Development of Computer Aided Process Planning (CAPP) for Rotational Parts

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GJRE Classification (FOR)
GJRE:F,080106

***Abstract*-In the process of product design and manufacturing and its interface, the role of process planning becoming increasingly important as competitive pressure call for improvements in product performance and quality and for reduction in development time-scales. Feature extraction and classification is considered as the bridge between Computer-Aided Design (CAD) and Computer-Aided Process Planning (CAPP). This paper proposes a method that can extract and classify for rotational parts taking a 2D data file as input. In addition, feature interactions are also taken into consideration in this methodology. The proposed feature extraction and classification method consists of three basic procedures. First, polyline of desired profile for certain object is drawn in certain manner and saved in DXF format of AutoCAD. Second, feature is extracted from the 2D CAD DXF data file. Third, G-Code compatible for CNC machine is generated using several logics. Two sample application descriptions are presented for demonstration purposes. The system has been implemented in Visual Studio (Visual C++) on a PC-based system.**

Keywords-Computer-Aided Process Planning, Drawing Interchange Format, Feature Recognition

I. INTRODUCTION

Process planning translates design information into the process steps and instructions to efficiently and effectively manufacture products. As the design process is supported by many computer-aided tools, computer-aided process planning (CAPP) has evolved to simplify and improve process planning and achieve more effective use of manufacturing resources. Process planning encompasses the activities and functions to prepare a detailed set of plans and instructions to produce a part. The planning begins with engineering drawings, specifications, parts or material lists and a forecast of demand (Groover, 1987). CAPP systems ensure significant reduction of time needed for fabrication of manufacturing processes plan. Process planning approaches can be basically classified into two types such as traditional manual process planning and computer aided process planning (CAPP) (ElMaraghy, 1993).

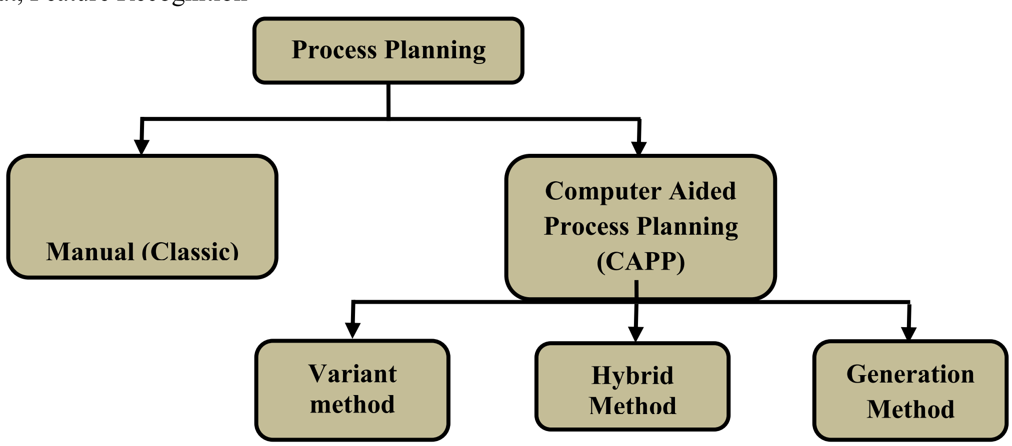

Figure 1: Process Planning

Manual process planning is based on a manufacturing engineer's experience and knowledge of production facilities, equipment, their capabilities, processes, and tooling. In some companies, process plans are manually classified and stored in workbooks (Lee, 1999). The manual approach is also considered a poor use of engineering skills because of the high clerical content in most of its functions (Zeid, 2002). Alting and Zhang (1989) reported that the idea of using the speed and consistency of the computer to assist in the determination of process plans was first presented by Niebel (1965).

Variant Approach: The variant approach, also known as the retrieval approach, can be regarded as an advanced manual approach in which the planner‘s memory retrieval process is aided by the computer. In other words, the planner‘s workbook is stored in the computer file (Lee, 1999). The first developed CAPP system, named CAPP (CAM-I Automated Process Planning), was a variant system (Link, 1976; Chang and Wysk, 1985). Houtzeel (1976) utilized the variant approach, where parts firstly are grouped into families considering their geometric or manufacturing similarities and a unique code is assigned for each family

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based on GT coding systems like OPITZ, MICLASS, KK-3 and DCLASS (Cay and Chassapis, 1997). Generative Approach: The generative process planning approach is viewed as the true automated approach to process planning. Unlike the variant approach, the generative approach does not require assistance from the user to generate a process plan (Zeid, 2002). Wysk (1977) presented a generative system called APPAS which focused on detailed process selection (Cay and Chassapis, 1997). Kanai et al. (1988) described a process planning system based on generative approach which extracts machining features and decides cutter path and cutting conditions. Lee et al. (2001) proposed a framework for integrating artificial intelligence techniques and mechanistic models in the task of generating process plans for prismatic parts with interacting features.

Hybrid Approach: In the presence of difficulties with a purely generative system, some researchers have proposed a hybrid approach, also known as semi-generative approach, which is basically a combination of the variant and generative methods. The system may just modify this standard plan or may build a new one for a specific part by generative approach (Cay and Chassapis, 1997). Or the system can work in a reverse order – firstly generating a tentative process plan and then examining for errors and modifying if it does not fit to the real production environment. Emerson and Ham presented a semi-generative system titled ACAPS in 1982 (Alting and Zhang, 1989). Marefat and Britanik (1996) focused on the development of a process planner which combines the advantages of the variant and generative approaches to process planning. Alam et al. (2000) presented a methodology of a computer aided process planning system for an injection mould component, slider.

Feature Recognition: Li and Adiga (1987) emphasized that part feature recognition systems are the key factors influencing the degree of CAD and CAM integration in general and level of automation in achieving this integration in particular. Atkinson (1991) mentioned that regardless of the particular selections of commercial engineering, design and part programming systems, the manufacturing part features will ultimately be the technological link between part geometry and the manufacturing operation used to create that geometry. Gindy (1989) described that two approaches to using features in manufacturing applications have been used by researchers: feature recognition and feature based design. Feature recognition calls for a procedure that can (without human intervention) find the features in a part specified by its boundary information (Trika and Kashyap, 1994). Han et al. (2000) classified the most active current approaches as graph-based approach, volumetric decomposition approach and hint-based approach. Tyan and Devarjan (1998) presented algorithms which can identify 3D feature of a part from its 2D CAD views. Pande and Prabhu (1990) discussed an expert system for automatic extraction of machining features both the internal and external from 2D drawing. Here, the internal features are drawn using dashed line to separate them from external features. Aslan et al. (1999) described a feature extraction method from 2D drawing in which only external features can be recognized.

Object-Oriented Approach to Process Planning: IICT (Pressman, 2001) mentioned that throughout the 1990s, object-oriented software engineering became the paradigm of choice for many software product builders and a growing number of information systems and engineering professionals. In addition, object-oriented systems are easier to adapt and easier to scale (i.e., large systems can be created by assembling reusable subsystems) (Pressman, 2001).

The use of object-oriented approach is reported in the literature in different areas of application. Wong and Wong (1995) described the development of an object-oriented feature-based design system where the geometric information of a feature is stored in feature object while drawing the feature and this feature object can be used in assisting process planning. Naish (1996) developed a system module which models cutting process capabilities by using object-oriented technique and this module forms a part of a computer aided process planning system within an integrated concurrent engineering system. Marefat and Britanik (1996) focused on the development of a case-based process planner based on semi-generative process planning approach which used object to represent the knowledge of the system. Law, et al. (2001) proposed an object-oriented model of a CAPP system for the manufacturing of circuit boards which represents process constraints and planning knowledge as objects.

II. Feature Based CAM System

In spite of using advanced manufacturing and automation technology the link, between CAD and CAM systems, is still not as integrated as desired. The process planning stage, which consists of the explanation of design drawings, is seen as a hindrance in the flow of information between CAD and CAM. An intelligent interface between CAD and CAPP systems is imperative because the CAPP systems depend on correct data obtained from CAD systems to perform precise process planning (Zeid, 2002). Figure 2 shows flow diagram for automatic feature recognition. There have been many previous attempts to recognize form features for manufacturing purposes, which can be broadly categorized into three areas: Rule-based, Graph based and Neural Network-based systems.

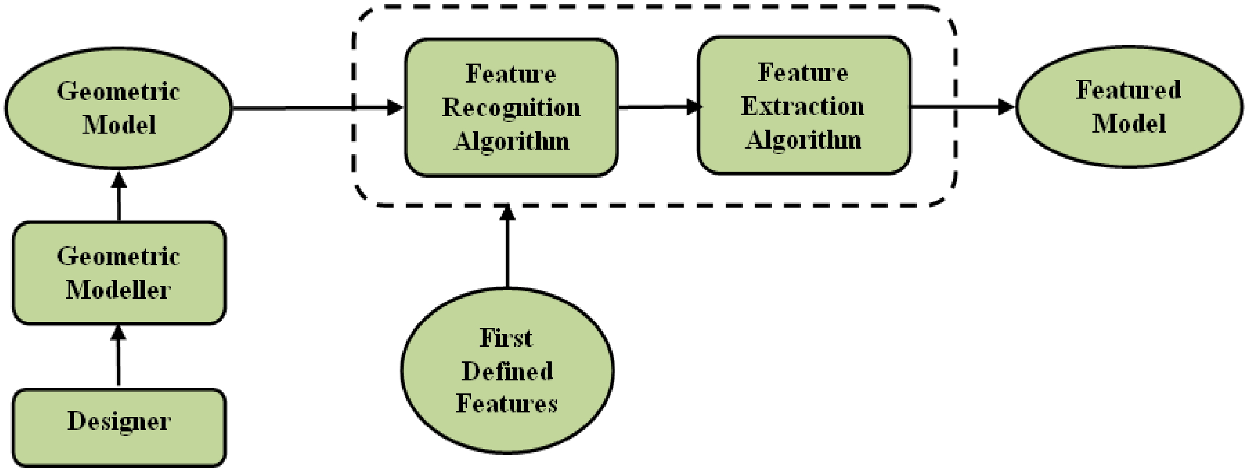


Figure 2: Flow Diagram for Automatic Feature Recognition

A. Developed System

CNC part programs are derived automatically using automatic feature recognition from 2D drawings in this system. The CAD model of the component including half of the 2D upper profile to be turned has to be designed in any CAD environment and be converted to DXF data structure to accomplish the feature recognition process of the system. Part programs have been derived appropriate to the Fanuc O-T control system. This system was prepared using Delphi version 7. In addition, the system is supported with material and cutting tool database prepared according to the Sandvik Cormorant catalogue. The system is composed of three important modules, file reading, feature recognition and tool path planning. The General structure of the system is shown in Figure 3.

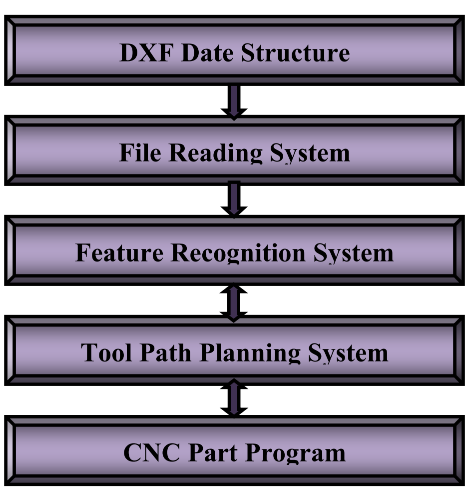


Figure 3: Structure of the System

File Reading System: After data input into the system using DXF format a set of processes is done automatically according to a specific hierarchy. Firstly, the features in the drawing are found and defined to the system. After these processes, all coordinates of the features are sequenced according to their start points and transferred to the origin. Finally the shape of the work piece is drawn with the program with its sub symmetry.

Feature Recognition System: Owing to the fact that the rotational parts are symmetrical along their axis, designing their processes can be done according to the symmetry axis so the feature recognition process is performed on the symmetry axis. Features including rotational parts could be classified as outside features and inside features according to machining attributes. Each feature in these figures could be used in recognition of turning operations such as long turning, grooving, drilling and boring.

Tool Path Planning System: In this stage operations are executed as external and internal processes (such as grooving and boring) by the developed system according to feature characteristics after whole recognitions. General turning operations to be done from the length or outside diameter of the part are made depending on the raw material sizes or the operator according to minimum and maximum measures taken from DXF data. Face and long turning operations are made according to differences between these minimum maximum and raw material sizes.

The method of profile recognition and necessary tool paths are shown in Figure 4. The figures under the geometry represent the number of feature sequence and the figures on top of the geometry represent the number of the feature.

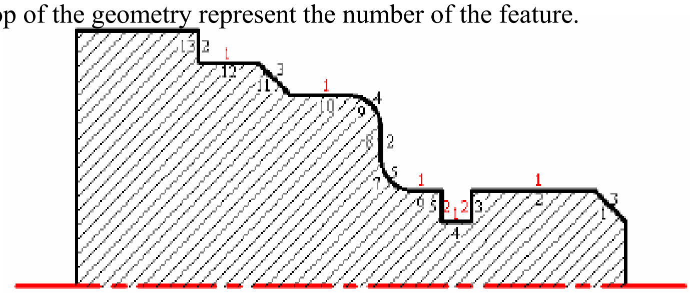


Figure 4: Method of Feature Recognition and Tool Path

The system separates the machining features such as grooving, threading and drilling after sequencing the features in respect of their start points. Tool paths are generated separately as to feature characteristics for each feature from the latest feature to the first feature appropriately with desired and equal depth.

B. Process Plans For Rotational Parts

Computer aided process planning is done in this study by generating G-CODE for CNC machine for rotational parts. Profile without fillet and profile with fillet are studied here. First of all it is needed to understand what G-code is.

G- Code, or preparatory code or function, are functions in the Numerical control programming language. The G-codes are the codes that position the tool and do the actual work. The programming language of Numerical Control (NC) is sometimes informally called G-code. But in actuality, G-codes are only a part of the NC-programming language that controls NC and CNC machine tools. Today, the main manufacturers of CNC control systems are GE Fanuc Automation (joint venture of General Electric and Fanuc), Siemens, Mitsubishi, and Heidenhain, but there still exist many smaller and/or older controller systems.

Some CNC machine manufacturers attempted to overcome compatibility difficulties by standardizing on a machine tool controller built by Fanuc. Unfortunately, Fanuc does not remain consistent with RS-274 or its own previous versions, and has been slow at adding new features, as well as exploiting increases in computing power. For example, they changed G70/G71 to G20/G21; they used parentheses for comments which caused difficulty when they introduced mathematical calculations so they use square parentheses for macro calculations; they now have nano technology recently in 32-bit mode but in the Fanuc 15MB control they introduced HPCC (high-precision contour control) which uses a 64-bit RISC processor and this now has a 500 block buffer for look-ahead for correct shape contouring and surfacing of small block programs and 5-axis continuous machining. This is also used for NURBS to be able to work closely with industrial designers and the systems that are used to design flowing surfaces. The NURBS has its origins from the ship building industry and is described by using a knot and a weight as for bending steamed wooden planks and beams.

G-codes are also called preparatory codes, and are any word in a CNC program that begins with the letter 'G'. Generally it is a code telling the machine tool what type of action to perform, such as:

1. Rapid move
2. Controlled feed move in a straight line or arc
3. Series of controlled feed moves that would result in a hole being bored, a workpiece cut (routed) to a specific dimension, or a decorative profile shape added to the edge of a workpiece.
4. Change a pallet
5. Set tool information such as offset.

Some G words alter the state of the machine so that it changes from cutting straight lines to cutting arcs. Other G words cause the interpretation of numbers as millimeters rather than inches.

G0 rapid positioning G1 linear interpolation G2 circular/helical interpolation (clockwise) G3 circular/helical interpolation (c-clockwise) G4 dwell G10 coordinate system origin setting G17 xy plane selection G18 xz plane selection G19 yz plane selection G20 inch system selection G21 millimeter system selection G40 cancel cutter diameter compensation G41 start cutter diameter compensation left G42 start cutter diameter compensation right G43 tool length offset (plus) G49 cancel tool length offset G53 motion in machine coordinate system G54 use preset work coordinate system 1 G55 use preset work coordinate system 2 G56 use preset work coordinate system 3 G57 use preset work coordinate system 4	G58 use preset work coordinate system 5 G59 use preset work coordinate system 6 G59.1 use preset work coordinate system 7 G59.2 use preset work coordinate system 8 G59.3 use preset work coordinate system 9 G80 cancel motion mode (includes canned) G81 drilling canned cycle G82 drilling with dwell canned cycle G83 chip-breaking drilling canned cycle G84 right hand tapping canned cycle G85 boring, no dwell, feed out canned cycle G86 boring, spindle stop, rapid out canned G87 back boring canned cycle G88 boring, spindle stop, manual out canned G89 boring, dwell, feed out canned cycle G90 absolute distance mode G91 incremental distance mode G92 offset coordinate systems G92.2 cancel offset coordinate systems G93 inverse time feed mode G94 feed per minute mode G98 initial level return in canned cycles

Figure 5: G- Code List

III. CASE STUDY

A. Profile without Fillet

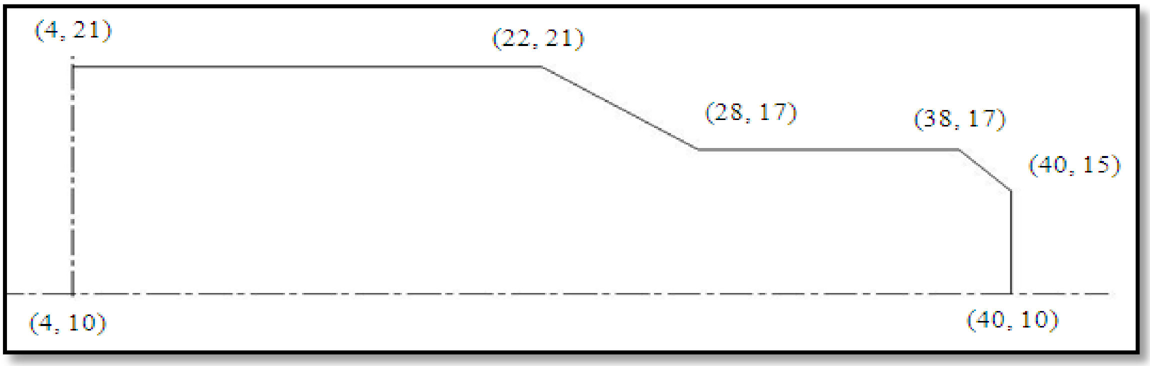
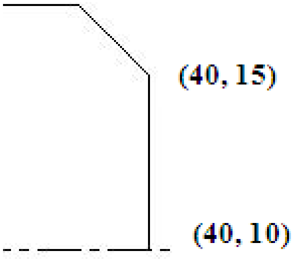


Figure: 6 Profile Without Fillet

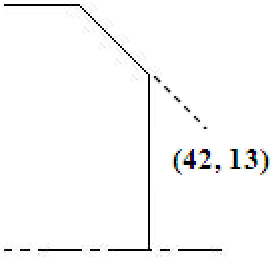
For this profile first part zero is determined. Here part zero is at point (4, 10). Then for absolute positioning other points are determined from the vertex coordinate system. Points found from vertex coordinate system are (40, 10), (40, 15), (38, 17), (28, 17), (22, 21) and (4, 21). From those points least value of X coordinate and least value of Y coordinate is determined which is found to be (4, 10). So by subtracting the value of X and Y from all the coordinates' conversion from global to local system is made.

Steps to generate G-Code from DXF file format:

1. Drawing is saved in DXF format.
2. From large list of data ENTITIES is to be found
3. From ENTITIES several features are identified
4. Every line is start with AcDbLine and ends with a character 0
5. X_{start} is shown by 10 and Y_{start} is by 20
6. X_{end} is shown by 11 and Y_{end} is by 21
7. Lowest value of X and Y is determined and is set to origin of the coordinate by subtracting them from all the coordinates.
8. Generation of G-Code is executed from the highest value of x at which the value of Y is no equal to the value of coordinate origin value of Y. there is such one point, in this case this value is (40, 15)



9. As cutting is starting from some far from the workpiece thus for rapid positioning cutting tool is positioned in the position at +2 in X axis and -2 in y axis from point(in this case (40, 15)).
10. For this case starting point is (42, 13).



11. For G-Code representation X axis of the coordinate system is represented as Z and Y axis of coordinate system is as X. The Codes used is elaborated later in the chapter. So for initial rapid positioning G-code is G00. The formulae used to define is as following
    $(X\text{-}X_{origin}) = X_{start}$
    Represented as Z….
    $(Y\text{-}Y_{origin}) \times 2 =$ diameter
    Represented as X…
    So after rapid positioning first line become
    G 00 Z 38 X 6
12. Then linear interpolation is made with respect to descending order of X axis coordinate in the DXF file 10, 11 commands. So next line in G-code become
    G 01 Z 34 X 14
    Similarly next interpolation is made by the formulae.

```
ENTITIES
  0
LINE
  5
89
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
40.0
 20
10.0
 30
0.0
 11
40.0
 21
15.0
 31
0.0
  0
LINE
  5
8A
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
40.0
 20
15.0
 30
0.0
 11
38.0
 21
17.0
 31
0.0
  0
LINE
  5
8B
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
38.0
 20
17.0
 30
0.0
 11
28.0
 21
17.0
 31
0.0
  0
LINE
  5
8C
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
28.0
 20
17.0
 30
0.0
 11
22.0
 21
21.0
 31
0.0
  0
LINE
  5
8D
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
22.0
 20
21.0
 30
0.0
 11
4.0
 21
21.0
 31
0.0
  0
ENDSEC
  0
```

Figure 7: DXF Format for Profile without Fillet

B. Profile with Fillet

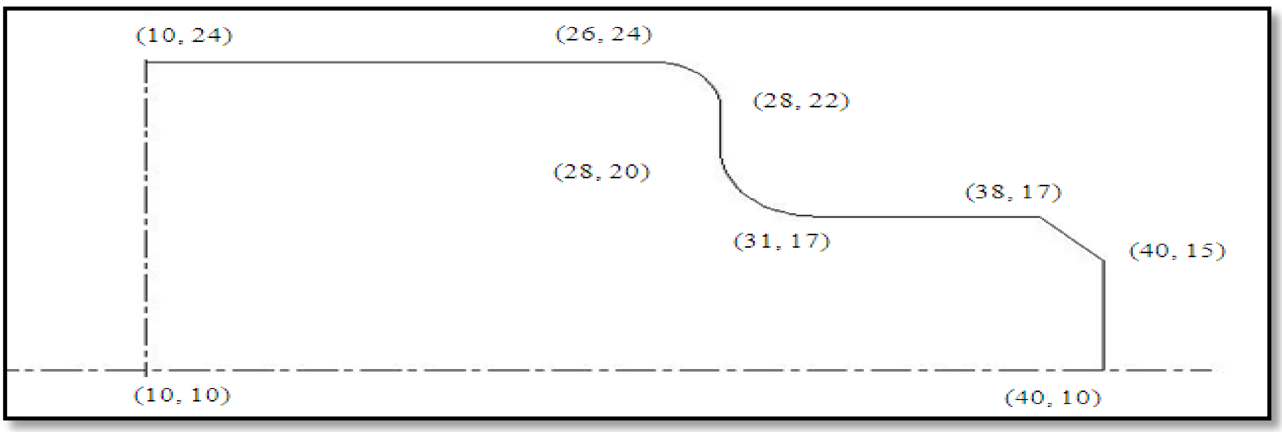


Figure 8: Profile with Fillet

For this profile first part zero is determined. Here part zero is at point (10, 10). Then for absolute positioning other points are determined from the vertex coordinate system. Points found from vertex coordinate system are (40, 10), (40, 15), (38, 17), (31, 17), (28, 20), (28, 22), (26, 24) and (10, 24). From those points least value of X coordinate and least value of Y coordinate is determined which is found to be (10, 10). So by subtracting the value of X and Y from all the coordinates' conversion from global to local system is made. Profile with fillet needs to consider extra features. For those features extra calculation and idea is generated.

Steps to generate G-Code from DXF file format:

1. Drawing is saved in DXF format.
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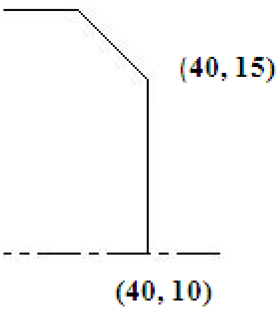
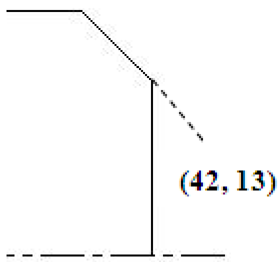
3. From ENTITIES several features are identified
4. Every line is start with AcDbLine and ends with a character 0
5. X_{start} is shown by 10 and Y_{start} is by 20
6. X_{end} is shown by 11 and Y_{end} is by 21
7. Lowest value of X and Y is determined and is set to origin of the coordinate by subtracting them from all the coordinates.
8. Generation of G-Code is executed from the highest value of x at which the value of Y is no equal to the value of coordinate origin value of Y. there is such one point, in this case this value is (40, 15)



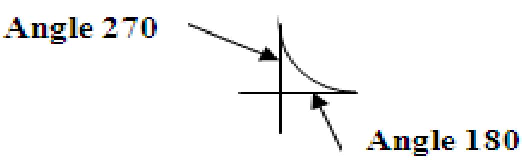
9. As cutting is starting from some far from the workpiece thus for rapid positioning cutting tool is

positioned in the position at +2 in X axis and -2 in y axis from the first point(in this case (40, 15)).

10. For this case starting point is (42, 13).



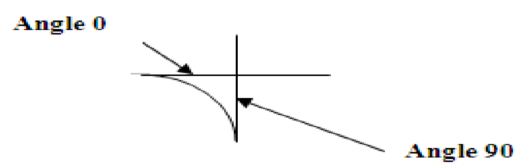
11. For G-Code representation X axis of the coordinate system is represented as Z and Y axis of coordinate system is as X. The Codes used is elaborated later in the chapter. So for initial rapid positioning G-code is G00. The formulae used to define is as following
    $(X-X_{origin}) = X_{start}$
    Represented as Z….
    $(Y-Y_{origin}) \times 2 =$ diameteRepresented as X…
    So after rapid positioning first line become



So for corresponding G-code for clockwise circular interpolation is G02 and for counterclockwise circular interpolation is G03.

G 00 Z 32 X 6

12. Then linear interpolation is made with respect to descending order of X axis coordinate in the DXF file 10, 11 commands. So next line in G-code become G 01 Z 28 X 14
13. Another type of feature include in the profile is fillet. To represent fillet circular interpolation is necessary. When AcDbCircle is found in the DXF file it implies there is some circular shape.
14. For circular shape 10, 20 imply coordinate of center of the circle and 40 implies radius of the circle. One important measure is either the circle is clockwise or anticlockwise. 50, 51 imply the starting angle and ending angle. If 50 and 51 range from 0 to 179 degree then the circular shape is clockwise and if range of 50, 51 is 180 to 359 then circular shape is counterclockwise



15. For this sample problem for first fillet which is clockwise and following G-code is obtained for the input of DXF file.
    G02 Z18 X20 R 3
16. For this sample problem for second fillet which is counterclockwise and following G-code is obtained for the input of DXF file.
    G03 Z16 X28 R 2
    After linear interpolation when there is some gap program understand it as fillet and by the descending order of X coordinate it arrange the G-code command.
    Similarly circular interpolation is done for all AcDb Circle command.

```
ENTITIES
  0
LINE
  5
89
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
40.0
 20
10.0
 30
0.0
 11
40.0
 21
15.0
 31
0.0
  0
LINE
  5
8A
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
40.0
 20
15.0
 30
0.0
 11
38.0
 21
17.0
 31
0.0
  0
LINE
  5
8B
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
38.0
 20
17.0
 30
0.0
 11
31.0
 21
17.0
 31
0.0
  0
LINE
  5
8C
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
28.0
 20
20.0
 30
0.0
 11
28.0
 21
22.0
 31
0.0
  0
LINE
  5
8D
330
1F
100
AcDbEntity
  8
0
100
AcDbLine
 10
26.0
 20
24.0
 30
0.0
 11
10.0
 21
24.0
 31
0.0
  0
ARC
  5
8E
330
1F
100
AcDbEntity
  8
0
100
AcDbCircle
 10
31.0
 20
20.0
 30
0.0
 40
3.0
100
AcDbArc
 50
180.0
 51
270.0
  0
ARC
  5
8F
330
1F
100
AcDbEntity
  8
```

IV. CONCLUSION

Computer-Integrated Manufacturing has gained recognition as a most effective tool in increasing manufacturing competitiveness. The paper provides a rigorous basis for the understanding of process planning of rotational parts and the development of effective and efficient Computer-Aided Process Planning systems. This paper defined CAPP module for data transmissions which is based on information received from the computer aided design of the products and on the technological database with information on technological equipment, devices and cutting tools. Realizing the CAPP module for data transmissions has led to an increase of the flexibility and correctness of the technological planning, having favorable influences on the manufacturing costs.

IV. REFERENCES

1) Alting, L. and Zhang, H. C., (1989), ―Computer aided process planning: the state-of-the-art survey", *International Journal of Production Research*, vol. 27(4), pp. 553 – 585.
2) Alam, M. R., Lee, K. S., Rahman, M. and Zhang, Y. F., (2000), ―Automated process planning for the manufacture of sliders", *Computers in Industry*, vol. 43, pp. 249-262.
3) Aslan, E., Seker, U and Alpdemir, N., (1999), ―Data extraction from CAD model for rotational parts to be machined at turning centres", *Journal of Engineering and Environmental Science*, vol. 23, pp. 339-347.
4) Atkinson, A., (1991), ―Manufacturing parts features: CIM's technological common denominator", *Integrated Production Systems – Design, Planning, Control and Scheduling*, fourth edition, Institute of Industrial Engineers, Norcross, Georgia.
5) Cay, F. and Chassapis, C., (1997), ―An IT view on perspectives of computer aided process planning research", *Computers in Industry*, vol. 34, pp. 307-337.
6) Chang, T. C. and Wysk, R. A, (1985), ―Introduction to Automated Process Planning System", Prentice-Hall International Inc., pp 165-181.
7) ElMaraghy, H. A., (1993), ―Evolution and future perspectives of CAPP", *Annals of CIRP*, vol. 42(2), pp. 1-13.
8) Groover, M. P., (1987), ―Automation, production systems and computer integrated manufacturing", Prentice-Hall International Inc., pp 721.
9) Gindy, N. N. Z., (1989), ―A hierarchical structure for form features", *International Journal of Production Research*, vol. 27, no. 12, pp. 2089-2103.
10) Han, J. H., Pratt, M. and Regli, W. C., (2000), ―Manufacturing feature recognition from solid models: a status report", *IEEE Transactions on Robotics and Automation*, vol. 16, no. 6, December.
11) Houtzeel, A., (1976), ―The MICLASS system", Proceedings of CAM-I's Executive Seminar – Coding, Classification and Group Technology for Automated Planning, p-76-ppp01, CAM-I, Arlington, TX, USA.
12) Kanai, S., Sugawara, M., Kishinami, T. and Saito, K., (1988), ―The flexible process planning by combining the advanced CAPP, CAM and measuring system", 16^{th} North American Manufacturing Research Conference Proceedings, University of Illinois, Urbana, Illinois, May 24-27.
13) Marefat, M. and Britanik, J, (1996), ―Automated reuse of solutions in manufacturing process planning through a case-based approach", Proceedings of the 1996 ASME Design Engineering Technical Conference and Computers

in Engineering Conference, Irvine, California, August 18-22.

14) Naish, J. C., (1996) ―Process capability modeling in an integrated concurrent engineering system – the feature-oriented capability module", *Journal of Materials Processing Technology*, vol. 61, pp. 124 – 129.
15) Niebel, B. W., (1965), ―Mechanized process selection for planning new designs", *ASME*, paper no. 737
16) Pande, S. S. and Prabhu, B. S., (1990) ―An expert system for automatic extraction of machining features and tooling selection for automats", *Computer Aided Engineering Journal*, pp. 99-103, August.
17) Pressman, R. S., (2001) ―Software engineering – a practitioner's approach", McGraw Hill, 5th Edition.
18) Law, H. W., Tam, H. Y., Chan, A. H. S. and Hui, I. K., (2001), ―Object-oriented knowledge-based computer-aided process planning system for bare circuit boards manufacturing", *Computers in Industry*, vol. 45, pp. 137 – 153.
19) Lee, K., (1999), ―Principles of CAD/CAM/CAE Systems", Addison-Wesley, pp. 294-304.
20) Lee, K. S., Alam, M. R., Rahman, M. and Zhang, Y. F., (2001), ―Automated process planning for the manufacture of lifters", *The International Journal of Advanced Manufacturing Technology*, vol. 17, pp. 727-734.
21) Li, R. K. and Adiga, S., (1987), ―Part feature recognition system – a vital link in the integration of CAD and CAM", Proceedings of 9th International Conference on Production Research, Cincinnati, Ohio, USA, August 17-20.
22) Link, C. H., (1976), ―CAPP – CAM-I automated process planning system", Proceedings of 13th Numerical Control Society Annual Meeting and Technical Conference, pp. 401-408, March.
23) Trika, S. N. and Kashyap, R. L., (1994), ―Geometric reasoning for extraction of manufacturing features in iso-oriented polyhedrons", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 16, no. 11, November.
24) Tyan, L. W. and Devarajan, V., (1998), ―Automatic identification of non-intersecting machining features from 2D CAD input", *Computer Aided Design*, vol. 30, no. 5, pp. 357-366.
25) Wong, T. N. and Wong, K. W., (1995), ―A feature-based design system for computer-aided process planning", *Journal of Materials Processing Technology*, vol. 52, pp. 122 – 132.
26) Wysk, R. A., (1977), ―An automated process planning and selection program: APPAS", PhD dissertation, Purdue University, West Lafayette, IN, USA.
27) Zeid, Ibrahim, (2002), ―CAD/CAM Theory and Practice", Tata-McGraw-Hill, sixth reprint,pp.9951