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Intelligent computer aided process planning system for milling operation

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Abstract

Computer-aided process planning **(**CAPP**)** is the use of computer technology to aid in the process planning of a part or product, in manufacturing. CAPP is the link between CAD and CAM in that it provides for the planning of the process to be used in producing a designed part. CAPP can be used to develop a product manufacturing plan based on projected variables such as cost, lead times, equipment availability, production volumes, potential material substitution routings and testing requirements. Manufacturing firms try to automate the task of process planning using CAPP systems due to many limitations of manual process planning. Process planning is a production activity that transforms a product design into a set of instruction (sequence, machine tool setup etc.) to manufacture machined part economically and competitively. Harnessing the power of the computer is extremely advantageous in process planning. CAPP translates design information into the process steps and instructions to efficiently manufacture parts. CAPP thus appears to fully integrate CAD and CAM. Computer Aided Process Planning (CAPP) has been recognized as playing a key role in Computer Integrated Manufacturing (CIM). In the last two decades, a tremendous effort has been made in developing CAPP systems. However, the benefits of CAPP in the real industrial environment are still to be seen. In this paper, a software package is developed which will generate the manufacturing process sheet automatically. A computer program, using visual basic programming languages, is written for this purpose. The process sheet is developed by selecting the operation from the menu and then by feeding the part drawing details. The approach involves, asking a series of questions by the system to the user, about the component drawing and related details. Initially the system asks the user, about the choice of machining operation. The developed system is interactive and simple in use. Machining time and cost of experimental process planning is compare with generative computer aided process planning for each operation.

Keywords: computer aided process planning, operation plan code, milling, expert system

1. Introduction

Computer Aided Process Planning (CAPP) has been recognized as playing a key role in Computer Integrated Manufacturing (CIM). In the last two decades, a tremendous effort has been made in developing CAPP systems. Modern organization of manufacturing, featuring novel design and manufacturing technologies, with emphasis on flexible automation and extensive application of computers. 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 is the act of preparing detailed operating instructions for turning an engineering design into an end product, i.e. the part. This implies the need to translate the design specifications of a part into the required manufacturing operating instructions, to convert it from the raw material to the part in its final state [1]. There is a great deal of manufacturing data involved in process planning such as the identification of machines, tools, flanging, parameters selection for the, process, operations, etc. [2]. The fact that there are few experienced process planners and that, when faced with the same problem, different process planners would probably come up with different plans is an indication of the heterogeneity that exists in process planning [1]. Consistent and correct planning requires two things: knowledge of manufacturing processes and experience [3]. This has led to the development of computer aided process planning (CAPP) systems which are becoming more and more important in this field. The most maturely developed area so far has been focused on machining applications. Research and development in manufacture applications such as heat treatment, forging, injection moulding, and waterjet machining is still premature, and the reported systems for sheet metal manufacture rely on a high level of interaction from the expert who provides the decision-making at different stages of planning [4]. Waterjet machining components are widely used in various industries and they form a significant part of manufacturing activity. Waterjet machining components are important not only from a functional point of view, but also from an aesthetic point of view, since they are used as enclosures to cover products and are visible to the outside world. These components vary in size, shape and complexity. The manufacturing processes required for sheet metal components are identified by analyzing the component layout, and then design information is manually translated into manufacturing information [5]. To overcome inherent difficulties and limitations associated with human beings, research work is progressing into the area of automatic transformation of design information into manufacturing information through feature recognition. Automation of manufacturing systems is primarily focused on product design, process planning, production planning and control, as well as manufacturing. Design automation is successfully solved using CAD/CAE systems, manufacturing is automated using CAM and NC (numerical control) systems, production control is solved using MRP and ERP (enterprise resource planning) systems, while the process planning is solved by CAPP systems [6]. Due to a relatively low level of

CAPP systems, process planning activities represent a significant problem in integration of manufacturing. Process planning is mostly based on the know-how and experience of engineers. Intensive use of computers has allowed significant advances, resulting in a number of CAPP systems. The basic goal of developmental activities in manufacturing technologies is the integration of all segments of manufacturing and a setup of computer integrated manufacturing (CIM). CAPP systems have key role in the integration of design and manufacturing, i.e. they are a bridge between CAD and CAM systems [7, 8]. Traditionally, process planning is performed manually by highly experienced planners who posses in depth knowledge of the manufacturing processes involved and the capabilities of the shop floor facilities. Because of the experience factor involved in the planning for the physical reality of the product and in the absence of standardization of the process, conventional process planning has largely very subjective. Moreover this activity is highly labour-intensive and often becomes tedious when dealing with a large number of process plans and revisions to those plans. Rather than carry out exhaustive analysis and arrive at optimal values, which would be too time consuming, process planners often tend to play safe by using conservative values and this situation invariably leads to non optimal utilization of the manufacturing facilities and longer lead times. They also would not be in a position to see whether a similar component has already been planned in view of the difficulties involved in going through all old process plans. The need of shorter lead times, satisfying varied customer demands on the product variety and the optimum use of the manufacturing facilities, prompted research organizations and industries to automate many functions in the product cycle. Harnessing the power of the computer is extremely advantageous in process planning since a vast amount of data needs to be used for arriving at the right decision for planning the manufacturing operations. Computer aided process planning (CAPP) is a means to automatically develop the process plan from the geometric image of the component. The key of the development of such CAPP System is to structure the data concerning part design, manufacturing facilities and capabilities into categories and logical relationships. CAPP thus appears to fully integrate CAD and CAM. Several researchers have attempted to do the research in CAPP and have identified areas that need further research. CAPP systems have distinctly evolved in the literature as variant approach and generative approach [9][10]. Variant approach follows the principle that similar part requires similar plans. Generative approach utilizes decision logic, mathematical formulae, manufacturing rules and geometric data to determine the process required to convert the new material into a finished part. J. Ciurana *et al.* [11] developed a model to integrate process planning function with production planning and control. However before all these functions one of the important decisions to be made is the manufacturing feasibility decision which is not considered. Zhang Wei Bo *et al.* [12] optimized process route by genetic algorithm which is one of the key function in computer aided process planning. More detailed in [13, 16]. Process planning involves the preparation for the manufacture of products. Process planning deals with the selection and definition of the processes that have to be performed in order to transform raw material into a given shape. Process planning in part manufacturing includes:

- The interpretation of the product model.
- The selection of machine tools.
- The selection of tool sets.
- The determination of set-ups.
- The design of fixtures.
- The determination of machining methods.
- The selection of cutting tools.
- The determination of machining sequences.
- The calculation of tool paths.
- The calculation of cutting conditions.
- The generation of NC programs
- Capacity planning.

All the information determined by the process planning function is recorded on a sheet called process plan. A process plan is frequently known as operation sheet, route sheet or operation planning sheet. This provides the instructions for the production of the parts. It contains the operating sequence, processes, process parameters and machine tools used. Process planning is classified into two categories: Manual/Traditional process planning and Computer aided process planning. At present, there are two general approaches to CAPP variant and generative; each one is associated with specific planning techniques. Manual process planning is based on a manufacturing engineer's experience and knowledge of production facilities, equipment, their capabilities, processes, and tooling. Process planning is very time-consuming and the results vary based on the person doing the planning". The process planner must have the knowledge of the followings:

- Ability to interpret an engineering drawing.
- Familiar with manufacturing processes and practice.
- Familiar with tooling and fixtures.
- Know what resources are available in the shop.
- Know how to use reference books, such as machinability data handbook.
- Able to do computations on machining time and cost.
- Familiar with the raw materials.
- Know the relative costs of processes, tooling, and raw materials.

Process Planning including the following Steps

- Study the overall shape of the part and study the drawing.
- Use this information to classify the part and determine the type of workstation needed.
- Try to identify every manufacturing features and notes.
- If raw stock is not given, determine the best raw material shape to use.
- Identify datum surfaces. Use information on datum surfaces to determine the setups.
- Select machines for each setup.
- For each setup determine the rough sequence of operations necessary to create all the features.
- Sequence the operations determined in the previous step.
- Select tools for each operation. Try to use the same tool for several operations if it is possible
- Select or design fixtures for each setup.
- Evaluate the plan generate thus far and make necessary modifications.
- Select cutting parameters for each operation.
- Prepare the final process plan document

2. Computer aided process planning (CAPP)

CAPP means process planning with the aid of computer. Process planning is concerned with the preparation of route sheets that list the sequence of operations and work centers require to produce the product and its components. Manufacturing firms try to automate the task of process planning using CAPP systems due to many limitations of manual process planning. These includes: a) Tied to personal experience: b) knowledge of planner of production facilities, equipment, their capabilities, process and tooling. This results in inconsistent plans. c) Manual process planning is time consuming and slow. d) Slow in responding to changes in product design and production. The experience of manufacturing engineers, is needed to develop CAPP. CAPP is usually considered to be part of CAM, however this results CAM as stand alone system. Synergy of CAM can be achieved by integrating it with CAD system and CAPP acts as a connection between the two. Readymade CAPP systems are available today to prepare route sheets. The following Steps Involved in CAPP: a) design input; b) material selection; c) process selection; d) process sequencing; e) machine selection; f) tool selection; g) intermediate surface determination; h)fixture selection; i) machining parameter selection; j) cost/time estimation; k) Plan preparation; m) NC tap generation.

Variant and Generative Process planing are two important approaches in CAPP for integration of CAD and CAM.

Variant CAPP/ Retrieval CAPP systems has evolved out of the traditional manual process planning method. A process plan for a new part is created by identifying and retrieving an existing plan for a similar part, followed by the necessary modifications to adapt it to the new part. Variant CAPP is based on GT principles, i.e., part classification and coding. These coding allow the CAPP system to select a baseline process plan for the part family and accomplish about 90% of the planning work. The planner adds the remaining 10% of the planning by modifying the baseline plan. If the code of the part does not match with the codes stored in the database, a new process plan must be generated manually and then entered into database to create a new baseline process plan for future use. Advantages and limitations of variant CAPP including: a) Investment in hardware and software is not much; b) The system offers a shorter development time and lower manpower consumption to develop process plan; c) The system is very reliable and reasonable in real production environments for small and medium size companies; d) Quality of process plan depends on knowledge and background of process planner.

Generative Process plans are generated by means of decision logics, formulas, algorithms, and geometry based data that are built or fed as input to the system. Format of input including text input (interactive) and graphical input (from CAD models). First key: to develop decision rules appropriate for the part to be processed. These rules are specified using decision trees, logical statements, such as if-then-else, or artificial intelligence approaches with object oriented programming. Second key: Finding out the data related to part to drive the planning. Simple forms of generative CAPP systems may be driven by GT codes. from part classification and other design data which does not require any further modification or manual interaction. In generating such plans, initial state of the part (stock) must be defined in order to reach the final state i.e., finished part. Forward or backward planning can be done. Forward and backward planning apparently appear to be similar but they effect programming significantly. The requirement and the results in of a setup in forward planning are the results and requirements, respectively, of the set up in backward planning. Forward planning suffers from conditioning problems; the results of a setup affects the next set up. In backward planning, conditioning problems are eliminated because setups are selected to satisfy the initial requirements only. The generative CAPP has all the advantages of variant CAPP however it has an additional advantage that it is fully automatic and a up-to-date process plan is generated at each time. It requires major revisions if a new equipment or processing capabilities became available.

3. Development of an intelligent Computer Aided Process Planning System

Production process of products depends significantly on cost of quality, time to market and cost to produce appropriate parts or products. Previously, the design and manufacturing largely based on individual approach, with unfavorable techno-economic effects. It has been noted that the majority of parts can be standardized, which allows the concept of group technology to be applied on mold design and manufacturing. As a result, standardization and batch manufacturing were introduced, allowing shorter lead times and delivery, high quality, low manufacturing costs, etc. The ever-intensive application of products has, in the last decade, inspired CAx manufacturers to develop systems which allow improvement of design and manufacturing of products. A significant advancement has been made considering the development of CAD systems dedicated to design, as well as the special CAE systems dedicated to simulation and analysis of parts or products. The manufacturing process planning domain has become a bottleneck in the overall system for manufacture. In order to rationalize and advance the manufacture, a model is proposed and the system for automated process planning for manufacturing is developed. Schematic diagram of Computer aided process planning is demonstrated in figure 1.

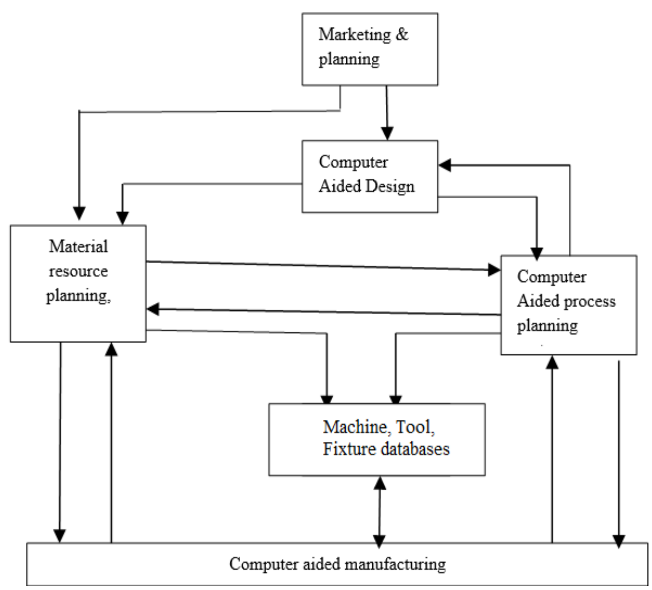

Fig 1: Computer aided process planning

4. Module of the developed CAPP system

4.1 Operation Selection Module

This module is the initial module of the system. It allows user to make a choice of the operation for which he wants to prepare the process sheet. It contains a milling operation.

4.2 Component Representation Module

Analogues to the conventional process planning, where the process planner physically examines the part design and then based on geometrical and technological constrains prepare the sequence of operations to be followed to produce the part, the first task in the developed system would be the creation of computer model of the component. In this package, interactive modeling concept is used to create the computer model of the part.

4.3 Database Management Module

The utility of any process planning software depends very much on the quality and extent of data available to it. It requires a large amount of data for manufacturing. This large data is to be properly organized for easy access as well as for maintaining integrity. For this reason an extensive manufacturing database has been designed.

4.4 Time and Speed Computation Module

In this module, the time required for various operations are computed. The machining time for operation is calculated using the geometry of work-piece, and the process parameters. The time of machining for each operation can be calculated using these formulas and then production time per piece also can be determined and hence total production time is calculated. In speed computation module, the system will analyze the part drawing, for different surfaces and calculate the rpm required for the operation. The quality of surface finish and tool life are highly depends on the rpm. For computing the rpm, the system selects the permissible cutting speed from the database files for a given material and cutting tool. Then the system computes the spindle speed i.e. RPM for the machinable diameter using the formula.

$$\text{Speed (N)} = 1000 \times V\Pi \times D$$

Where, D = Cutter Diameter in mm; V = Cutting speed in m/min

4.5 Operation Extraction and Sequence Module

This module is the heart of the software. This module scans the part description, in the component representation module and in the database modules, to generate the process plan sheet for the part. The system collects all the information provided by the user and the information collects from the database, and then according to the decision logic written in this module, it prepares the process sheet for the components. Some of the typical rules which form the basic guideline for sequencing:

- The face containing a large number of features is generally machined towards the end.
- As many operation as possible must be performed in one setting so as to reduce handling time between the operation.
- Surface requiring high finishes are machined last.

5. System Implementation and Results

In order to demonstrate the performance of the system, a part drawing shown in figure 2 is used. After receiving necessary information for setup planning system, the system implements setup planning for machining of reference surfaces and machining of features, respectively. A computer program executing the logical sequence has been written in visual basic language. The basic algorithmic structure of the proposed system is demonstrated in figure 3.

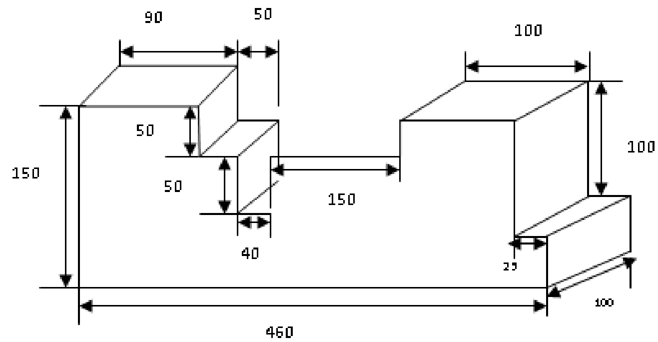

Fig 2: Part Drawing (All Dimensions in mm)

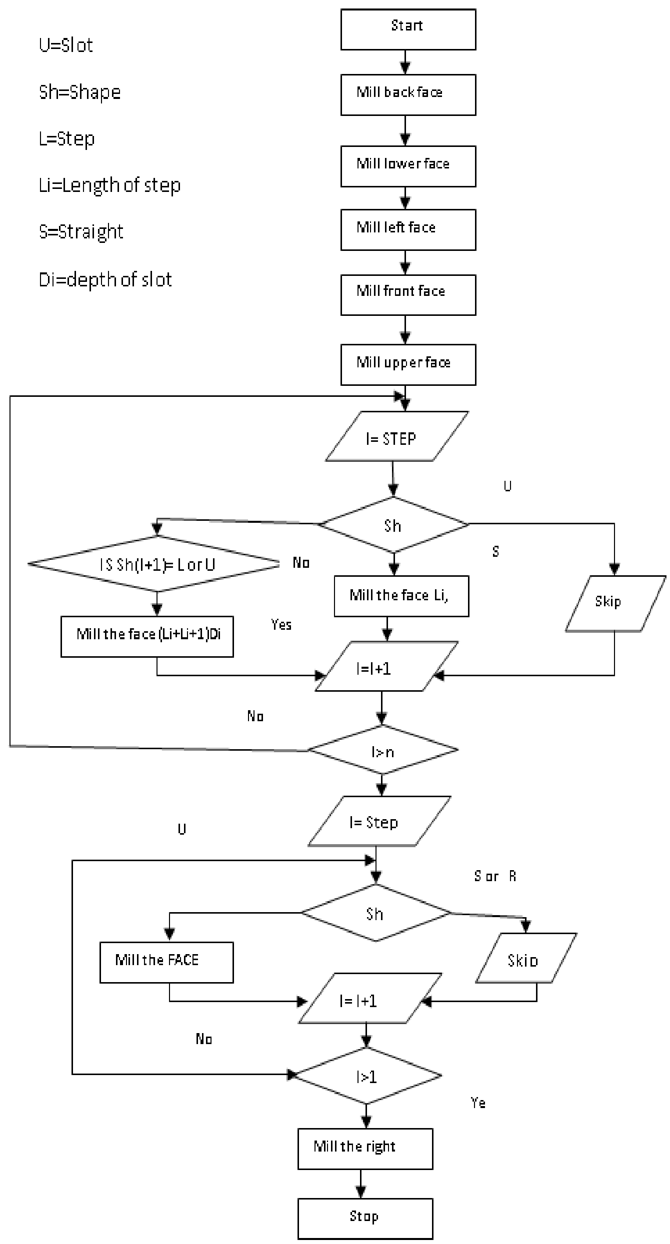

Fig 3: The basic algorithmic structure of sequence of milling operation

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6. Materials and methods

Major headings are to be column centered in a bold font without underline. They need be numbered. "2. Headings and Footnotes" at the top of this paragraph is a major heading.

7. Subheadings

Process Sheet for Milling Operation is demonstrated in table 1. Comparative between experimental processes planning with Intelligent Computer Aided Process planning is shown in table 2.

Table 1: Process Sheet for Milling Operation

S. No	Operation	M/c Code	Tool	Speed	Feed	Time	Cost
1	Mill Back Face	M-01	T-01	-	-	-	-
2	Mill Lower Face	M-01	T-01	-	-	-	-
3	Mill Left Face	M-01	T-01	-	-	-	-
4	Mill front face	M-01	T-01	-	-	-	-
5	Mill upper face	M-01	T-01	-	-	-	-
6	Mill the length of 90 mm	M-02	T-01	550	6.85	10.8	6000
7	Mill the length of 100mm	M-02	T-01	550	5.85	12.0	6000
8	Mill the L slot of length 25mm, depth 100mm, width 50mm	M-03	T-02	330	8.25	3.0	1500
9	Mill the U slot of length 150mm, depth 100mm, width 50mm.	M-04	T-02	220	16.5	6.0	3000
10	Mill the U Slot of length 40mm, Depth 50mm, width 50mm	M-04	T-03	220	16.5	6.0	3000
11	Mill the right face	M-01	T-03				

Table 2: Comparative between experimental process planning with Intelligent Computer Aided Process planning

S. No	Operation	M/c Code	Tool	Speed	Feed	Time	Cost	Speed	Feed	Time	Cost
				Experimental manual process planning				Intelligent CAPP system			
1	Mill B Milling back Face	M-01	T-01	-	-	-	-	-	-	-	-
2	Mill Lower Face	M-01	T-01	-	-	-	-	-	-	-	-
3	Mill Left Face	M-01	T-01	-	-	-	-	-	-	-	-
4	Mill front face	M-01	T-01	-	-	-	-	-	-	-	-
5	Mill upper face	M-01	T-01	-	-	-	-	-	-	-	-
6	Mill the length of 100mm	M-02	T-01	550	5.3	13.2	6600	550	5.85	12.0	6000
7	Mill the length of 75mm	M-02	T-01	550	6.6	11.2	5600	550	7.25	10.0	5000
8	Mill the L slot of length 25mm, depth 100mm, width 50mm	M-03	T-02	330	7.5	3.33	1665	330	8.25	3.0	1500
9	Mill the U slot of length 140mm, depth 100mm, width 50mm.	M-04	T-02	220	15	6.67	3335	220	16.5	6.0	3000
10	Mill the U Slot of length 40mm, Depth 50mm, width 50mm	M-04	T-03	220	15	6.67	3335	220	16.5	6.0	3000
11	Mill the right face	M-01	T-03	-	-	-	-	-	-	-	-

7. Conclusion

In this paper, a CAPP is developed for milling operation. This CAPP system generates the process planning sheet automatically, by feeding the part description drawing. Various modules is used for operation selection component representation and database management for calculating the machine time for calculating the spindle speed and operation extraction and logical sequence of operation. The system also can prepare the process sheet for complex components which required more than one operation to be done on part. The system has provides a quick and efficient method for generating process plan. The lead time is preparing process sheets has been reduced.

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