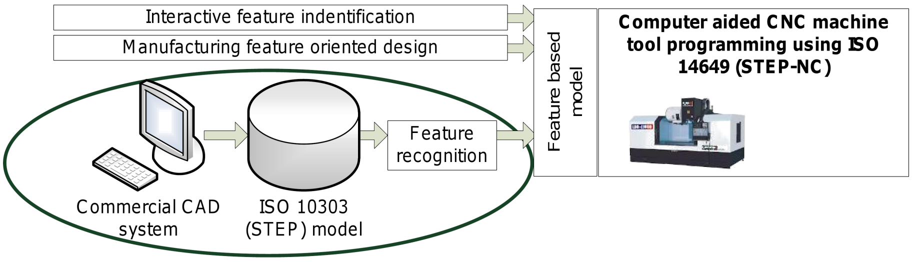

Fig. 1. The place of feature recognition during programming in STEP-NC standard.

To fully use all capabilities of STEP-NC standard during the automation of computer aided CNC machine tool programming, the automatic recognition of the features in the part to be machined is necessary. The following chapters of this paper contains the analysis of STEP-NC manufacturing features and the review of feature recognition methods. The results clearly show, that it is not possibly to directly apply one of the already developed feature recognition methods [11–13]. The paper presents the algorithm for efficient recognition of features defined in STEP-NC standard. The development of such algorithms is the key condition for the use of the full potential of STEP-NC.

Manufacturing features in STEP-NC standard

ISO 14649 standard (STEP-NC) [3] defines the manufacturing features machined by milling. Two groups were distinguished. This first is related to the machining of free-form surfaces (Region), while the second covers the 2.5D features (Two5D_ManufacturingFeature). 2.5D manufacturing features defined in STEP-NC were analyzed from the point of view of the selection of recognition algorithm. Figure 2 presents the results of the analysis of 2.5D features defined in STEP-NC.

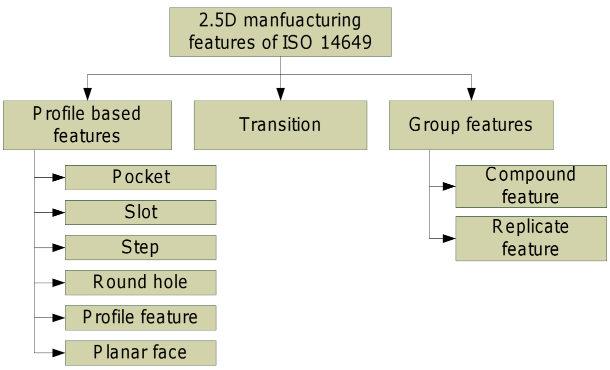

Fig. 2. Manufacturing features defined in ISO 14649 standard.

2.5D manufacturing features can be divided into profile based features, transition features and group features. Profile based features represent most of 2.5 features. They are created by moving the profile along the path. For example, to create the closed pocket feature, the closed and non self intersecting profile is moved by defined length along the straight line. Pocket profile must be defined in the XY plane of the feature coordinate system and the movement is done toward the negative values of Z axis. Each feature is assigned a coordinate system describing its position and orientation against the part coordinate system. Of course, feature has also a lot of additional parameters. In case of pockets, we can define the bosses, slope of pocket sides, bottom type and two radiuses. Bosses (islands) represent the material on the pocket bottom, which are not cut during the manufacturing of the pocket. Slope defines the angle between the pocket side faces and the Z axis. Pocket can have the through bottom (no physical bottom), plane bottom, radiused bottom and general bottom represented by free-form surface. The first radius can be used to define the edge fillet between the side faces and the bottom and the second to define the edge fillet between pocket side faces. The other features are defined similarly. For example, the slot is defined by moving the open profile along the curve and selecting the slot end type (open slot end type, flat slot end type, etc.). Transition features can be defined only on the border of two features. These features describe the type of connection between adjacent manufacturing features. This group includes chamfers and edge rounds (fillets). Each feature is defined by appropriate parameters. For example, chamfer is defined by the angle and one linear dimension.

The third group (Fig. 2) includes the features resulting from the connection or duplication of other features. Compound feature is the result of the connection of two or more features. The example is the counterbored hole, consisting of two holes with different diameters. Bottom of the non-through hole with larger diameter is the starting surface for the through hole with smaller diameter. The replicate features is the set of the same features evenly distributed, for example on circle or net.

Recognition methods of manufacturing features

Two dominant model representations in CAD systems are CSG (Constructive Solid Geometry) and B-Rep (Boundary Representation). CSG representation looses its popularity and because of it, the recognition algorithms based on this representation will be not discussed. The task of manufacturing feature recognition in case of B-Rep representation is the grouping of low-level entities like faces, loops, edges. etc. into the manufacturing features. Low-level entities are read from the drawing database of commercial CAD systems. Three commonly used recognition methods are graph-based algorithms, volumetric decomposition techniques and hint based geometric reasoning [11]. AAG (Attributed Adjacency Graph) developed by Joshi [12] is the typical representative of the first method. In this method, Joshi uses B-Rep representation of the part transformed into AAG graph. The nodes of this graph represents the surfaces, while the edges represent the angles between the surfaces. If the two adjacent surfaces form the convex angle, the value of 1 is assigned to the edge between the nodes representing these surfaces. If the two adjacent surfaces form the concave angle, the value of 0 is assigned to the edge between the nodes representing these surfaces. The sub-graphs containing only the edges with the value of 0 represents the manufacturing features. The drawback of this methods is the fact, that the pattern of each manufacturing feature must be represented in the knowledge database. It is not possible to create such patterns for all possible manufacturing features. For example, it is not possible to create the patterns for all possible closed pocket, differing in the number of side surfaces (rectangular, hexagonal, round pockets, arbitrary shape pockets, etc.).

Volumetric decomposition algorithms decompose the delta volume into the smaller parts and either directly classify them as features, or combine them into new volumes to be classified. The two main approaches are convex hull decomposition and cell-based decomposition [11]. As noted in this work [11], multiple step reasoning is a common characteristics and drawback of the these approaches. For example, the initial step – ASVP decomposition (in the convex hull decomposition algorithm) and delta volume decomposition into cells (in the cell –based decomposition) are done independently of features and manufacturing process rationale. No robust methods, justifiable from a manufacturing point of view, has been developed to manipulate the intermediate volumes created by these initial steps.

In hint based geometric reasoning, the production rules generate the hints for the presence of machining features [13]. Feature hint may be generated by a characteristic combination of part faces, by a design feature from which a manufacturing feature can be interfered, or by a tolerance or attribute specific specification that can be associated with a certain feature type. These production rules use the fact, that some features should have left the trace in the part geometry even when their geometries are distorted by the intersection with other features. The recognition results of this approach depends on the defined hints. Some authors suggest that large number of hints does not lead to the correct manufacturing features. Usually, the hints are heuristic, not based on the mathematic rules. During the development of such hints, the features to be recognized, for example defined in ISO 14649 (STEP-NC) must be taken into account.

Description of algorithm for ISO 14649 (STEP-NC) feature recognition

Analysis of STEP-NC features from the point of view of their recognition

Even the initial analysis of the manufacturing features defined in ISO 14649 (STEP-NC) shows, that graph based methods can not be used. The reason is the definition of some of manufacturing features. Most of manufacturing features is created by moving the profile along the path or specified depth. When considering the closed profile, used for the definition of closed pockets, the standard distinguish rectangular closed profile, circular closed profile, ngon profile (for example pentagon or hexagon profile) and the general closed profile. In case of this last type, there is no restrictions on the profile except it must by closed and without self-intersections. Such profile can contain any number of lines, arcs or spline curves. It is necessary to represent the different shapes of parts used in the machine industry, but does not allow to store all possible patterns in the recognition database. The recognition methods belonging to this group can not be also used for the recognition of convex features, which are part of STEP-NC standard (profile feature and boss). This is due to the fact that face surrounded by convex edges at its boundary is not a feature face and can be removed from the AAG graph. Such face can form the element of profile feature or boss.

The presented classification of manufacturing features in STEP-NC shows, that different feature can have the same representation in B-Rep format. As already mentioned, closed pocket is created by moving the closed profile onto the specified depth (Fig. 3), while slot feature is created by moving the open profile along the path. The slot feature definition must be complemented by specifying the slot end type. After selected radiused slot end type, the slot presented on Fig. 3 can be created. The radius of the end rounding is equal to the half of the slot width. Because two different definitions lead to the same low level entities, the feature definition can not be used as the factor deciding about the selection of the recognition methods.

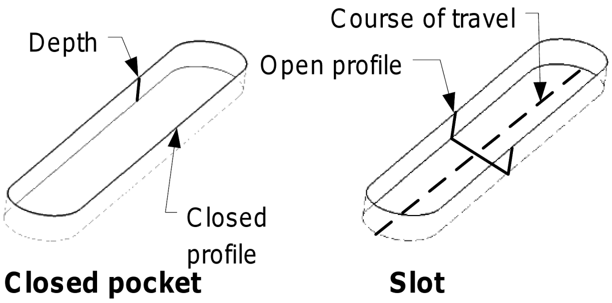

Fig. 3. Definition of slot and closed pocket features.

Basis processing of B-Rep representation

The developed recognition method of features defined in STEP-NC standard uses the simple rules suggesting the occurrence of manufacturing features. So, it is hint based geometric reasoning. Input data are represented in ISO-10303-21 format. This format is based on B-Rep representation. In this representation, the faces creating the shape are stored (faces $f_1 \ldots f_{11}$ in Fig. 4). These can be plane, cylindrical, conical, b-spline faces, etc. Each face has one external loop defining its boundary. The faces can have optionally the internal loops. The face has internal loops when it is the base for the concave (for example pockets) or convex parts (for example boss) (Fig. 4). Each loop has the edge list. For each edge, the start point, end point and the edge type are stored. The edge types are lines, arcs, b_spline_curve, b_spline_curve_with_knots, etc. Each edge is shared by exactly two faces. Figure 4 shows the edges shared by f_1/f_3 and f_1/f_8 faces. Faces sharing the same edge form the angle. It can be convex (as the angle between faces f_1 and f_3) or concave angle (as the angle between faces f_1 and f_9). The edge between the faces forming the convex angle is the convex edge, while the edge between the faces forming the concave angel is the concave edge.

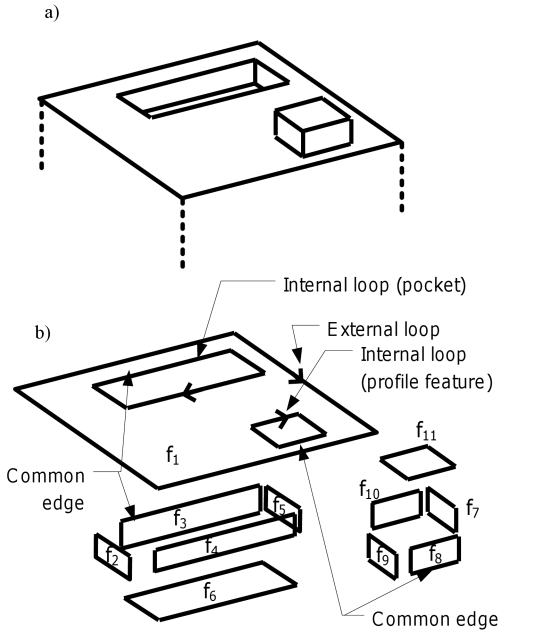

Fig. 4. B-Rep representation.

The algorithm for feature recognition is presented in Fig. 5. The first step covers the preparatory calculations. The result of these calculations is so-called adjacency matrix. It is the square matrix and its dimension is equal to the number of faces. The elements a_{ij} of this matrix describe the dependencies between faces:

$$a_{ij} = \begin{cases} 0: & \text{face } i \text{ and } j \text{ are not in contact} \\ x: & \text{elements on the diagonal of the matrix} \\ 1: & \text{faces } i \text{ and } j \text{ form the convex angle} \\ -1: & \text{faces } i \text{ and } j \text{ form the concave angle} \end{cases}$$

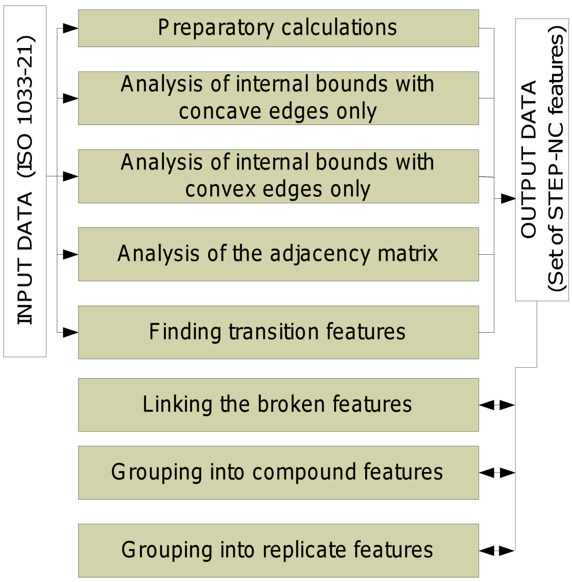

Fig. 5. Algorithm for ISO 14649 (STEP-NC) feature recognition.

The creation of this matrix speed up the calculations, because the algorithm checks these relations very often. Also the list of all edges is created. Each edge on the list is assigned the two faces sharing this edge. Also this list is created to speed up the calculation.

Recognition of profile based features

The next step of the algorithm analyses the internal loops with convex edges only. Such loops clearly confirm the existence of concave features like closed pocket or hole. The location of the loop and the face containing this loop is used to determine the location (x, y, z) and two vectors describing the orientation of the feature. The first vector normal to the face determines Z axis, while the vector laying on the face determine X axis. The face with that inner loop is the starting face of the feature. If the inner loop is formed by two arcs having the same radius and center, the feature is classified as the hole and the radius of the arcs is the radius of that hole. In other cases, the feature is classified as the closed pocket or non-through slot. If there is arcs between two adjacent loop edges forming concave angle, the radius of the arcs is used to select the value of orthogonal_radius parameter (Fig. 6). If the radiuses of such arcs have different values, the smallest radius is used as the value of this parameter. ISO 14649 [3] unnecessarily defines the same radius for the whole closed pocket as show in Fig. 6. From the manufacturing point of view, only the smallest radius is important and its value should be stored as the orthogonal_radius parameter. The next task during the recognition of closed pocket is the selection of its bottom. To find it, the surface having the greatest length in the direction of the vector normal to face with the internal loop is selected. This is necessary because the side faces can be partially removed as the result of the intersection with the other features. Such situation is shown in Fig. 6, where the slot on the side face divides the pocket side face into two parts. Such determined face is further used to select the pocket bottom. If this face contacts with the cylindrical or toroidal face and these two faces form the concave angle, the radius of such cylindrical or toroidal faces is selected as the value of planar_radius parameter and also pocket depth is modified.

After the depth was determined, to pocket bottom face must be also selected. The pocket bottom face is the face adjacent to the pocket side face selected in previous step and not classified as pocket side face. It is not possible to assume that the pocket bottom face must be parallel to the pocket start face. This is due to the fact, that pocket bottom can be inclined. After the pocket bottom face was selected, the pocket bottom type (through or not-through) must be determined.

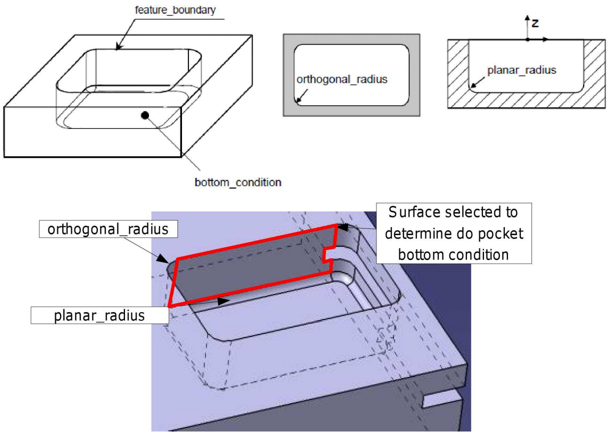

Fig. 6. Determination of the parameters of closed pocket feature.

To determine the bottom, the angle between the pocket bottom face and one of the side faces is checked (Fig. 7). If this is the concave angle, the pocket has physical bottom, while in the case of the convex edge, the feature is through pocket. If the pocket has physical bottom and the face representing this bottom has internal loops with the concave edges only, the pocket has so-called bosses. Boss is the part of the material, in this case on the pocket bottom, which must be not cut during the machining. The pocket bottom face can have also loop of convex edges, determining other concave feature, for example next pocket laying on this bottom. STEP-NC standard does not provide the means to represent such dependencies between features. All faces forming the bottom (i.e. side faces and bottom face) are marked as recognized. Such faces are no longer analyzed by the recognition procedure. The starting face for the pocket or hole are not marked as recognized, because such face can be the part of other feature. Also the pocket bottom face, although already assigned as part of the recognized feature can be the starting face of other feature, for example the starting face of the pocket on the bottom of already recognized pocket. This is very important characteristic of the algorithm, especially in the view of recognition of transition features. As already mentioned (Fig. 3), according to ISO 14649, some slots can be considered as the special types of pockets. If the appropriate conditions are satisfied (the pocket profile consists of specified elements and width of the pocket is twice the value of the radius on the pocket ends), the pocket is classified as slot.

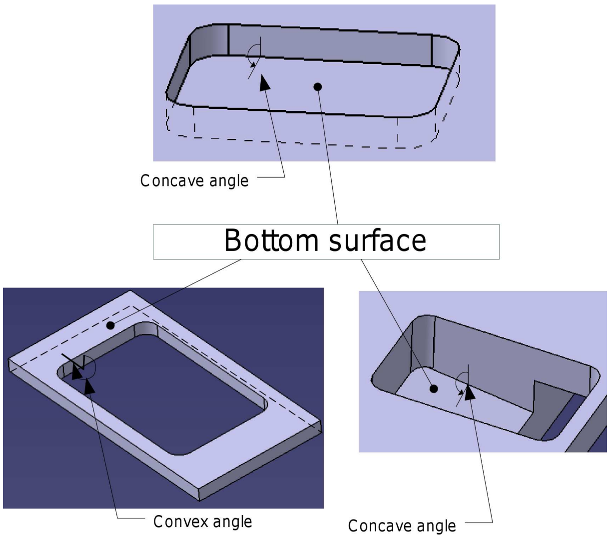

Fig. 7. Determination of the pocket bottom.

The next step of the algorithm is the analysis of the internal loops with concave edges only. Such internal loop with concave edges only marking the profile feature is shown in Fig. 4. This loop is the parameter feature_boundary. Based on the length of the side faces of the profile feature, measured in the direction of the vector normal to the base face of the profile feature, determines the Depth parameter (Fig. 8). Also to faces forming this feature are marked as recognized.

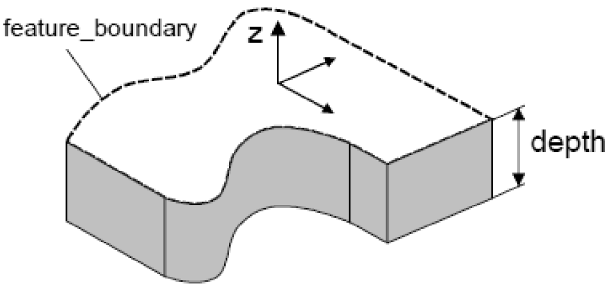

Fig. 8. Profile feature parameters [3].

The next step of the algorithm is the recognition of the open pockets and open/through slots. These features are recognized together using the unique rule, developed by the author. First, the concavity index is calculated. This index for the given face is the number of faces adjacent to that face and forming the concave angle with it. For example, the value of concavity index of the bottom face of open pocket is 7 (Fig. 9). The side cylindrical face of this pocket, pointed on the figure has the index of 3, because these face forms the concave angles with two side faces and the bottom face. In case of the through slot (Fig. 9), the concavity index is 2, because this face forms the concave angle with only two side faces. Of course, index is calculated only for the features not marked as recognized. So, the index is not calculated for the faces of the closed pockets, as such features were recognized in the previous step of the algorithm. All faces with the concavity index are sorted by decreasing value of this index. In case of the presented example (Fig. 9), the highest value of the index is 7. The face with that index value is selected as the bottom face of the new feature (pocket or slot, the classification takes place later). The faces forming the concave angle with the bottom face will be included as the side faces. The side face with the greatest dimension in the direction of the vector normal to the bottom is used to select the pocket depth. Bottom and side faces are marked as recognized. This also removes these faces from the list of faces with concavity index. Because of this, during the recognition of the next feature, the greatest index has the bottom face of the through slot. This face will be selected as the bottom face of the new feature. The description of this step of the algorithm omits the detailed presentation of the selection of the parameters describing the location and orientation of the start faces and feature classification, because the way of processing is similar to the calculations for the closed pocket.

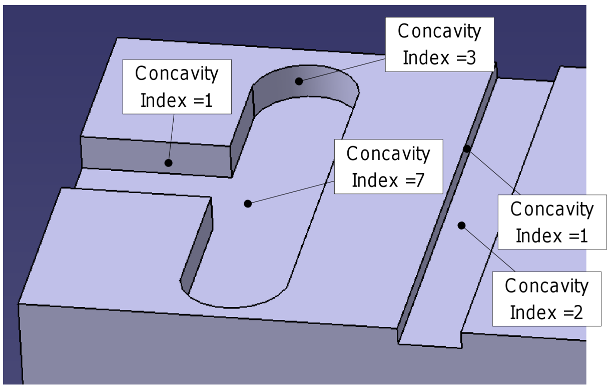

Fig. 9. Concavity index.

Recognition of transition and group features

The next step of the algorithm is the recognition of the transition features. ISO 14649 standard distinguish two forms of transitions: chamfers and edge rounds. The rule for the transition recognition is very simple. This group includes all features having the normal vector nor parallel or perpendicular to Z axis of part coordinate system. In the presented example (Fig. 10), this conditions is satisfied by the chamfers around the main body of part as well as edge rounds around the boss, as the normal vectors of these faces are not parallel or perpendicular to Z axis of the part global coordinate system. The side faces of V slot and the edge rounds on the bottom of circular pocket also satisfy this conditions, but they are already included on the list of already recognized features so can not be qualified as the transitions. During the further research works, this condition will be complemented by the manufacturing criteria. It will take place after complementing this algorithm by manufacturing knowledge database.

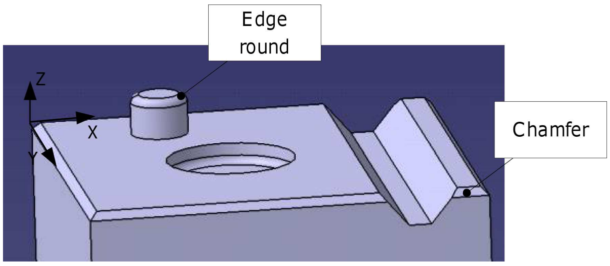

Fig. 10. Transition features.

The next step of the algorithm is the recognition of the broken features. Features are broken due to the intersection with other features. The example is given in Fig. 11. The through hole intersects with the slot on the side face. Because of this, two holes are recognized. During linking of broken features, the coincidence and the same value of selected parameters are used as the criteria. In the case of the hole, such parameter is the hole diameter.

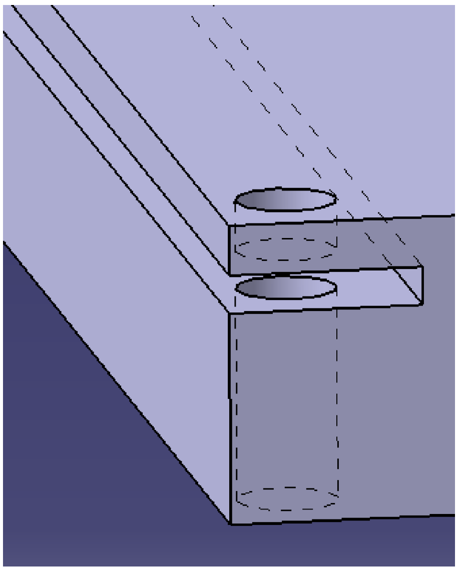

Fig. 11. Linking broken features.

The next step of the manufacturing feature recognition algorithm is the linking of simple features into complex features i.e. features consisting of two or more simple features. The example is counterbored feature. The manufacturing process includes drilling, counterboring and possible final machining, depending on the quality requirements. The reasons to group the simple features into complex features have manufacturing background. Because of this, during further research works, the recognition algorithm will be complemented by the manufacturing knowledge database. Such database should have the possibility to define the complex features by linking the simple features. The method of complex feature definition, for example by defining the patterns, should allow to automatically include them in the recognition algorithm. Such solution will be proposed in the further research works.

As already mentioned, STEP-NC standard also have replicate features. Such features allow for the fast definition of part geometry. Each CAD system has the tool for the duplication of geometry elements on the circle or on the nodes of nets. During the manufacturing process planning, the sequence of machining must be established. The existence of many features of the same type (as in case of replicate features) is only one of the criterion for the determination of machining cycle sequence. Also other criteria like tool change time, number of set-ups, etc. should be considered. Because of this and due to the topics of this paper focused on the recognition of already created part model, these features will be not recognized, although the recognition algorithm is similar to the algorithm of forming the complex features.

Conclusions

The presented algorithm for the recognition of manufacturing features defined in ISO 14649 (STEP-NC) was verified by developing the software (Fig. 12). The input data are the geometric models created in CATIA V5 system and saved in STEP format (ISO-10303-21). The data in this format are represented as uncoded text files, which facilitates processing. The software was developed with Borland Delphi Professional 7.0. OpenGl graphic library was used for the visualization. The software interface is very simple. The loaded part data are presented as wire-frame model. Basic display commands, for example for rotation about the selected axis, zoom in/zoom out or restoring default display values are available. Feature recognition button start the recognition process. The recognized features are presented on the list. The feature selected on the list is highlighted on the wire-frame model. When the feature is double-clicked, the dialog box presenting the feature parameters is shown.

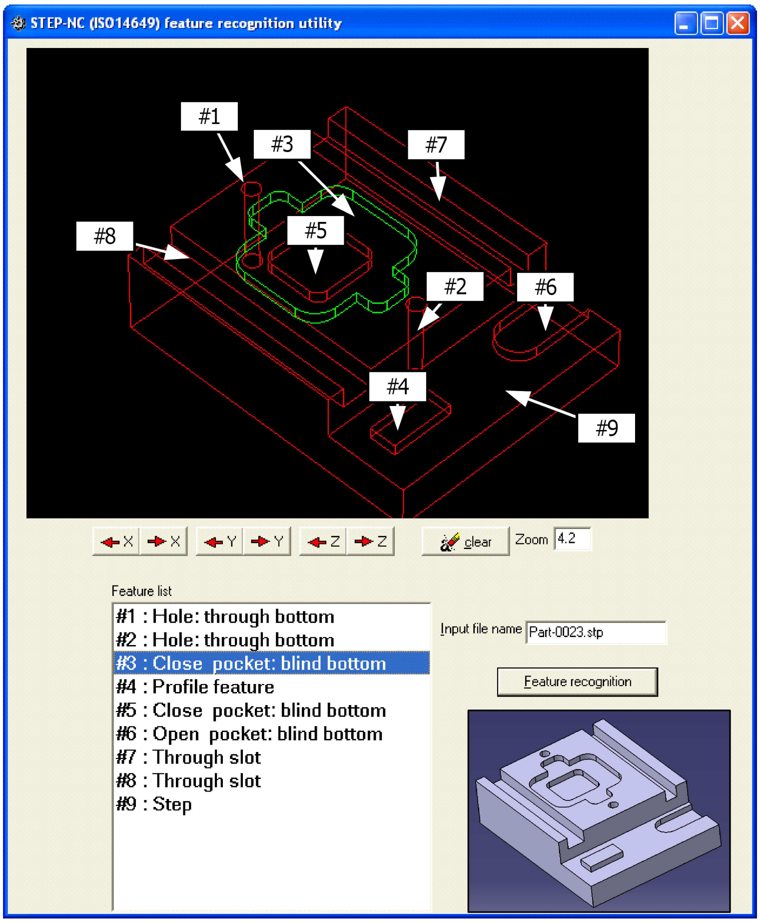

Fig. 12. Screenshot of developed software for STEP-NC feature recognition (annotations added manually).

The software positively verified the presented algorithm. Nevertheless, it is the starting point for the further works. These works will be focused on:

- improvement of the algorithm for the recognition of feature with the geometry distorted due to the intersection with other manufacturing features,
- development of the algorithm for the machining cycle sequence determination without using the graph of links between features (STEP-NC standard does not allows to represent such graphs),
- development of the part intermediate state representation,
- dynamic refinement of manufacturing features,
- the use of manufacturing knowledge database in feature recognition algorithm.

References

[1] ISO 6983-1:2009, Numerical Control of Machines – Program Format and Definition of Address Words – Part 1: Data Format for Positioning, Line Motion and Contouring Control Systems, 2009.

[2] Pobożniak J., *STEP-NC: Nowy standard programowania obrabiarek sterowanych numerycznie. Rewolucyjna zmiana?*, Mechanik, 5–6, 2013.

[3] ISO 14649-10, Industrial automation systems and integration – Physical device control – Data model for computerized numerical controllers – Part 10: General process data, 2004.

[4] Kardoš J., Čuboňová N., *Design of the Structure STEP-NC Data Model*, Technological Engineering, No. 1/2012, IX., Zilina, Slovak Republic.

[5] Chlebus E., *Collaborative engineering in products development and manufacturing*, Management and Production Engineering Review, 1, 2, July 2010.

[6] Koch T., Horbal R., Kagan R., Sobczyk T., Plebanek S., *10 commandments for the boss of a company implementing lean philosophy*, Management and Production Engineering Review, 3, 2, June 2012.

[7] Antosz K., Sęp J., *Efective management of technological machines system in a production company*, Management and Production Engineering Review, 1, 4, December 2010.

[8] Gola A., Świć A., Kramar V., *Multiple-criteria approach to machine-tool selection*, Management and Production Engineering Review, 2, 4, December 2011.

[9] Świć A., Gola A., *Elements of design of production systems – methodology of machine tool selection in casing-class FMS*, Management and Production Engineering Review, 1, 2, July 2010.

[10] ISO 10303-1:1994, Industrial automation systems and integration – Product data representation and exchange – Part 1: Overview and fundamental principles, 1994.

[11] Babic B., Nesic N., Milijkovic Z., *A review of automated feature recognition with rule-based pattern recognition*, Computers in Industry, 59, 4, April 2008.

[12] Joshi S., Chang T.C., *Graph based heuristics for recognition of mechanical features form 3-D solid model*, Computer Aided Design, 30 (2), 1988.

[13] Vandenbrande J.H., Requicha A.A.G., *Spatial Reasoning for the Automatic Recognition of Machinable Features in Solid Models*, IEEE Transactions on Pattern Analysis and Machine Intelligence archive, 15, 12, December 1993.