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A FEATURE RECOGNITION AND EXTRACTION METHOD USED TO DEVELOP A CAPP MODEL FOR "L-BLOCK" FAMILY OF PARTS

Iaroslav Francisc PIȘEC, Florin Sandu BLAGA, Gheorghe OANCEA

Abstract: *A Computer Aided Design (CAD) model system represents designed parts as a volume. This type of representation is not usable for most manufacturing programs even for Computer Aided Process Planning (CAPP). The volumes of material that are necessary to remove from a stock material represent the geometric features. These features have to be recognized and extracted from the CAD data. Being an important task that bridge CAD and CAPP, feature recognition provided greatest contribution to fully automated CAPP system development. An approach for feature recognition is based on boundary representation (B-Rep). Data is collected from a STEP file provided by the CAD system and is compared with the predefined variant of the feature. This paper describes the development of a CAPP model specific for a family of parts whose preprocessor have the role to extract the information from neutral format file and to settle it for recognizing process. The recognizing process is using a rule-based algorithm. The output of the preprocessor is the feature data such as dimensions, coordinates and spatial position relative to the XYZ axis system. CAPP system mainly replaces this information in a predefined machining sequence with variables.*

Key words: *Computer Aided Process Planning, boundary representation, feature recognition, feature extraction, family of parts.*

1. INTRODUCTION

Digitalization has changed the way companies communicate, manufacture and organize themselves. Facing new challenges as fast product cycles originating from changing customer needs, companies mainly focus on the increase of productivity, efficiency and profitability through the integration of new technology to connect devices and machines, digital tools such as platforms, digitalized distribution channels or even digital business models [1].

Efficient integration of such computer aided technologies as CAD, CAPP and CAM still represent a problem in engineering practice which constantly attracts research attention. For many years, researchers tried to develop a CAPP system which to realize this integration is capable to realize this integration. These CAPP systems can be classified depending on whether they are feature-based, knowledge-based, agent-based, or whether they use neural networks, genetic algorithms, fuzzy logic or Petri Nets. Among these, feature-based technologies have long been used in CAD/CAM integrations, as most CAM systems identify features as input data [2].

Babic et al. [3] classified feature-based technologies into three types: design by features, interactive form feature recognition and automated feature recognition.

Feature recognition has been considered as an important task that bridges CAD and CAPP and has provided the greatest contribution to fully automated CAPP system development. CAPP system involves the analyzation of part design and then, elaborate a set of detail manufacturing sequence to produce the part.

Nevertheless, most of the existing CAD system does not provide enough data especially the part feature information which contain the entities suitable for CAPP input. For this reason, CAPP systems do not understand the three-dimensional geometry of the designed parts from CAD systems in term of their engineering meaning related to manufacturing [4]. For solving the interference problem between CAD and CAPP, is proposed for using feature recognition, which is one of the most efficient approaches to this problem.

Feature recognition involves identifying the various manufacturing or design feature of which a finished part is composed. These features include holes, pockets, fillets, slots, bosses and other related features.

Wong T. N. and Wong K. W. [5] gave one of the earlier definitions of a feature. “Form feature is the volume to be removed from stock by some conventional machining processes”.

Some of the approaches in feature recognition are based on traditional approaches like boundary representation (B-Rep, Constructive Solid Geometry (CSG), Volumetric Decomposition and Graph-based approach [5,6,7,8,9].

Artificial Intelligence technique are also primally used in feature recognition, especially to avoid combinatorial problems, to achieve higher speeds in computations or when complex features are involved [10,11,12,13,14].

After features identification, the next step is extraction of them and transfer to a CAPP system. The CAPP system has two main roles: first to determinate the technological sequences and the second to determinate the machining parameters. These parameters have an important influence regarding the cost and the productivity of different machining process. Furthermore, Ivan et al [15] consider that the depth of cut requires a special attention and they propose a new method for establishing the depths of cut related to technological sequences -roughing, semi-finishing and finishing- such as to gradually eliminate the errors that occur during surface machining in order to ensure the required accuracy.

Manufacture of a product can be achieved through several technological processes, but the important thing is choosing technological options that it offers the many advantages of economically. Identification of the optimal variant can be achieved through an economic analysis based on indicators considered important. These indicators can be of two types namely: in kind and value of cost indicators [16].

The importance of using an optimal technological process is required also because the manufacturing industry often produces hazardous waste materials. This is the material which, for technological reasons, results as auxiliary material – companion of the primary one. In some situations, it can be exploited by reintegration using the 3R technologies (recirculation, recycling and regeneration [17].

Taking in consideration also this part, industry is forwarding to smart manufacturing which is a broad category of manufacturing with the goal of optimizing, concept generation, production, and product transaction [18]. Smart manufacturing is a subset that employs computer control and high levels of adaptability.

2. LITERATURE REVIEW ABOUT BOUNDARY REPRESENTATION

In Jiang and Hui's work [19], features are recognized by using templates. The approach is based on B-rep. A template is transformed in every possible configuration like translation, rotation or scaling to match the profile of a feature. It involves two phases, a hunting phase and a refinement phase. In hunting phase, a rough match is found. First, a point match is made and after that, match for the infinite numbers of points that lie on curve are matched. And based on template-match ratio, a satisfactory recognition is selected. This approach works for 2D applications and research is going on for 3D applications.

Ismail et al [20] presented a new method for automatic form feature recognition from B-rep of a solid model. Instead of just topological and geometrical data, they developed a method that gets ”spatial addressability” information from a B-rep. Spatial addressability tells where a point is lying with respect to an object (inside, outside, on the surface).

Traditional methods based on B-rep require complex transformation of geometric a topological data extracted and in turn restrict the application of such techniques to specific part domain. Using “Spatial addressability” does not require transformation of the geometric or topological data and thus simplifies the feature recognition process. Since B-rep consists of the geometric data (lengths, angles, etc.) and topological data, it is possible to determinate the existence of a point with respect to the planar surface under consideration.

A feature is recognized when the sequence of pattern of a face under consideration matches with the already present feature pattern in the library.

Henderson et al [21] discussed the automated recognition of form features from boundary representations of solid models. Rule based, graph-based and neutral net-based techniques are used for automatic recognition. Different methods are explained in detail, with neural net-based technique receiving more attention. Their characteristics are identified and limitations of each method are discussed. Some of the hybrid mechanisms are also mentioned.

3. PAPER DESCRIPTION

In this paper it is present how to create a CAPP model for a specific family of parts, using feature recognition process and feature extraction process.

The feature extraction process is done from CAD program, in this case CATIA supplied by *Dassault Systèmes*. After finishing the L-block design, the designer is running a macro by accessing a button. This macro will save the part design in a STEP file from where the CAPP preprocessor will extract the needed data.

The feature recognition process is done by a CAPP preprocessor which is transforming the data from STEP file into correct data for CAPP program. The CAPP software needs this information for the following activities [22]:

- Determination of the data about surfaces inputting (type, position, dimensions, upper /lower deviations, and roughness);
- Determination of semi-finished part type;
- Calculation of the tolerances using the deviations;
- Choosing the manufacturing sequence for the considered surface based on precision and roughness;
- Selection the cutting tools for each manufacturing process;
- Determination the cutting parameters for each manufacturing process, selecting them based on the recommendation of tools manufacturer simulation of each manufacturing process.

Further, this CAPP software will be connected to an integrated planning and scheduling model [23] which will take into account:

- customer demand specified at certain moments in time;
- resource capacity indicated for every period of the planning horizon;
- moments when tasks or production of products would start or end;
- set-up times required by resources to switch to a different product or task;
- processing times;
- resource allocation rules.

3.1 Family of parts reviewed

The family of parts of interest in this research is those parts which have an „L" shape, at least two surfaces milled and at least two sets of drilled holes. The family of parts is named „L-BLOCK" family of parts and is specific of the vehicle body fastener and assembly devices. The role is to connect two or more other components between them, as showed in figure 1. For this reason, the drilled holes set is composed of two reamed holes and minimum one clearance/threaded hole.

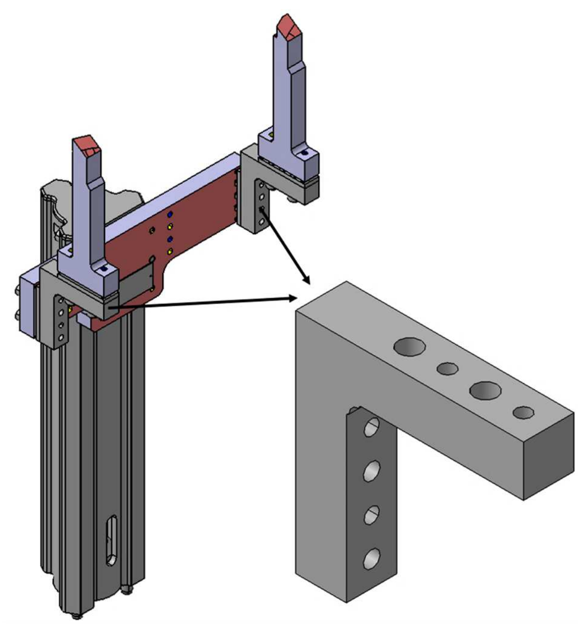


Fig. 1. "L-BLOCK" part

Even that these parts are considered simple parts, are used in a large number within a car body production line. With an approximately usage of 40%, these parts determinate an important interest for developing a specific CAPP system. In case of using a CAPP system for this family of parts, the manufacturing time will not be reduced but the preparing time will be significantly decreased, in best cases even with 90% which will lead to decreasing the production time and increasing the efficiency of the manufacturing department.

3.2 Specific manufacturing features

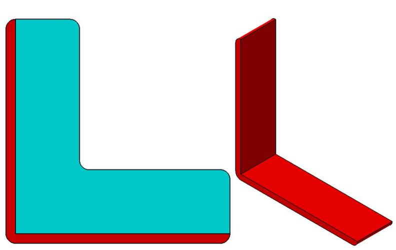
Before starting to create a CAPP model based on features, is necessary to identify them. Some researchers have analyzed the final designed part from which they have extracted the entities that were of interest. For example, in case of a hole feature, their model had a missing volume that was considered to be machined. That volume was a cylinder which had a diameter and so they could determinate the hole dimensions and position.

Another mode is to consider the entire volume as a solid body which must be extracted from stock material. Next steps are similar for first mode.

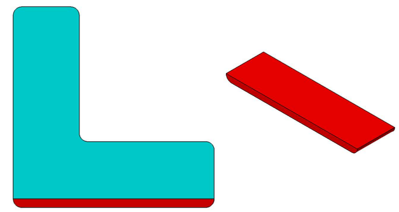
Also, in case of a milled surface or a pocket the volume is a solid body which has in most of the cases, a parallelepiped form.

In the figure 2, are showed the three possibilities of the parallelepiped form feature that represent the needed volume to be removed: a) two outsider faces, b) one outside face and c) one inside milled step.

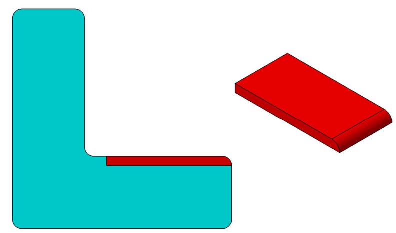
The feature can be placed everywhere spatially but have some specific entities as length and width. The thickness is in every case 3mm because this is minimum requested thickness for removable material. This area can be affected by heat generated in the flame cut process.



a)



b)



c)

Fig. 2. Variants of parallelepiped features

In the figure 3, is showed the cylindrical form feature that represent the needed volume to be removed in case of a hole.

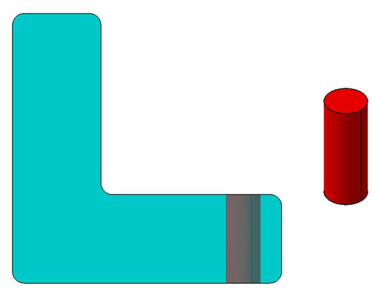


Fig. 3. Hole represented as cylindrical form feature

Depending of the diameter hole, it can deduct what kind of hole is and which is the machining process needed: Ø6/Ø8 => reamed hole for a Ø6/Ø8 m6 dowel pin;

- Ø7/Ø9 = > clearance hole for a M6/M8 screw;
- Ø6.647 => threaded hole for a M8 screw.

The diameter hole determinate also the position tolerance. For example, if there are two reamed holes on the same plane and the distance between them is 30mm then automatically an ±0.02mm tolerance is added to that dimension. For the other holes which are in same plane the tolerance is ±0.1mm

In case of a counterbore hole, the feature will be a set of two cylinders with different diameters but the ending point of the first cylinder have the same coordinates as the starting point of the second cylinder, figure 4.

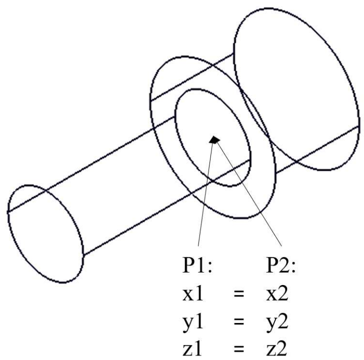


Fig. 4. Aspect for recognizing a counterbore hole

3.3 B-Rep for geometric features

Most of current solid modelers are hybrids which use CSG as a user interaction tool along with other tools and maintain the internal representation in terms of B-Rep model.

The STEP file is a text file that contains geometrical data of a component including boundary representation data such as vertices, shells, faces; curve geometric such as lines, circles, ellipses, b-spline curves; surface geometric data such as planes, cylinders, etc. [5].

The STEP file purpose of is to build a common standard platform that ensures the transfer of the product data across different computer aided systems, e.g. CAD, CAM and CAE.

Boundary representation is one of the solid modelling techniques in which the geometry of a part is described in terms of its bounding surfaces. This geometric information associated with four topological entities such as face, loop, edge and vertex form the basic constituents of Boundary-representation models. B-Rep is a geometric implementation of the mathematical theory of 2D manifolds. The solid model of a part is composed of bounding faces, figure 5.

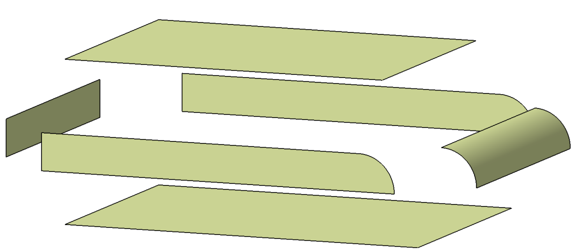


Fig. 5. Bounding faces that compose the solid model

A face is a mathematically defined surface with a defined boundary. A face may contain several bounding loops. Each loop is made of edges. Each edge is a curve with a defined start and end vertex. Figure 6 illustrates the basic constituents of B-Rep model for the parallelepiped form feature.

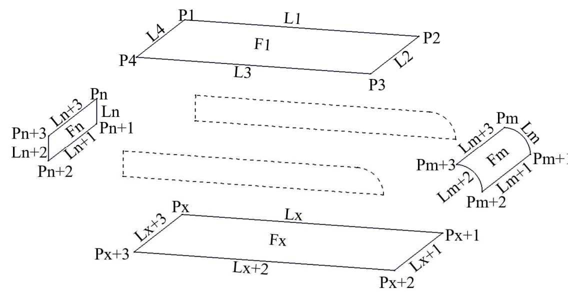


Fig. 6. Constituents of B-Rep models

An example of STEP file for a through hole is shown in Table 1.

Table 1

Partial STEP file of a through hole

```
ISO-10303-21;
HEADER;
..........
DATA;
..........
#52=CARTESIAN_POINT('Axis2P3D
Location',(33.75,60.,15.)) ;
..........
#66=CARTESIAN_POINT('Axis2P3D
Location',(25.,60.,15.)) ;
..........
#80=CARTESIAN_POINT('Axis2P3D
Location',(42.5,60.,15.)) ;
..........
#67=DIRECTION('Axis2P3D Direction',(1.,0.,0.)) ;
..........
#81=DIRECTION('Axis2P3D Direction',(1.,0.,0.)) ;
..........
#53=DIRECTION('Axis2P3D Direction',(1.,0.,0.)) ;
#54=DIRECTION('Axis2P3D XDirection',(0.,1.,0.)) ;
..........
#55=AXIS2_PLACEMENT_3D('Cylinder
Axis2P3D',#52,#53,#54);
..........
#68=AXIS2_PLACEMENT_3D('Circle
Axis2P3D',#66,#67,$) ;
..........
#82=AXIS2_PLACEMENT_3D('Circle
Axis2P3D',#80,#81,$) ;
..........
#69=CIRCLE('generated circle',#68,4.5) ;
#83=CIRCLE('generated circle',#82,4.5) ;
..........
#56=CYLINDRICAL_SURFACE('generated
cylinder',#55,4.5) ;
..........
ENDSEC;
END-ISO-10303-21;
```

4. FEATURE RECOGNIZING ALGORITHM

The first step is to create a preprocessor which is able to extract the correct information from the neutral file. When developing a feature recognizing algorithm, an important aspect is to know what kind of information is supplied by STEP file and the links between its elements. In figure 7 is presented hierarchical structure of the STEP file and in table 2 the elements are described. These elements are the input of the feature recognizing algorithm.

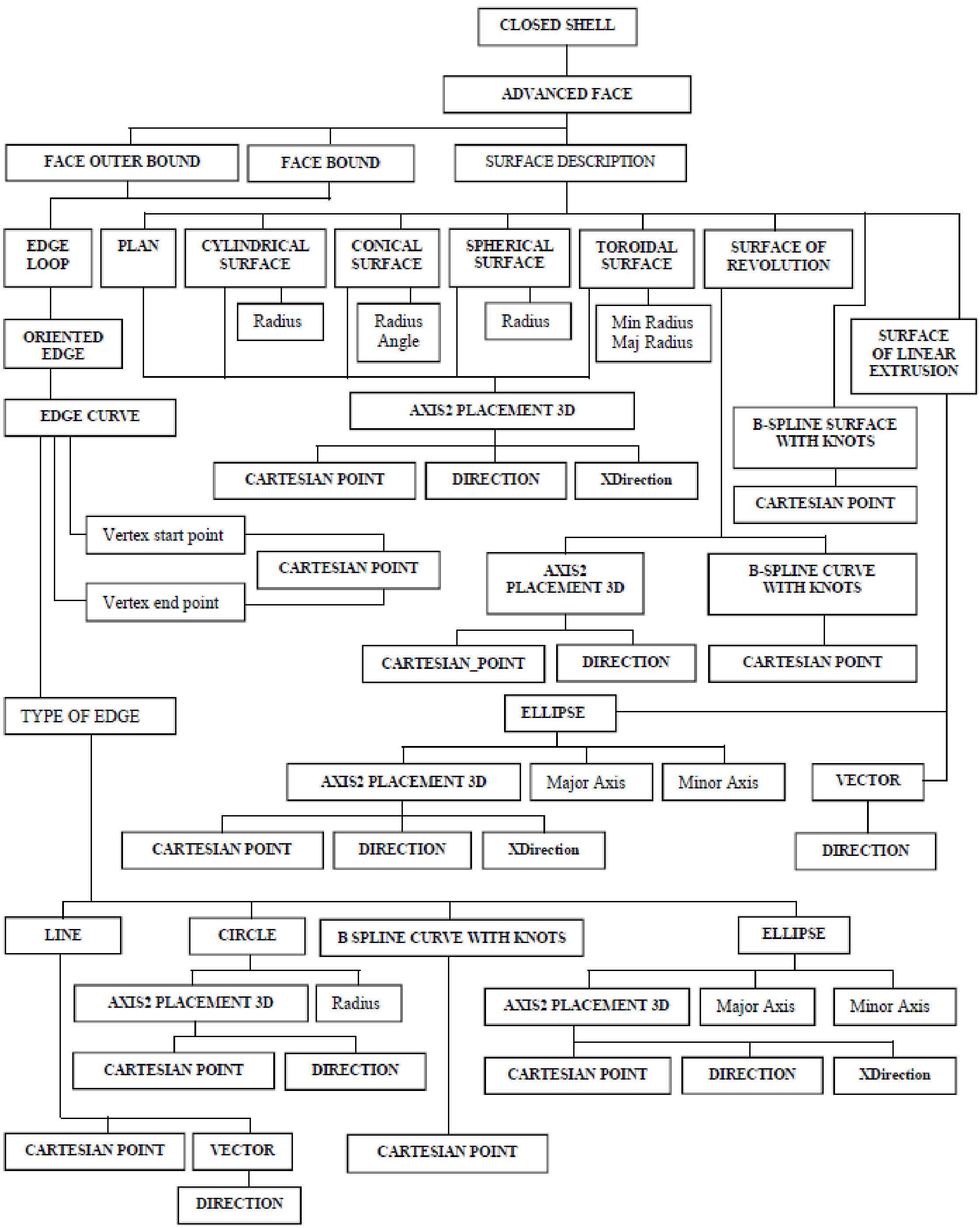


Fig. 7. Hierarchical structure of the STEP file

Table 2

Description of STEP elements

STEP element	***Description***
Closed shell	A collection of one or more faces which bounds a region in three-dimensional space
Advance face	The face that is associated with a type of surface
Face surface	A type of face in which the geometry is defined by the associated surface, boundary and vertices
Face outer bound and face bound	A loop used for bounding a face. The face outer bound represents the external loop whereas face bound represents the internal loop
Edge loop	The closed path formed by the oriented edges
Edge	It contains the magnitude and direction information of an edge
Vertex point	A point defining the geometry of a vertex
Cartesian point	Location of a point in Cartesian space

4.1 Proposed methodology

The developed algorithm is used to recognize and group feature faces and find out their geometric properties. The technological features contained in the part recognized by establishing the rules based on geometric reasoning. The process parameters such as machining operation, cutting tool, machine tool, machining parameters and tool access direction are defined based on the feature data obtained using feature recognition procedures. The setup plan algorithm assigns all recognized features to a specific setup for CAM applications. The methodology is presented in the form of flow chart in Figure 8.

In case of introducing a new entity, methodology describes the steps regarding the definition of new specific features. Is necessary to establish which are the elements that compose the entity and which are the rules for recognizing this.

After finishing the design, the designer run the macro which create a STEP file with the removed volume from stock part. In figure 9 is showed a simple "L-block" part, the result of the designed part and the overall machinable volume. This volume represents the subject of the feature recognition activity. In our case, the overall machinable volume is decomposed in two types of form features: holes and parallelepipeds.

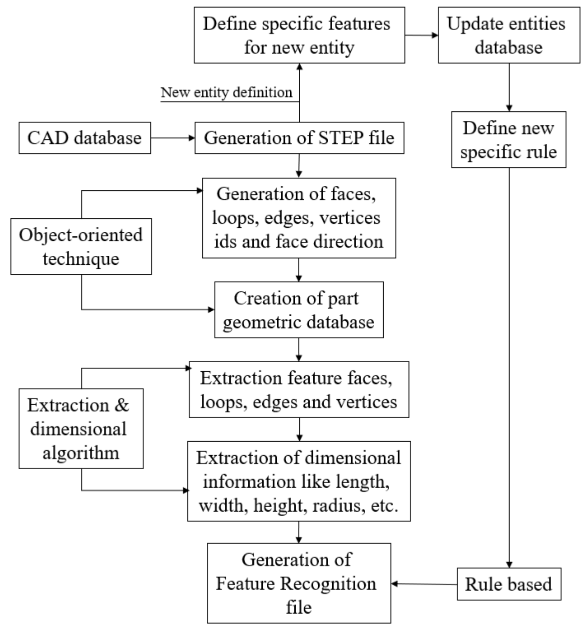


Fig. 8. Proposed methodology

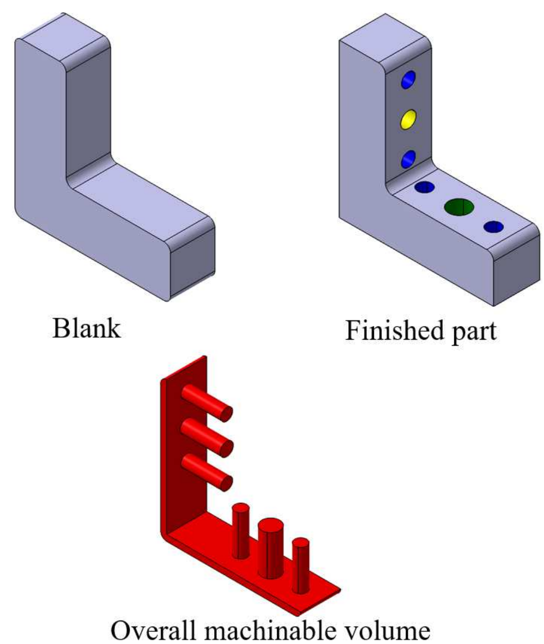


Fig.9. Overall machinable volume result

The input in the feature recognizing preprocessor is STEP file which is then browsed by it. The preprocessor program is written in C++ language and the role is to matches the structure of ASCII file with patterns in a database, developed using appropriate standard for particular type of part representation.

If is found a sequence of elements in STEP file similar to a predefined pattern in database, it will be transformed to appropriate entity label which can be used by CAPP program.

The recognition algorithm uses rule-based technique where rules are specified with an IF condition and THEN conclusion syntax. Condition is composed by a set of tests on object attributes linked by logic operator (AND, OR).

4.2 Algorithm for recognizing a hole

Altrougth we are discusing about a hole, in fact in the step file we will found a cylinder. So is necesary to recoqnize a cylinder.

After extracting data from STEP file features are recognized. Geometry for a cylinder is shown in Figure 10.

The recognition of a cylindrical feature is based on four rules.

- Rule 1: EDGE_CURVE construction must be circle, line, circle, line
- Rule 2: Radius of circles in EDGE_CURVE is equal to cylinder radius.
- Rule 3: X and Z coordinates of circle centers are same and Y coordinate is different,
  or X and Y coordinates of circle centers are same and Z coordinate is different,
  or Y and Z coordinates of circle centers are same and X coordinate is different.
- Rule 4: Surface must be CYLINDRICAL_ SURFACE.

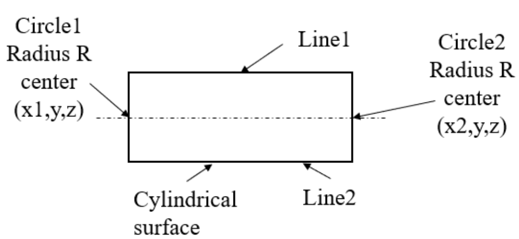


Fig.10. Cylinder geometry

The geometrical data of a cylinder (as a through hole) is as follows:

- The entity #432, refers to CIRCLE with the radius of 4.0 mm. The CARTESIAN_POINT or center of the circle is entity #429 and described as: X = 10.0, Y = 45.0, Z = 3.
- After the entity of circle, there is an entity of plane (#398) with CARTESIAN_POINT as: X = 10.0, Y = 45.0, Z = 3.0.
  If this plane corresponds with a machined surface, then from this side, the hole will be drilled.
- The second CIRCLE is shown in entity #437 with a radius of 4.0 mm. The CARTESIAN_POINT or center of the second circle is: X = 10.0, Y = 60.0, Z = 3.0
- The entity #560 shows a CYLINDRICAL_ SURFACE with the radius of 4 mm. The CARTESIAN_POINT or center of the CYLINDRICAL_SURFACE is described as: X =10.0, Y = 52.5, Z = 3.0

4.3 Algorithm for recognizing a machined face

The prismatic feature extraction and recognition process starts with the extraction of feature faces from data extraction output file. A feature face extraction and dimensional algorithm is applied to extract these faces along with their dimensions.

5. DATA PROVIDED BY THE FEATURE RECOGNIZING SYSTEM

The partial results of features recognized for a part analyzed, are shown in Table 3. The CAPP preprocessor can recognize holes features in the parallel planes with XYZ planes with the length, radius and position of each hole and the machined volumes specific for a "L-BLOCK" part.

Table 3

Partial processed data results

Feature:	Through hole				
Length:	20				
Radius:	4				
Plane:	xy				
Cartesian point:	X= 10	Y=30	Z=3		
Feature:	Through hole				
Length:	20				
Radius:	3.34				
Plane:	xy				
Cartesian point:	X= 10	Y=45	Z=3		
Feature:	Machined face				
Length:	70				
Width:	20				
Deep:	3				
Plane:	xy				
Cartesian point:	X=	0	70	70	0
	Y=	0	0	20	20
	Z=	3	3	3	3

All this data is then transferred to CAPP system which is convert it into a NC sequence code based on a predefined sequence with variables.

6. CONCLUSION AND FUTURE WORK

The feature recognition is one of the key activities in developing a Computer Aided Process Planning (CAPP). This research work is a part of development CAPP system.

The main contribution of the research is the development of a feature extraction system which takes a STEP file as input which can be exchanged between various computer aided programs and can serve as input to further activities such as process planning, material requirement planning, resources planning and scheduling.

The primary objective of this work is to develop a feature extraction system that can recognize the entities, and which can store the feature data in such format that it can be used by CAPP.

The extraction system developed is aimed at feature approach which is limited by the features that are pre-defined and stored in a database.

The form feature information gives higher level meaning to the group the faces forming the solid and can be used for CAPP and CAM.

Despite the achievements in handling manufacturing information, recognition of relevant features of complex shapes still remains a bottleneck. Without a complex feature recognizing system, an interface between design and manufacturing could not be automated.

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Metoda de recunoaștere și determinare a entităților geometrice utilizat pentru dezvoltarea unui model CAPP pentru familia de piese "L-BLOCK"

Rezumat: *Un model de sistem de proiectare asistată de calculator (Computer Aided Design, CAD) reprezintă piesele proiectate ca și un volum. Acest tip de representare nu este potrivit pentru majoritatea aplicațiilor de fabricație, cum ar fi planificarea proceselor asistate de calculator (Computer Aided Process Planning, CAPP). Volumele de material care necesită a fi indepărtate dintr-un semifabricat reprezintă entitătiile geometrice. Aceste entități trebuie să fie recunoscute și extrase din datele CAD. Fiind o functie importantă care a leagă CAD și CAPP, recunoașterea entităților a oferit cea mai mare contribuție la dezvoltarea a sistemului CAPP complet automatizat. O abordare pentru recunoașterea entitățiilor se bazează pe reprezentarea limitelor (boundary representation, B-Rep). Datele sunt colectate dintr-un fişier STEP furnizat de sistemul CAD și sunt comparate cu varianta predefinită a entității. Această lucrare descrie dezvoltarea unui model CAPP specific unei familii de piese al cărui preprocesor are rolul de a extrage informațiile din fişierul de format neutru și de a le selecționa pentru procesul de recunoaștere. Procesul de recunoaștere utilizează un algoritm bazat pe reguli. Ieşirile preprocesorului reprezintă datele entităților, cum ar fi dimensiunile, coordonatele și poziția spațială față de sistemul de axe XYZ. Sistemul CAPP în principiu, înlocuieşte aceaste informație cu variabilele dintr-o secvență de prelucrare predefinită.*

Cuvinte cheie: *planificarea proceselor asistate de calculator, reprezentarea limitelor, recunoaşterea caracteristicilor, determinarea caracteristicilor, familie de piese.*

Iaroslav Francisc PIȘEC, Mechanical Engineer, Ph.D. student, University of Oradea, Department of Industrial Engineering, E-mail: pisec.iaroslav@gmail.com, Home Address: Str. Nufărului, nr. 72, Oradea, Home Phone: +40742528047.

Florin Sandu BLAGA, Ph.D. Eng., Professor, University of Oradea, Department of Industrial Engineering, E-mail: florin_blaga2000@yahoo.com, Address: Str. Universităţii nr. 1, Oradea, 410087, Bihor, Romania

Gheorghe OANCEA, Ph.D. Eng., Professor, Transilvania University of Brasov, Department of Manufacturing Engineering, E-mail: gh.oancea@unitbv.ro, Address: Str. Colina Universităţii nr.1, cod 500036, Braşov, România.