PC-CAPP — a computer-assisted process planning system for prismatic components

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The paper reports the design and implementation of a computer-assisted process planning system (PC-CAPP) for prismatic components used in the batch production of portable electric tools. The software incorporates various modules for component feature representation; automatic machine, toolings and process parameter selection; set-up planning; production time calculation and finally the report generation. The user-friendly software package has been developed on an IBM PC/XT compatible system. It provides a quick and efficient method for generating consistent process plans.

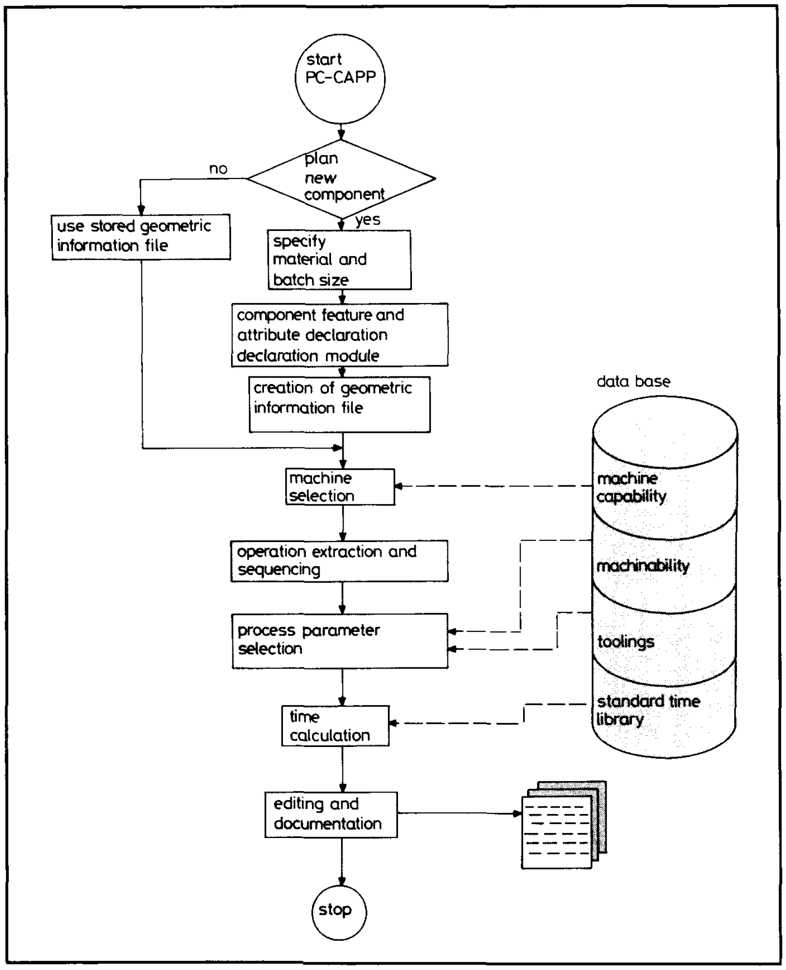


Fig. 1 Modular structure of PC-CAPP

Introduction

Process planning is an important activity that serves as a vital link between design and manufacturing functions, by planning the strategy for manufacture of a component. A process plan includes information about the component route; manufacturing processes, machines and toolings involved; process parameters etc. It thus directly dictates the cost, quality and rate of production in a manufacturing set-up.

Although, during the past few years, computer-aided design (CAD) and computer-aided manufacturing (CAM) have emerged as the most effective tools for improving productivity and efficiency, the process planning activity has still not been completely integrated into the CAD-CAM cycle. A need, therefore, exists to automate the process planning activity and link it with the CAD-CAM cycle for a true computer-integrated manufacturing system (Ref. 1).

Literature reveals that three typical approaches have been taken for computer-assisted process planning (CAPP) (Ref. 2). These are the variant approach, the generative approach and the knowledge-based expert system approach.

The variant approach uses the group-technology-based part-coding and classification system for creating groups of parts having 'similar' geometric and technological characteristics. Several variant process planning systems like AUTOCAP (Ref. 3), MIPLAN (Ref. 4) etc. have been developed for turned components which can be neatly coded and classified into families. They suffer from drawbacks such as inflexibility, continuous updating of the system, and a laborious preparatory stage.

Following the generative approach, process planning systems such as APPAS (Ref. 5), ICAPP (Ref. 6) etc. have been reported for prismatic parts. They utilise decision logic, technology algorithms, and geometry-based data to uniquely decide

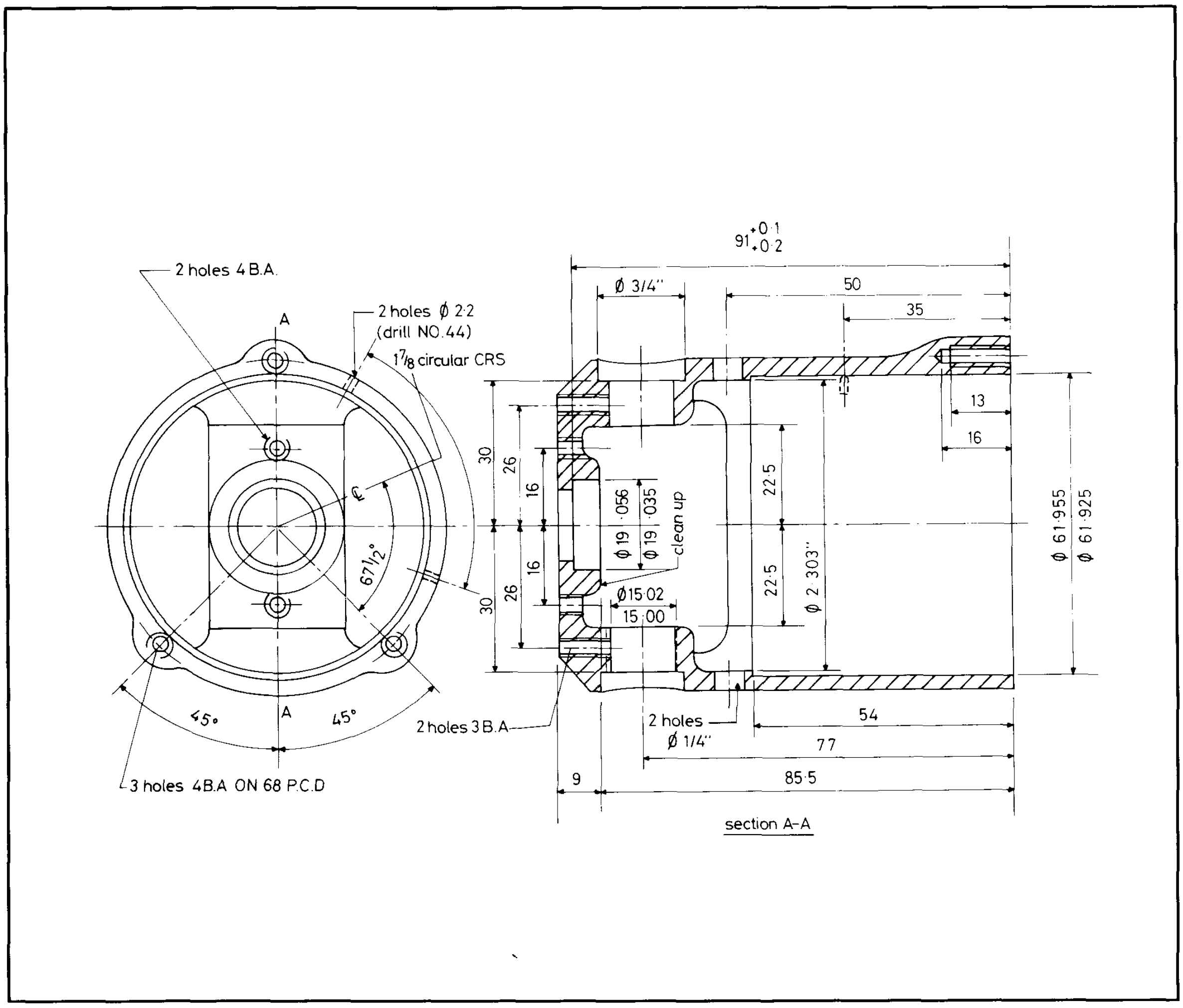


Fig. 2 Typical motor frame

the process planning. The systems developed for prismatic parts are mostly the operation planning type, considering very simple features on the components.

Recently, researchers have been attempting to use the techniques of artificial intelligence for automating the reasoning activity in CAPP. Systems like AMRF (Ref. 7), XPLANE (Ref. 8), EXCAP (Ref. 9) etc. have been reported. These systems are still under development and have not been tested for industrial components.

Literature reveals that although several CAPP systems have been developed for rotational components, there is a significant dearth of similar work for prismatic components.

The present work is mainly concerned with the design and implementation of an interactive computer-assisted process planning system (PC-CAPP) for prismatic components used in the batch manufacture of small portable electric tools for a multinational company.

The software implementation of PC-CAPP is discussed in detail in the following sections.

Design of PC-CAPP

Product range

In the product range of the company, the motor frame was the major and the most complex prismatic component occurring, with several variations in its shape and features.

Hence it was decided to develop a generalised CAPP system for motor frames. For all varieties of motor frame, the relevant drawings and process plans were studied to identify the variety of external and internal features; their dimensions; tolerances; material specifications; machines and tools employed, and the existing process planning strategy. This information formed the data base of the PC-CAPP system.

Block diagram of PC-CAPP

Fig. 1 shows the overall modular structure of the PC-CAPP. The software is implemented using the FORTRAN-77 language running under Microsoft DOS 3.2 on an IBM PC/XT compatible system.

The user-friendly PC-CAPP system consists of various functional modules such as

- component representation
- machine selection
- operation extraction and sequencing
- process parameter selection
- time calculation
- report generation.

The component representation module interactively gathers the information about the manufacturable features and their attributes to the component. The user is given an option to edit this input data if desired. PC-CAPP selects proper machine tools to produce the component features based on the machine and process capabilities. The operation extraction and sequencing module breaks each feature into different machining operations, sequences them and forms the logical set-ups for the machines selected. Process parameters are then selected, based on the machinability database. The total production time, comprising machining time and non-cutting time, is computed. The report generation module generates the process plan which contains all the information required on the shop floor.

In the following, each of these modules is discussed at length.

Component representation module: Fig. 2 shows the drawing of a typical motor frame. On studying the drawings, it was observed that the features occur on components in a variety of locations and orientations. Their sizes, preceding and succeeding features, and opening sides are very diversified (Fig. 3). To unify these attributes and to provide an easy interface to the machine, set-up and process selection modules, it was decided to relate these features in terms of manufacturing processes. The various features supported by PC-CAPP are logically organised in an hierarchic fashion for internal storage and representation (Fig. 4).

For PC-CAPP, the user can input the features in any order desired. Design and manufacturing attributes of each feature, such as dimensions, tolerance, surface finish, side to which the feature opens (access) etc., are acquired interactively from the user.

Fig. 5 shows a typical user-interactive dialogue for gathering feature information for the component shown in Fig. 2.

Machine selection module: This module matches machine capabilities with the tolerance required for respective features. The machine database, with machine process capability data like permissible minimum and maximum workpiece sizes, achievable tolerances, maximum stroke length etc., was created for this purpose.

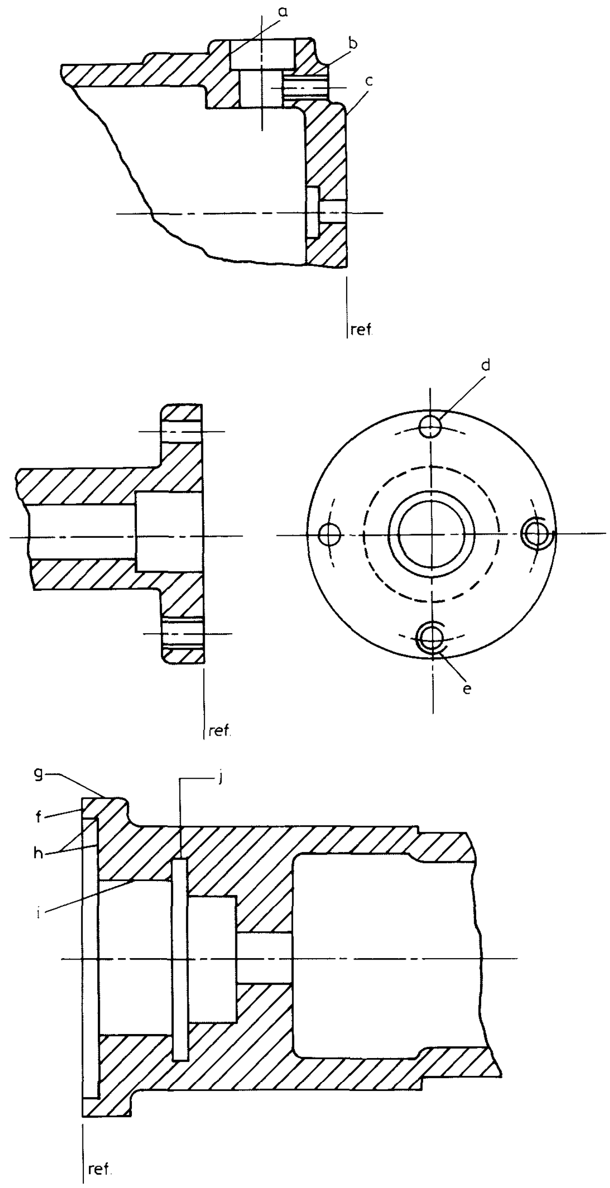
The strategy of this module is such that it selects the efficient machines (i.e. those which give minimum cost of production with the capability to achieve the desired tolerance). In the case of operations which can be done on more than one machine (e.g. a set of four holes approachable from the same side can be drilled on a single spindle drilling machine, as well as on a multispindle drilling machine), the cost data such as machine-hour-rate and setting time of the machine are used to calculate 'break even point' (BEP) batch quantity.

In the case of boring, as the operation can be done on a lathe as well as on a boring machine, a decision rule is fixed, taking into consideration the machine capabilities, batch quantity, toolings available etc., which is represented in the form of a pseudocode, shown in Fig. 6.

Operation extraction and sequencing: The strategy of manufacturing the component was formulated in the form of decision rules (Ref. 10).

The working of this control module incorporating decision rules is qualitatively discussed below:

● All the coaxial step turning and boring features (Fig. 2) accessible from one side of



a Stepped hole
b Cross hole
c Milling
d Straight hole
e Tapped hole
f Facing
g Turning
h Register turning with end face
i Bore
j Undercut

Fig. 3 Features supported by PC-CAPP

Features	Attributes
● turning	diameter (D), length (L)
● facing	D , L
● milling	L, width (W)
● boring	undercut, number of, D , L
● hole making	type (straight, tapped, stepped), number of, D,L,pitch, shoulder size

Fig. 4 Features and their attributes

Process layout

Material description: Alum_Alloy (GDC)				Unit qty. one	Drawing number 23.BMT.013		
Part: Motor frame			Type XYZ	Sheet number 1	Issued by MGW	Date issued 2/21/89	
Op. no.	Operation description	Speed rpm		Feed mm/rev	Time min	M/C GR	M/C no.
10	Face Mating_face to dimn. 91.20	1000		0.100	1.294	15	1
20	Rough and Finish bore Field_bore Bore no. 1 : 61.955/ 61.925	750		0.381	1.776	39	1
30	Drill 3 Gearbox_fixing hole(s) dia. 4.000	2420		0.150	0.945	33	1
40	Drill 2 Brush_contact hole(s) dia 15.000	950		0.127	2.314	8	2
	Chmfr 2 Brush_contact hole(s)	950		hand			
	Step drill 2 Brush_contact hole(s) dia. 18.200/ 18.00	700		0.127			
	Ream 2 Brush_contact hole(s) dia. 15.020/ 15.000	1450		0.127			
50	Tap 3 Gearbox_fixing hole(s) dia. 4.1 * 0.99, 13 deep	250		pitch	1.312	7	1
(All timings are estimated)							

Fig. 5 Software user dialogue

the components are grouped together. Based on the machine selection, the operations are grouped to form the set-ups.

- While sequencing the hole-making operations, operation extraction is done, based on the selected machine capability, length-to-diameter ratio, tolerance etc. This module uses a strategy which divides any hole-making feature into two broad categories as follows:

☐ Single machining operation on a number of axes — four holes approachable from same side

☐ Multi-machining on one axis — presence of a stepped hole.

```
IF        /* feature is bore */
          { [ Batch size more than BEP ] .AND.
                [ dimension, tooling constraints satisfied ] }
                          USE BORING MACHINE
   ELSE
     IF
          { Dimension, tooling constraints of lathe satisfied }
                          USE CAPSTAN LATHE
     ELSE
          IF
               [ boring machine capable ]
                          USE BORING MACHINE
          ELSE
                          PROCESS CAPABILITY LIMITATION
          ENDIF
     ENDIF
ENDIF     /* finish feature bore */
```

Fig. 6 Decision rule pseudocode

For the first category, the machine selected will be either a single-spindle drilling machine or a multispindle drilling machine, and the component is routed to other machines for further processing of these holes (e.g. tapping on a tapping machine).

Alternatively, the component can be manufactured on a drilling machine with four indexable stations. PC-CAPP prepares the sequence of machining operations on these indexable stations for manufacturing the component in a single set-up.

Finally, all operations requiring a single-spindle drilling machine are grouped together, followed by those requiring a four-spindle drilling machine and multispindle drilling machine. This is required to minimise the material movement, as the machine shop is arranged according to 'process layout'.

- In the case of the milling operation, all the features whose dimensions have reference surfaces milled are isolated. The milling operation is sequenced before such operations so that the milled surface can be taken as reference for these features.

- Cross holes (Fig. 2) are always sequenced before the principal hole to avoid burr opening out into the principal hole. This is because most of the cross holes are used either for oiling or fixation purposes, whereas the principal holes are used for functional requirements such as mounting of bearings, installation of carbon brushes etc.

Selection of process parameters: Once the operations have been extracted, sequenced and grouped to form set-ups, the next task is to decide the process parameters.

The machinability database is created, which gives the cutting speed and feed values for the particular tool and workpiece material combination for each operation (for various dimensions wherever applicable). Since these standards assume that the cutting conditions in the shop are excellent, which is rarely the case, the user has been given a facility to give a 'cutting efficiency factor' which will represent the shop conditions. Speed and feed values are accordingly reduced by that percentage after retrieving it from the machinability database (Ref. 11). The speed in rpm is calculated, based on the diameter of the workpiece, and on the particular process/ feature.

The speeds and feeds selected for each operation are adjusted to the closest available on the machine selected.

Time calculation: The machining time for an operation is calculated from the geometry of the feature and process parameters decided.

During the operation extraction, a unique code is generated and assigned to each operation which contains a string of numbers of all non-cutting activities required to perform that particular operation.

A standard time library for non-cutting times is stored in the system, based on shop experience and time and motion studies carried out. For a particular feature, these are accessed, and the standard non-cutting times are added to the machining time to get the total production time for an operation.

Finally, the time taken for all the operations in a set-up is added up, and to that, loading, unloading and inspection time is added to get the time for the entire set-up.

Report generation module: To improve the understandability of a process plan at the shop-floor level, each operation is explained in a textual manner. Standard macros are created for different pointers which are set during operation extraction.

Standard headers and footers are prepared. Software asks information from the user about date, type of model, material, name of planner etc.

The process layout can be stored as an ASCII file which can be edited independently through a text editor, if desired. The user is provided with a facility to edit any part of the process plan before documentation. If the user changes any process parameters, then the machining parameters and time are recalculated.

Typical data files used by PC-CAPP

Close study of the manufacturing and planning strategies of a variety of components revealed that there were four types of technological data files which were necessary, as far as the present application was concerned. They are as follows:

- machine capability database
- machinability database
- toolings database
- non-cutting time library.

Machine capability database: In manufacturing prismatic parts, many machines are used, such as capstan lathes, horizontal and vertical boring machines, milling machines, drilling and tapping machines etc. PC-CAPP uses this database for information about the machines. A typical database record for a particular machine includes information on speeds, feeds and maximum stroke available, machinable minimum and maximum dimension and tolerance.

Machinability database: For selecting the recommended speed and feed, the machinability database is created, which specifies speed/feed values for a particular tool/workpiece material combination. This database is used for computing various process parameters.

Tooling database: Tool file has the data regarding the cutting tools on each machine and hence is indexed on the machine. The information stored for a particular machine is tool code number, length of cutting edge, maximum speed and feed permitted.

Non-cutting time library: The non-cutting times of the operation include the time taken for non-cutting activities such as speed change, coolant on/off etc.

A standard time set for all these operations was already existing, based on the time and motion study conducted. Since the time required for these operations largely depends on the configuration of machine, job and operator, it was decided to use these existing standards.

Planning with PC-CAPP — typical example

The PC-CAPP system is fully user friendly and guides the user about format and ranges of the data input wherever required. A typical user software dialogue for a few of the features of the component in Fig. 2 is shown in Fig. 5.

Conclusion

The PC-CAPP system was tested extensively for various prismatic components. The system provided a quick and efficient way to generate consistent process plans acceptable to the company's standards.

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Appendix

PC-CAPP Computer-assisted process planning system for motor frames

Press a key to proceed . . .

/* The user starts by giving the command 'MOTOR' */

Component to be planned is new ?(Y/N) . . . Y

Product type ? . . . XYZ

Please select the material type. . .

1. gravity die casting
2. pressure die casting

Select option and ENTER. . . 1

ENTER number of components per batch. . . 400

Input information about machined features according to the menu displayed.

1. turning
2. facing
3. boring
4. hole making

For feature 1, select and ENTER. . . 2

Input following information (in mm) for facing. . .
Enter d-maintain, dmax,dmin of faced feature. . .91.00 80.00 60.00

Please input the stock thickness. . .0.15

Title for feature ?(20 char. max.). . .Mating face

More features ?(Y/N). . .Y

/* Like this, the user inputs all turning, boring and facing features one by one in any order desired. */

1. turning
2. facing
3. boring
4. hole making

For feature 3, select and ENTER. . .4

1. straight hole
2. stepped hole
3. tapped hole

Select option and ENTER. . .3

How many holes in this set ?. . .3

ENTER nominal dia, pitch and depth. . .4.1 0.99 13.00

Title for feature ?(20 char. max.). . .Gearbox fixing

/* Like this, the user inputs all hole-making features */
/* Overlay geometric file is created and program jumps to machine selection routine */
/* Operation extraction and sequencing is executed */

Operation sequencing table

Set-up	Operation	Feature for	Machine
1	Face	Mating_face	capstan lathe
2	Rough bore	Field_bore	excello machine
2	Finish bore	Field_bore	
3	Drill	Gearbox_fixing	multispindle drill
4	Drill	Brush_contact	four-spindle drill
4	Chmfr	Brush_contact	
4	Step drill	Brush_contact	
4	Ream	Brush_contact	
5	Tap	Gearbox_fixing	tapping machine

/* Process parameters and time are calculated and the program jumps to documentation */

Print process layout ? (Y/N). . .Y

Enter date (MM/DD/YY). . .02/21/89

Material specification. . .Alum Alloy (GDC)

Part number. 23.BMT.013

Initials of planner. . . . . .MGW

(END OF JOB)