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# Development of a Feature Based CAM System for Rotational Parts

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**ABSTRACT**

Computer Aided Process Planning (CAPP) plays an important role in the development of Computer Integrated Manufacturing systems (CIM) and provides a vital link between Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). Automatic extraction and recognition of part features directly from a CAD database also strengthen the link between CAD and CAPP. In this study, an automatic feature recognition and CNC code generation (AFR/ACCG) system was developed for rotational parts. This system was prepared using Delphi 7 programming language. The data input to the system is done by DXF (Drawing Interchange Format) prepared in any CAD programme. CNC part programme of the work piece to be produced is generated automatically as to machining features in this system. Sample parts were machined by the generated tool paths and part geometries were obtained accurately. All of the internal and external machining features of complex parts such as grooving, threading and boring can be defined automatically using this system by the nine determined elements.

***Keywords:*** CAD/CAM, CAPP, AFR, Automatic CNC code generation

## 1. INTRODUCTION

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. Feature recognition techniques provide such a connection between CAD and CAPP. However, CAD and CAPP systems form different databases. While CAD databases are usually geometry-based, consisting of geometric primitives such as points, lines and arcs, CAPP systems are feature-based such as faces, cylinders, grooves or pockets. It could be said that the CAPP systems describe in terms of manufacturing features, whereas CAD describes parts by their solid model or design features (1-3). One of the solutions for these problems between CAD and CAM is the automatic feature recognition technique. Miscellaneous techniques including graph-based and hint based such as cell division, cavity volume, convex hull and lamina slicing have been used in automatic feature recognition. Necessary tool paths for the manufacturing of parts can be generated automatically in the AFR process. These systems gave users a three-step process: to pick certain entities and define them as feature, choose the proper machining process and to supply necessary information the feature does not provide. AFR systems involve a set of automated steps in spite of how many features the model contains. These steps include: extraction of machinable features, generation of an operation plan and generation of a tool path (4-8). Fig. 1 shows flow diagram for automatic feature recognition (8).

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. One typical example of a rule-based system was developed by Meeran and Pratt using PROLOG. The input to the system is three view orthographic drawings in DXF format. However, the system was limited to prismatic parts and limited by its rules base (9). Madurai and Lin developed a rule-based system using the expert system approaches for automatic extraction and recognition of part features directly from

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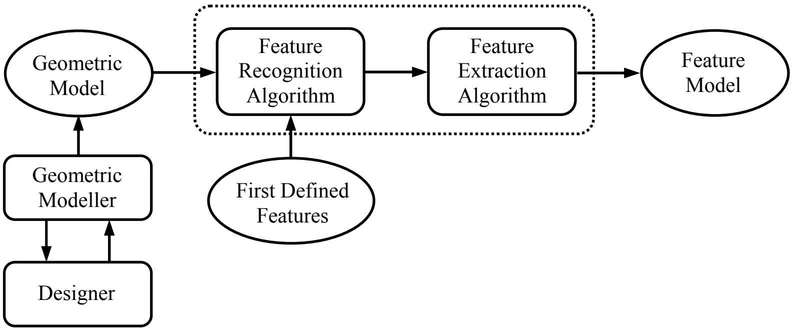



**Figure 1.** Flow diagram for automatic feature recognition (8)

CAD data for rotational part features. Geometric and topological data of the part in IGES (Initial Graphics Exchange Specifications) format are read by a feature extraction data-compactor, a pre-processor of the system. Manufacturing features are generated by production rules written in LISP. They demonstrated the functioning of the system by two illustrative examples (10). One important type of a feature recognition method is graph-based recognition, which recognizes features by matching a feature graph to the appropriate subgraph, in a graph-representation of the part. This method has advantages such as being applicable to many domains not just machining, allowing the user to add new feature types without changing the codes, being suitable for incremental feature modelling, and being able to recognize isolated features effectively. The disadvantage of this method is that feature interaction and multiple interpretations of features can not be handled well (11). Marefat and Kashyap developed a graph-based feature recognition method. They define features by cavity graphs including some geometric constraints. They first recover virtual links using an AI (Artificial Intelligent) technique and add them into the cavity graph of the part to recognize interacting features. Then they generated all hypothesized features by subgraph matching (12). Neural network systems have been used in feature recognition because of their capability of learning from examples. The most important advantage of using a neural network is the high possibility of recognizing features. As it is not definite in recognizing some features in the case of rule-based and graph-based systems, the neural network-based systems are able to recognize features that are not certain (13). Peters developed a neural network-based system to define 2D features. The main purpose of his research is to develop an encoding scheme for defining 2D features. He did this by giving a generic description consisting of curvature, interior angle and curve segment of the 2D entities lines and curves (14). In this study, a system deriving CNC code automatically was developed for cylindrical parts using the automatic feature recognition method. All of the internal and external machining features necessary for turning operations have been recognized by the nine determined elements. Sample parts were machined by the generated part programmes.

## 2. DEVELOPED SYSTEM

CNC part programmes 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 programmes 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 Coromant 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 Fig. 2.

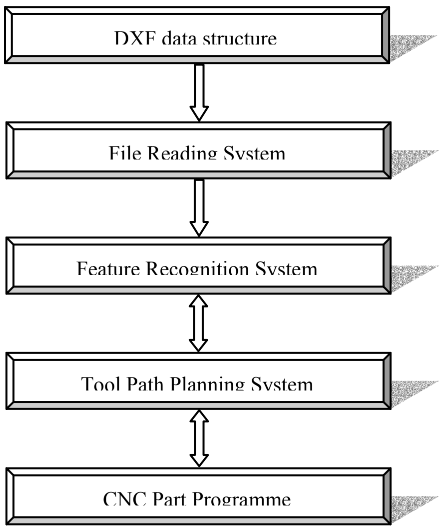



**Figure 2.** Structure of the system

### 2.1. 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. In this stage, the coordinates of the start and end points of arc features which is not obtained directly from DXF database are found using trigonometric equations and all of feature coordinates are modified from right to left and from below to above.

These processes provide the precise feasibility of the sequencing process to be done in the following stages. It may be possible that the drawing could have been constructed anywhere in the CAD environment according to the Cartesian coordinate system. In that case all of the feature coordinates of the design are modified according to the quadrant II (x<0,y>0) of the coordinate system because of the fact that tool paths, according to the absolute dimension system, are formed by generally taking the face of the component in the manufacturing of cylindrical components. 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. The direction and sequence of the recognized features after the file reading system are illustrated in Fig. 3.

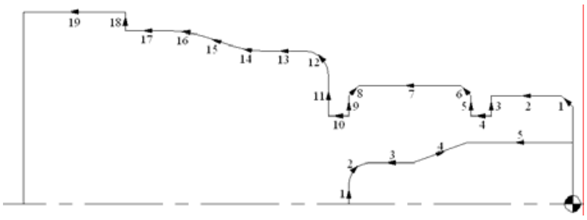


**Figure 3.** The direction and sequence of the recognized features

### 2.2. 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. These features are also classified to sub features by the system such as long turning and grooving according to machining attributes. All of the basic line and arc features obtained from the CAD database are represented independently for all turning operations as illustrated in Fig. 4 and Fig. 5. Each feature in these figures could be used in recognition of turning operations such as long turning, grooving, drilling and boring. All necessary definitions were made for the turning operations with the nine determined elements.

### 2.3. 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

| Operation Types of Using Features | Types of Geometric Features | | Rules for Feature Recognition | Feature Number |
|---|---|---|---|---|
| | External | Internal | | |
| Long Turning, Profile Turning Grooving, Threading Drilling Boring | x2,y2 ← x1,y1 | x2,y2 ← x1,y1 | (y1 = y2) | 1 |
| Facing Out Profile Turning Grooving Drilling Boring | x2,y2 ↑ x1,y1 | x2,y2 ↑ x1,y1 | (x1 = x2) | 2 |
| Profile Turning Grooving Drilling Boring | x2,y2 ↗ x1,y1 | x2,y2 ↖ x1,y1 | (x1< >x2) & (y1< >y2) | 3 |
| Profile Turning Grooving Drilling Boring | x2,y2 ↖ x1,y1 | x2,y2 ↗ x1,y1 | (x1< >x2) & (y1< >y2) | 3 |

**Figure 4.** Determined rules for defining of the line features

| Operation Types of Using Features | Types of Geometric Features | | Rules for Feature Recognition | Feature Number |
|---|---|---|---|---|
| | External | Internal | | |
| Profile Turning Grooving Boring | | | (a1>=0) & (a2<=90) | 4 |
| Profile Turning Grooving Boring | | | (a1>=180) & (a2<=270) | 5 |
| Profile Turning Grooving Boring | | | (a1>=90) & (a2<=180) | 6 |
| Profile Turning Grooving Boring | | | (a1>=270) & (a2<=360) | 7 |
| Profile Turning Grooving Boring | | | (a1<90) & (a2>90) | 8 |
| Profile Turning Grooving Boring | | | (a1<270) & (a2>270) | 9 |

**Figure 5.** Determined rules for defining the arc features

from DXF data. Face and long turning operations are made according to differences between these minimum-maximum and raw material sizes. These sizes are the total depth of the cut on the face or outside diameter of the work piece. Tool paths necessary for operations such as long, face and profile turning in this system are generated according to equal intervals and linear-parallel tool path geometry. The method of profile recognition and necessary tool paths are shown in Fig. 6. 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.

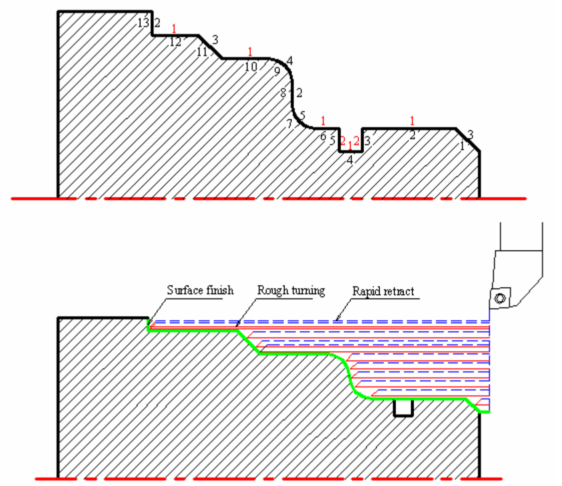



**Figure 6.** The method of profile recognition and necessary tool paths

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. In this process, features of number one and machining features such as grooving which do not include profile turning are skipped by the system during tool path planning. Tool path methods for tapered and curved surfaces with parallel tool path and equal intervals are demonstrated in Fig. 7.

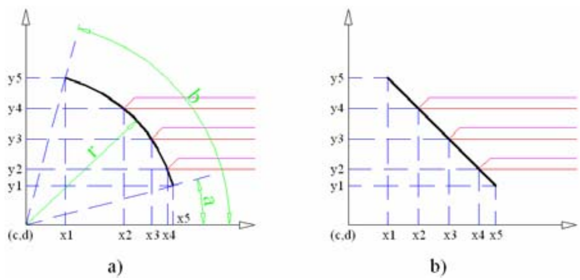



**Figure 7.** a) Tool paths for arc features, b) Tool paths for tapered surfaces

Tool paths in boring operations are also performed using linear and equal interval tool path geometry similar to the outside profile turning shown in Fig. 8. Before boring operations, a pre-drilling process is carried out in the maximum allowable diameter in order to be able to use the tool holder for roughing and finishing operations. After this process the cutting tool is moved rapidly in this hole to reduce the non-cutting time of the tool. The boring operation can be considered as the symmetry of the outside profile turning operation. Some machining features such as number 1 and grooving features are separated by the system during tool path planning.

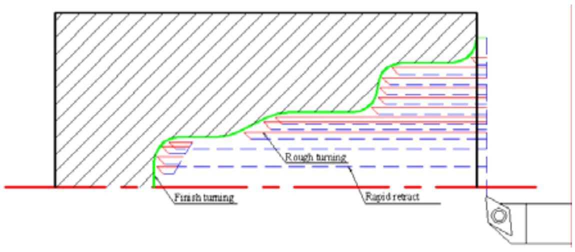



**Figure 8.** Tool paths for boring

Before general turning operations such as profile, long and face, the cutting parameters menu shown in Fig. 9 supports the user to determine the cutting conditions. The user can determine the cutting speed and feed rates at ISO P (alloy and non-alloy steels), M (stainless steel) and K (iron casting) qualities according to cemented carbides, coated carbides, cermets, ceramics, polycrystalline diamonds (PCD) and cubic boron nitrides (CBN) cutting tools. A decrease in the diameter in the shape of the work piece is perceived as a groove by the system in order to recognize all grooving shapes. In this approach, with comparison of all features in the component, the start of the groove, end of the groove and the interior entities of the groove are represented and tool paths are realized by this definition. During comparison of the start and end points of the entities, if there is any decrease along the *y* axis value of the next element it is described as beginning of the groove. As shown in Fig. 9, '*yi*' is the finish point of the first element of the groove, '*yj*' is the finish point of the second element and '*yk*' is the beginning point of the same element. '*yl*' is the finish point of the last element which is bigger than '*yi*' or equal to it. All the entities between these beginning and ending elements are assumed as the bottom elements of groove.

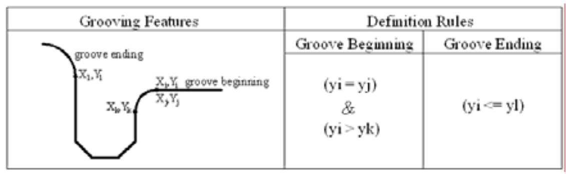



**Figure 9.** Definition rules for grooving features

The root diameter of the thread must be stated in drawings for automatic recognition of the threading features. There is an arrangement for thread machining features after sequencing of entities as illustrated in Fig. 10. In order to recognize these elements, the initial entity is supposed to be feature (number 3), two features after this are supposed to be feature 1 as illustrated in Fig. 4 and it is supposed that the start points of the first feature (number 3) and the next feature (number 1, *xj* and *xk* or *yj* and *yk*) are to be the same. The start and end point of the threading feature is start and end point of feature 1 (*xk*, *xl*) whose sequence number is 2. The system accomplishes tool paths for threading operation using a G76 cycle according to start-end points and root diameter in the drawing.

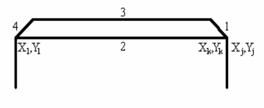
| Threading Features | Definition Rules |
|---|---|
|   | ( i = 3 ) & ( i+1 = 1 ) & ( i+2=1 ) & ( xj = xk )<br>xk = thread beginning<br>xl = thread ending |

**Figure 10.** Definition rules for threading features

Hole geometries must also be stated in drawings for automatic definition of the drilling operation. Recognition processes of the system are shown in Fig. 11. Drilling features can be recognized from two or three components and the entities are sequenced as shown in Fig. 11 in file reading stage. In the recognition of the features, (*xj*) the start point of the feature number 1 whose sequence number is 2 is determined as the start point of the hole, (*xk*) the end point of the feature number 3 whose sequence number is 1 is determined as the end point of the hole. The drilling operation is performed using a drill peck. The parting off operation is done automatically using peck cutting as drilling depends on the latest feature in the drawing.

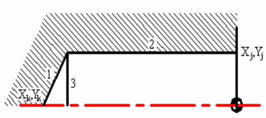
| Drilling Features | Definition Rules |
|---|---|
|   | ( i = 2 ) & ( unsur = 1 )<br>xj = hole beginning<br>( i = 1 ) & ( unsur = 3 )<br>xk = hole ending |

**Figure 11.** Definition rules for drilling features

## 3. SAMPLE PART

Fig. 12 a shows the sample work piece shape to be manufactured and b shows the method of design of the shape in a CAD environment for a DXF data structure. Fig 13 shows the main menu of the system and derived CNC programme of the sample part. The programme can be saved as "txt" format after the derivation.

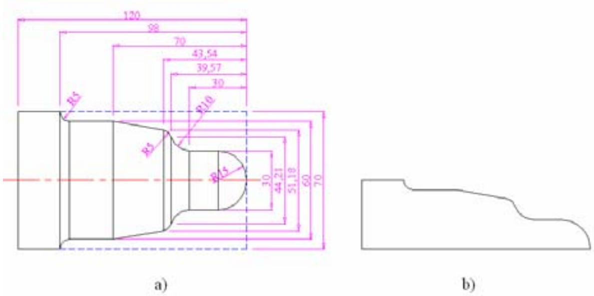



**Figure 12.** Sample part geometry

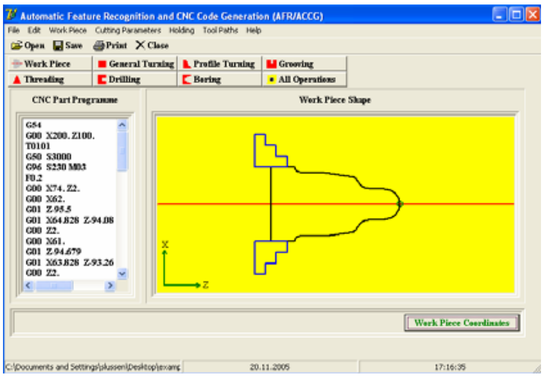



**Figure 13.** The main menu of the system and sample code derivation

## 4. CONCLUSIONS

- The AFR/ACCG system generates tool paths from DXF data structure using automatic feature recognition. Tool paths are generated according to linear tool path geometry which is used as the most efficient.
- Most commercial CAD/CAM packages are insufficient in terms of geometric definition because of their weak connection between CAD and CAM/NC part programming modules. This weak connection between CAD and CAM is strengthened using the automatic feature recognition approach.
- All of the external and internal operations, which comprise primary and secondary cutting actions, are made by defining nine features, the system is capable of processing and representing complicated turned components including finishing and roughing operations separately. After experimental machining tests, all of the geometries were obtained accurately.
- Particularly in grooving operations using a different defining approach that decreases the diameters is automatically perceived as a cavity by the system, as a result all of the cavity shapes can be recognized in grooving operations. There is no need to do a different definition for various groove shapes according to various work piece representation approaches.
- The material and cutting tool databases support the user in determining cutting parameters.

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