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CAD/CAPP Integration Using IGES

by

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Abstract

This paper describes an approach to the integration of a process planning system (ICAPP) to a CAD system. The link is established through the Initial Graphics Exchange Specification (IGES) used to transfer the feature geometric data from the CAD system to the ICAPP system. The ICAPP system can subsequently use this geometric data in generating a detailed process plan for the manufacture of the part as well as a part program in either APT or COMPACT II, thus constituting truly integrated part design and manufacture.

1 Introduction

Today's industrial climate is one of the intense competition with great emphasis being placed on reducing costs and improving productivity, product quality as well as reliability. To achieve these goals, manufacturers have had to adopt radical new production techniques. The use of computers in various fields such as design, control and manufacture has been of particular importance. The new computer-based technologies have penetrated most areas of industry ranging from simple clerical functions like word processing to the most sophisticated applications like astronautics and the space-shuttle program. What has most encouraged the spread of this new technology is its evident efficacy in achieving greater productivity and hence improved competitiveness.

Experience in the use of various computer-based systems in industry has shown that while each can individually benefit the production process, these gains would be enhanced if the various systems were integrated. There are many functions in which at least some of the required information is common. In such cases, it makes sense to provide a means by which these functions can share the common information. This would be an important step in moving towards the goal of achieving a fully integrated manufacturing system.

Computer Integrated Manufacturing (CIM) is a major long term research objective including elements such as Computer-Aided Design (CAD), Robotics, Numerical Control (NC), Process Planning, Manufacturing Resource Planning (MRP II) and others. This paper discusses the general need for integration of various CIM modules and how research involving the ICAPP process planning system is moving towards the integration of the important functions of manufacturing and design. As it has been observed, of all kinds of manufacturing technology being researched, developed and implemented today, CIM promises far greater productivity than anything that has appeared on the scene since the Industrial Revolution [1].

2 Process Planning

In the modern industry, manufacturing time and cost are of major importance, and factory automation is common practice used to increase productivity while normally reducing the production time and cost. Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) are two recent products of automation revolution. CAD is a powerful tool for modern designer and it eliminates the tedious task of redrawing and calculation during the design phase. The computer can also provide the designer with information which enables him to make more effective decisions. CAM is a more recent product of industry. Its major focus has been on the automation of the machining processes. In a CAM system, the computer directly controls machine tools and material handling equipment in order to accompolish such objectives as: increased production rate and improved product quality.

An important phase which links the design function to the manufacturing function, by forming a bridge between them, is process planning. The best definition of process planning to date is that 'It is the subsystem responsible for the conversion of design data to work instructions' [2]. Process planning is a detailed and difficult task, traditionally carried out by highly skilled workers who have an intimate knowledge of a wide range of manufacturing processes and are themselves experienced machine operators.

By studying a drawing, the process planner is required to determine the operations that need to be performed on a workpiece to produce the specified component and the order in which they are to be carried out; select the appropriate machine tools, cutting tools as well as fixturing devices, establish the cutting conditions to be used and hence obtain the machining times and also determine the associated non-machining times (e.g. set ups, tool changing etc.), which can be used as a basis to determine costs. A detailed knowledge of the particular working environment is essential since these decisions will inevitably be affected by such things as the capabilities of the machines, availability of the machines, cutting tools, jigs and fixtures as well as the labor.

It can be appreciated that when done manually, this can be a tedious and time consuming task. The problem is exacerbated by the fact that in general, process planning engineers tend to rely on personal experience and there is no formal universally accepted theory for process planning. Thus if several process planners with different industrial backgrounds are given the same component to plan, the probability is that each will produce a different solution to the problem (although each solution should be technically feasible and lead to the same end result). Even in the same firm, it will generally be found that no two process planners will plan a given component in exactly the same way. More ironically, if a particular planner is given the same component on two different occasions, the process plans generated on each occasion will probably be different. Various surveys have been carried out in which different process planners have been required to plan a set of components. In general the results showed that almost as many process plans resulted as the participants involved. Halevi [3] presents an example for a simple component which resulted in four different process plans. For a more complex component, the variation in process plans obtained by different planners can be expected to be even more pronounced. Clearly a situation like this is undesirable since all the plans produced cannot be equally economical. The case for standardizing process planning procedures is unquestionable. The critical issue then becomes establishing a suitable standard to be followed.

It has become recognized that the application of computers in this field has great potential. By using a computer, the tedious and repetitive aspects of process planning can be speeded up and thus help to optimize the total manufacturing function by releasing the experienced planners and enabling them to concentrate on those creative tasks which are outside the scope of the computer [4]. At the same time, more consistent process plans can be obtained by applying a standard set of rules which increases confidence in the system and helps in the rationalization of production.

In the application of computers to process planning, two main types of computer-aided process planning have emerged, these being variant and generative process planning systems.

2.1 Variant Process Planning

The technique is based on the application of group technology (GT) principles. In GT, the components to be made are grouped together according to their similarity in shape and hence required machining operations. A group of similar parts is referred to as a family. All members of a family are then manufactured in a single GT cell. This helps to standardize tooling, minimize tool changes and optimize routing for each component. When applied to process planning, a representative member of a part family is planned in detail and the resulting process plan is stored by the computer. If a plan is required by another member of the family, the plan for the representative component is recalled and reviewed by an experienced planner. He carries out any modifications that may be required to make the plan suitable for the new component. If the representative component was properly selected, the modifications to the plan should be minimal thus making it possible for a new process plan to be generated with ease.

The main criticism to be made of variant process planning system is that they do not fundamentally solve the problem. Essentially what they do is to speed up the process, but by relying on a process planner to develop a plan for a representative component and reviewing this for specific applications, they clearly lock in the difficulties and problems associated with manual systems [5]. The systems do not really generate new process plans. It is for this reason that the generative approach to process planning was developed. Variant type process planning systems are still dominant in industry however because they are easy to implement, they can handle a wide variety of parts and conceptually they are very similar to what has been done in the past and therefore are easily accepted. Some examples of variant process planning systems are CAPP [6], MIPLAN [7], and TOJICAPP [8].

2.2 Generative Process Planning

The generative approach to process planning is aimed at creating a new process plan by completely automatic means. This requires as input some form of geometric description of the component to be made. By applying some established logical rules to the input data, the processes required to produce the machined component are then generated automatically. These systems are generally based on simple elementary surfaces which can be recognized by some form of algorithm which then selects a suitable machining process to generate the surface. An alternative approach groups simple surfaces into recognizable features and then the necessary processes to produce the relevant features are generated automatically by the system. Examples of such systems include TIPPS [9], STOPP [10], AUTAP [11] and ICAPP [12,13].

Generative process planning is still in its early stages of development. The main obstacle to its development is that for any given type of surface, there is generally a multiplicity of operations which can generate a surface. Determining which one is optimal is influenced by such factors as production volume, required dimensional and surface accuracies, what other operations have to be carried out on the component, which machines are to be used, availability of resources. etc. This is a complex decision problem and the AI techniques are increasingly being applied in an effort to find reasonable solutions on the basis of experiential reasoning about the problem [14]. Although still in development, it is now recognized that generative process planning has considerable long term potential. Its analysis is based on the geometrical definition of the component and is therefore a prime canditate for use in an integrated CAD/CAM system, with geometry data from the CAD system being accessed by the process planning function for generation of manufacturing instructions for example in the form of NC data.

2.3 Expert Process Planning Systems

Artificial Intelligence (AI) is a field of research directed at using a computer to perform functions that are normally carried out by human intelligence. The field of AI encompasses a wide range of technologies including expert systems, natural language processing, machine vision, etc. Expert systems are probably the best developed part of AI and these grew out of research interest in how humans think, in particular how humans deduce results from a set of facts.

An expert system uses application-specific problem-solving knowledge to achieve a high level of performance in a field which we would normally think of as requiring a human expert. Application programs like the ones for process planning make use of specialized problem solving knowledge. The level of performance of such systems depends on the depth or granularity of knowledge. The knowledge base contains the knowledge about the domain and this does not appear implicitly as part of the coding of the program. There will be a separate control strategy, clearly identifiable, which manipulates the knowledge. It is convenient to use such techniques to construct sophisticated problem-solving tools, since the knowledge base can be modified as and when new knowledge is acquired.

An expert system differs from a conventional computer program. The conventional programs organize knowledge in two levels, known as the data and the program. On the other hand, most expert systems have their knowledge organized in three levels. The *data* level will have the declarative knowledge about the particular problem being solved. The problem solving knowledge, which is specific to the *particular kind of problem the system is supposed to solve* is used to reason about the data. The *control structure* makes decisions about how to use the knowledge. If the problem-solving procedure is well understood, the knowledge base, which is procedural in nature, can best be represented as a conventional computer program. There are many expert computer systems which have been developed using conventional programming procedures. If the precise series of steps are not known, it is necessary to search through a space containing many alternative paths, some of which will lead to solutions. Search techniques are helpful under such situations.

In problems like process planning, where the quality of plan generated depends on the experience and expertize of the planner (or the program), new knowledge can be aquired very frequently and so expert process planning systems are very helpful. Depending upon what type of process planning approach an expert system follows, one can develop either a variant expert process planning system or a generative expert process planning system. Some examples of expert process planning systems are TOM [15], SIPS [16], and GARI [17].

3 Integration with Design

One of the primary shortcomings in most process planning systems is the inability of the system to query the CAD database and gather the necessary geometric information for automated manufacture of the part. The reason for this gap in automated communication between CAD and CAPP/CAM was because at early stages when automation began in the CAD/CAM systems, CAM was the first to be widely used and hence worked on for automation in manufacturing of a part. With the development of Numerically Controlled (NC) machines and NC machine tools was the inception of Automatic Programmed Tools (APT) language. APT provides convenient communication link between the process planning and the NC machine tools for the manufacture of a part. The NC machines use geometric statements describing the machine cuts to be made. Parts are described in terms of machining surfaces which are useful in calculating the tool paths. The actual part geometry was not considered as important as machining surfaces and therefore was not included in the data. As a result, the early CAM sytems did not deal with the part description from the designers point of view i.e. in terms of its geometry and topology. The automation of CAM systems therefore expanded without including the CAD database thereby increasing the gap between CAD and CAM systems.

CAD systems, on the other hand, contain a part definition which is related to the construction of part as per the drafting methods of part description. A part may be constructed from lines and surfaces. As a result the differences in storing the data in the design and manufacturing systems led to the lack of communication between CAD and CAM systems.

Today, a major area of concern in the CAD/CAM systems is automatic extraction of geometric information for the different features constituting a part from a 3-D CAD solid database. Several systems had been built in the past, using different approaches by which to input the part description. The method in which the part description is input had a direct bearing on the degree of automation that could be achieved. The early process planning systems used GT codes to describe parts, and the code was used by variant process planning systems as discussed earlier. Interpretation of the part was performed manually, and consequently exact size and detail information were lost; hence GT codes are not suitable for complete automation.

The next generation of process planning systems developed special descriptive languages to assist in describing the parts. The format of these languages allowed planning to be performed easily from the information provided. Conversion of part description into special language used was also a manual process. Some systems using this approach are AUTAP[11], GARI[17], CIMS/PRO[18].

The need for a part description suitable for complete automation led to the use of CAD models. The main aim of building up the CAD/CAM link to a single database is to carry out the complete design and manufacturing of a part with the least possible human interaction.

Literature review shows a number of systems driven by 3-D CAD part descriptions. The CADCAM[9] system, an interactive computer aided design and computer aided manufacturing system, illustrates how CAD can be interfaced to automatic process planning and cost estimation of CAM. The system functions are interactive hole design, plotting and modification of the design, automatic process planning for hole making and process cost estimation. The designer interacts with the system through a conversational dialogue. Then, the system uses 2-D model together with user interaction to identify features and thus perform the planning. Being interactive this approach was not completely automated. The system is limited to holes and moreover once the process plan is generated there is no way to communicate directly with the NC machine for automated manufacturing.

Another system using CAD model for automated process planning is TIPPS[9] which uses boundary representation from a CAD database for the part. The component design is represented by its bounding faces. TIPPS uses its own geometric modeling capability to create the surface and thereby store the data in a form used by the process planning modules. This restricts the integration of the systems with other available CAD geometric modeling packages. The features are indicated using the cursor on the screen. However, once the process plan is generated it cannot be implemented directly on the shop floor due to the missing communication link between process planning and manufacturing of the part.

Logic based approach is also being widely used for the extraction of features from the 3-D CAD database. Henderson developed a system FEATURES[19] under this logic based approach. FEATURES simulates the human part interpreter using logic programming to extract from a stored part description, a high level knowledge in the form of part feature definition. Techniques are presented in the system to recognize manufacturing features from a CAD database and organize them hierarchically according to their position in the modeled part. This system is broken down into three modules i.e. Feature Recognition, Feature Extraction, and Feature Graph Construction. The system interprets the CAD database and presents to the process planner a feature graph from which manufacturing plans can be generated. However, the system does not have built in capability to generate optimal process plan and thus the NC codes for machining the part. Once the features are extracted the system needs to be linked with another system GARI[17] which takes the feature graph as input and uses production rules to generate the process plan. As a result FEATURES is not completely automated from design to manufacturing.

Considerable interest has been shown in developing integrated CAD-CAPP-CAM systems. Although a lot of research is being conducted in this field it is hampered by the independent manner in which the individual modules have developed. This has resulted in systems and software incompatibility which requires building interfaces between the various systems. Hoping to develop a completely integrated system, ICAPP (Interactive Computer Aided Process Plan) has been extended to include an automatic transfer of geometric data into the system as well as the generation of NC codes for machining from the process plan.

3.1 Development of ICAPP

Initially ICAPP was developed as an interactive feature oriented process planning system for prismatic parts. The planner had to answer a series of dependent questions of geometry and details of features. It produced an operator readable process plan that included machine tools, operation times, feeds, speeds, depth of cut, etc. As a result the input to the ICAPP system was via interactive terminal from a drawing, and the output was the process plan[20]. This system was not different from the ones discussed earlier since human interaction was involved and moreover it had no communication link with the CAD database as well as the NC machines. It was only a process planning system.

The first extension to ICAPP[13] was to include an interactive mode for NC data generation to produce a COMPACT II part program. Additional geometric information was used for NC data generation. Even at this level there was no direct link established to transfer the geometric information to ICAPP without human interaction.

Since complexity of the parts that are being designed using different CAD systems is increasing, it is becoming difficult to enter the drawing data interactively into ICAPP without any errors. As a result work has extended to aim at automatic transfer of product model (part description) to ICAPP. In addition, since any CAD system could be used to design the model, a generalized way is required by which product model data could be transfered from any CAD system to ICAPP.

The main problem arising in this data transfer is the compatibility of present day systems with regards to CAD data. Every system has a unique way of representing the geometric data of the part within the CAD database. As a result work was started to develop a standard format that would provide a viable means of communication between different CADCAM systems. The earlier product data exchange standards that were developed were IGES (Initial Graphics Exchange Specification) in United States[21], SET in France, and VDA-FS in Germany. SET was developed primarily for the use by European Aerospace Industry[22]. In automotive engineering in Germany, the Association of Automobile Manufacturers (VDA) developed VDA-FS for exchanging curve and surface data[23]. Among the above three standards IGES is the most widely used specification for CADCAM data exchange processors. Since its introduction in 1981 as an American (ANSI) standard for the exchange of product data, IGES processors have been implemented by a majority of system vendors in their CAD systems.

3.2 IGES

IGES covers a range of application areas such as electrical, plant design as well as mechanical applications. IGES thus provides a standard format by which the users can transfer the data from one system to another. However, with a standard format such as IGES two types of translators are required. The first translator uses the CAD database of a system and converts it into standard IGES file format. The second translator is needed so as to read the IGES file and regenerate the CAD model [Figure 1].

IGES establishes information structures to be used for digital representation and communication of product definition data. The data is represented as a structured file in a specified format which enables exchange of product definition between various CAD/CAM systems. The product is described in terms of geometric and non-geometric information. The geometric information is the actual drawing consisting of different entities that make up a feature or a part. The non-geometric information consists of annotation, definition, and organization.

The fundamental unit of information in the file is the entity. Geometric entities represent the definition of the physical shape and include points, curves, surfaces, and relations which are collections of similarly structured entities. Non-geometric entities provide a viewing perspective in which a planar drawing may be composed and also provide annotation and dimensioning appropriate to the drawing. These non-geometric entities include view, drawing, dimensions, text, notation, witness line, and leader. To represent the part geometry, the edge representation method is implemented in IGES. This makes IGES an edge representation data exchange standard.

3.3 Implementing IGES in ICAPP

3.3.1 File transfer

To be able to generate an IGES file the CAD system in use should have a pre-processor incorporated into the system that reads the system design database and converts the data into standard IGES file. ANVIL5000 is an example of a CAD system available in the CAD research facility, University of Maryland, that has the capability of generating an IGES file. The system runs on VAX 11/750 and is accessible on any Tektronix terminals. The sample part for testing was created on ANVIL5000 [Figure 2] and the corresponding IGES file was generated.

A pre-processor has been developed and linked with ICAPP which is capable of reading the IGES file, scanning it for geometric data relevant for process planning and storing this in separate data file. At this level the IGES file is stripped of all the information not required by ICAPP and only the parametric section containing the geometric information is scanned and the entities are then grouped together. The features consisting of circular entities such as holes are grouped while the rest of the line entities are stored in a different array. Figure 3 shows the geometric data information. In this datafile code 110 in the first column indicates that the data corresponds to a line entity whereas code 100 indicates circular entity data. For a line entity the data consists of start point (x1,y1,z1) and an end point (x2,y2,z2). For the circular entity the data consists of 'z' coordinate location, location of the center for the circle or an arc (x,y), start point of the arc (x1,y1), and an end point of the arc. In the wireframe model generated on ANVIL5000 [Figure 2], holes consist of two circular entities associated with two line entities. A logic approach is used to scan the IGES file and locate all the entities associated with the first circular entity encountered in the file. The four entities are then grouped together along with an index number used to distinguish between the different holes, if more than one, present on the component. This file is then used in order to transfer the geometric information into the ICAPP system.

3.3.2 Graphics Interface

A graphics interface was developed and implemented into ICAPP which has the capability of reading the data file created from IGES and reproducing the part drawing. This package does not provide a CAD system to ICAPP. It was developed for simple transfer of feature data.

Earlier work on IGES implementation into ICAPP [24] provided a basic means of reproduction of the drawing via IGES. However, a 2-D drawing was used and some of the information required for ICAPP was obtained from visual geometric and textual information on the transfered drawing. This was not very different from the interactive data entry using the hardcopy of the drawing.

The present work on ICAPP was aimed at minimising the manual data entry by the operator. The final drawing thus reproduced via IGES is merely used to indicate the features for process planning. By the time the part drawing is passed onto ICAPP system it is in the final form and no editing is allowed in the built in graphics package. All the editing is done using the CAD system on which the part is created before the IGES file is generated. The reproduced drawing is a 3-D replica without any textual information. However it shows all the features on the part [Figure 4].

As the ICAPP system progresses the user is prompted to select the features from the part drawing whenever the geometric information is required by the process planner. The selection of features is established by moving the cursor onto the entity and making the selection [Figure 5]. The data associated with the selected entity is then scanned from the database and stored in an array for later use in the generation of the process plan. This process reduces the possible human error in entering the numeric values for a large number of entities constituting the part. Since the 3-D drawing resembles the finished part, it aids the operator in visualizing the final machined part.

The feature selection process is repeated until all the necessary features have been selected. Once the feature selection is completed the built in computing modules use the stored geometric data to extract the information such as diameter and depth of the hole, perimeter and depth of the pocket, length and depth of the slot, etc. The system then generates an optimal process plan using its basic process planning module [Figure 6]. ICAPP is also equipped with an APT processor [25] that generates APT part programs and thus the NC codes for machining [Figure 7]. Therefore the additional geometry information, besides the geometric data used for process plan, required by the APT processor is also entered by using the graphics facility.

Since the graphics capability is required only at certain stages in ICAPP system, the graphics package is implemented into the ICAPP system at a level where it appears only when the extraction of the geometric information from the database is required by the system.

Another main feature added to ICAPP is a Toolpath plotting module. Once the process planning and APT program generation is completed it is used to create a cutter location file which in turn is used for generating the tool path that would be followed in machining the feature [Figure 8]. For displaying the toolpath only the top face of the drawing is reproduced and the cutter movements are shown using colored graphics. The change of tool is indicated as change in color on the graphics screen. The complete ICAPP system implementation can be broken down as shown in Figure 9.

4 Example

The following example illustrates the IGES interface between CAD and CAPP. The wireframe model of the part consisting of a hole and a slot was generated on the CAD system ANVIL5000. The editing capabilities of ANVIL system were used to create a final part drawing as shown in figure 2. ANVIL5000 IGES processor was used to generate the IGES file on the system. This file was stored in the database accessible to the ICAPP system. The IGES pre-processor module of ICAPP system read the IGES file and stripped it of the information not required by the process planning module. From the basic stripped file lines and circular arc entities(holes) were grouped together by the processor [figure 3]. This file was then used by the graphics module to regenerate the part in order to transfer the feature information for process planning [figure 4]. Using the regenerated part drawing selection of features and entities was made for automatic data extraction from the database. For example, in a hole making operation, the system prompts the user to indicate which hole is to be planned by making a cursor selection on the screen. When the selection is made, the system retrieves all the geometric data associated with the selected hole by scanning the feature database. The hole feature is then highlighted on the screen for the user to verify that it is indeed the desired hole. If this is so, the appropriate geometric data is automatically transferred to the process planning module which then generates a suitable process plan for the feature. Figure 5 shows the hole selection. Additional boundary information was entered using the same process for later use in generation of part program. After all the necessary information was transferred to the process planning module, an optimized process plan was generated [figure 6]. Data file from the process planning module containing information such as speed, feed, rpm, etc. was read into the APT processor for generation of APT part program [figure 7] and a cutter location file. The cutter location location file along with the IGES file was used by the NC code generating module of the system. As a result, NC codes were generated and verified by the toolpath plot as shown in figure 8.

5 Conclusion

The purpose of this study was to integrate the design, process planning, and manufacturing phases. The geometric data is fed to the process planning module via IGES which in turn generates optimum process plan and part programs leading to NC code generation for machining of the component.

The system was tested using very simple features such as holes, pocket, straight slot, side, etc. The results obtained were very promising as shown in the illustrative example. The graphics link has overcome the problem of physical location of features on the part which was initially entered through a series of interactive questions. IGES is still developing and is not in its final form. The CAD system ANVIL5000 used in this research supported IGES version 3.0. Although IGES version 4.0 is out still it has not been implemented into the commercially available CAD systems. IGES version 3.0 contained all the necessary information that was required by the ICAPP system. Modifications are being made to the IGES file so as to support the tolerance information.

Use of IGES in transfering of simple geometric information has shown the flexibility and capability of linking different CAD-CAM systems for automation of the manufacturing cycle.

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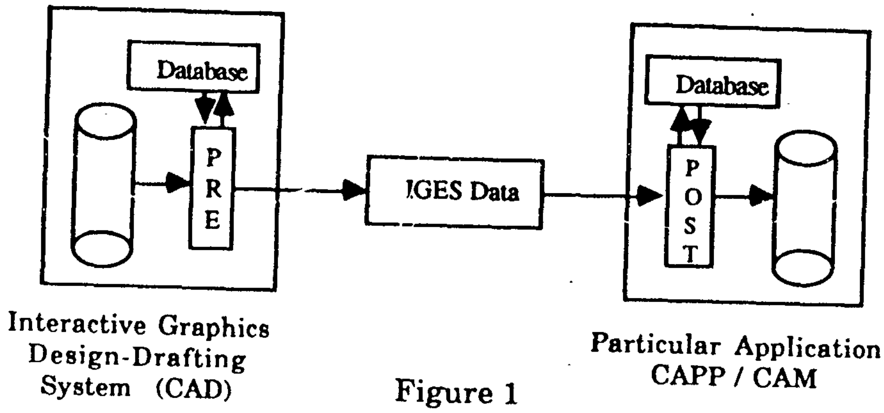


Figure 1

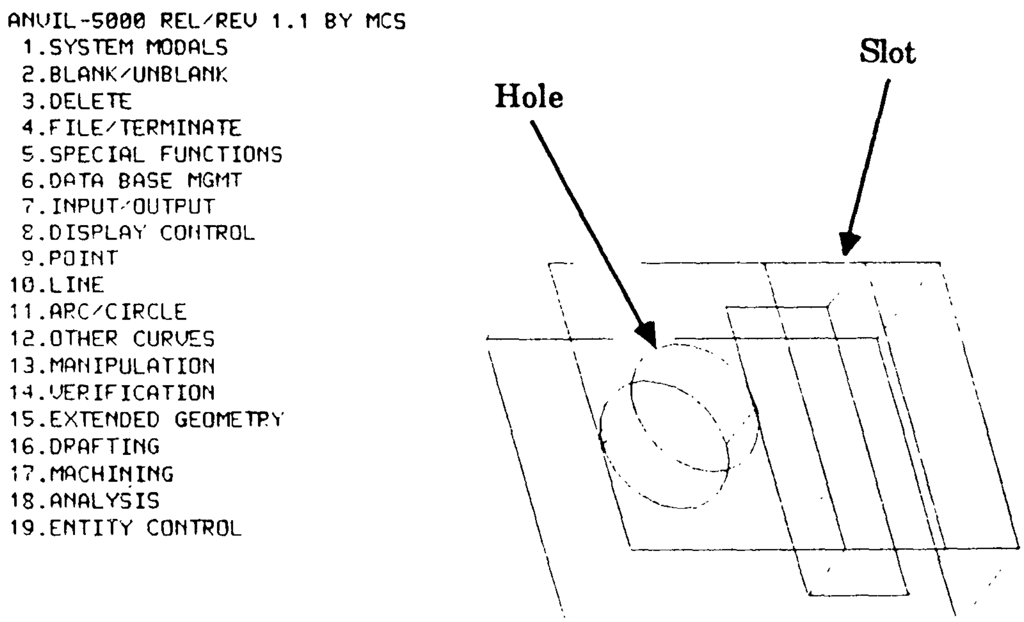


Figure 2

Lines

110	22.58	15.09	0.00	98.84	15.09	0.00
110	98.84	15.09	0.00	98.84	69.29	0.00
110	98.84	69.29	0.00	22.58	69.29	0.00
110	22.58	69.29	0.00	22.58	15.09	0.00
110	64.52	15.09	0.00	64.52	69.29	0.00
110	84.16	69.29	0.00	84.16	15.09	0.00
110	22.58	69.29	-25.00	22.58	15.09	-25.00
110	22.58	69.29	0.00	22.58	69.29	-25.00
110	22.58	15.09	0.00	22.58	15.09	-25.00
110	22.58	15.09	-25.00	98.84	15.09	-25.00
110	98.84	15.09	0.00	98.84	15.09	-25.00
110	98.84	15.09	-25.00	98.84	69.29	-25.00
110	98.84	69.29	0.00	98.84	69.29	-25.00
110	98.84	69.29	-25.00	22.58	69.29	-25.00
110	64.52	15.09	-15.00	64.52	69.29	-15.00
110	64.52	15.09	0.00	64.52	15.09	-15.00
110	64.52	69.29	0.00	64.52	69.29	-15.00
110	84.16	15.09	-15.00	64.52	15.09	-15.00
110	84.16	15.09	0.00	84.16	15.09	-15.00
110	84.16	69.29	-15.00	84.16	15.09	-15.00
110	84.16	69.29	0.00	84.16	69.29	-15.00
110	64.52	69.29	-15.00	84.16	69.29	-15.00
110	64.52	69.29	-15.00	84.16	69.29	-15.00
110	84.16	15.09	-15.00	64.52	15.09	-15.00

Hole

1	100	0.00	42.96	41.79	54.96	41.79	54.96	41.79
1	100	-12.00	42.96	41.79	54.96	41.79	54.96	41.79
1	110	54.96	41.79	0.00	54.96	41.79	-12.00	
1	110	30.96	41.79	0.00	30.96	41.79	-12.00	

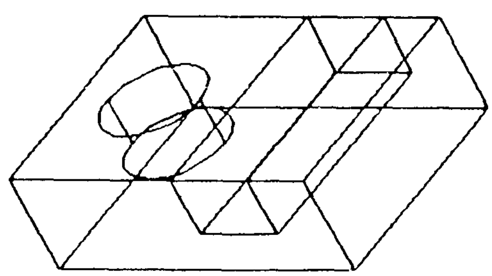
Figure 3

```
******************************
PROCESS PLANNING INFORMATION
******************************

SELECT FEATURE
   1-FACE                2-SIDE
   3-SLOT                4-POCKET
   5-HOLE                6-THREAD
   7-COUNTER BORE        8-COUNTER SINK
WHICH ? = 6

FEATURE TYPE = HOLE MAKING
 1--TYPE OF HOLE-MAKING
   1-HOLE CYCLE
   2-DRILLING
   3-BORING
   4-REAMING
WHICH ? = 1

 2-DRAWING CODE ? = h1
```



```
3-DIAMETER OF HOLE (MM) =   12.00
4-DEPTH OF HOLE (MM) =   12.00
 5-DIAMETER OF PRE DRILLED HOLE (MM)? = 0
 6-DEPTH OF THE PRE-DRILLED HOLE (MM)? = 0
 7-IS DIAMETRAL ACCURACY REQUIRED (Y/N)? = N
 8-IS ACCURACY REQUIRED FOR THE HOLE-CENTRE(Y/N)?=N
 9-REQUIRED SURFACE FINISH VALUE(MICROMETER)
   (0 IF NOT SPECIFIED)? = 0
10-WHAT MACHINE TOOL ? = 1
11-ON WHAT FACE IS THIS FEATURE(MAX. 2 DIGITS)? = 1
```

Figure 4

INDICATE THE HOLE 1
IS THE SELECTION O.K.?(1-YES,2-NO)

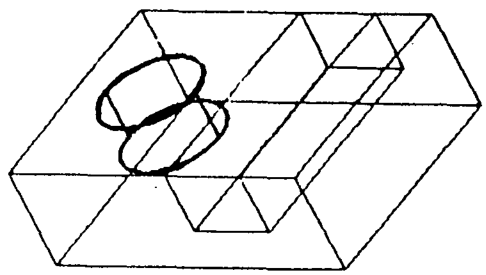


Figure 5

PART NAME = P12
PART NUMBER = 1
DRAWING NO. = 1
M/T NUMBERS = 20

MAT NAME = MILD STEEL
MAT SPECF = EN 1A
ASSEMBLY NO. = 1

BATCH SIZE = 1.
DATE = 25/09/88
PLANNER = GILL

OP	DRW C	OP DESCRP	TOOL CODE	TOOL DIAM.	MT CODE	CUTTING CONDITIONS FEED	SPEED	RPM	DEPTH	WIDTH	PASS	S. T.	M. T.	H. T.	NOTES
1		NEW M/T	0.	0.00	20	0 00	0 00	0.	0.00	0.00	0.	1.00	0.00	0.00	
2		LOAD M/T FACE '1 '	0	0.00	20	0 00	0.00	0.	0 00	0.00	0.	0.00	0 00	1.00	
3	SL1	SLOT MILL (ROUGH CUT)	2.	19 05	20	93 17	0.48	486.	15 00	19.05	3.	0.00	2.48	1.00	
4	H1	CENTRE DRILL	7.	1.50	20	0 09	0.21	2700.	4.50	0.00	1.	0 00	0.02	0.75	
5	H1	PILOT DRILL	6.	3 50	20	0 12	0.39	2103.	12.00	0.00	1.	0 00	0.03	0.75	
6	H1	DRILL TO FINAL DIAM	6.	12 00	20	0 25	0 43	682.	12.00	0.00	1	0.00	0.09	0.75	
7		UNLOAD M/T	0	0.00	20	0 00	0.00	0.	0.00	0.00	0	0 00	0 00	1.00	
8		INSPECTION	0.	0.00	20	0 00	0 00	0.	0.00	0.00	0.	0.00	0 00	1.00	

TOTAL SET-UP TIME = 1.00 MIN

TOTAL MACHINING TIME PER COMPONENT = 2.65 MIN

TOTAL HANDLING TIME PER COMPONENT = 6 25 MIN

TOTAL TIME FOR BATCH = 9 90 MIN

FEEDS = MM/RPM FOR HOLE MAKING OPERATIONS
MM/MIN FOR MILLING
SPEEDS = M/SEC
DEPTH = MM
WIDTH = MM

Figure 6

```
ARTNO DEMO
CLPRNT
MACHIN/HPUNCH,0
INTOL/ .1, .1, .1
OUTTOL/.1, .1, .1
STPT=POINT/   0.000,   0.000,   0.000
MATREF=MATRIX/TRANSL,   0.000,   0.000,   0.000
REFSYS/MATREF
PT  1=POINT/     42.963,    41.786,     0.000
PT   2=POINT/  84.161,  15.085,   0.000
PT   3=POINT/  64.522,  15.085,   0.000
LN  2=LINE/ PT   2, PT   3
PT   4=POINT/  84.161,  69.292,   0.000
PT   5=POINT/  84.161,  15.085,   0.000
LN  4=LINE/ PT   4, PT   5
PT   6=POINT/  64.522,  69.292,   0.000
PT   7=POINT/  84.161,  69.292,   0.000
LN  6=LINE/ PT   6, PT   7
PT  8=POINT/     74.341,    -4.465,     0.000
PT  9=POINT/     74.341,    88.842,     0.000
TOOL NO/ 1
LOADTL/ 1
CUTTER/  19.050
FROM/STPT
$$ rough cutting a slot
SPL= PLANE/ 0.0 , 0.0, -1.0, - 1.0
FEDRAT/  93.165
SPINDL/ 485.547
RAPID
GOTO/ PT 8
$$ passes for depth level          1
SPL=PLANE/CANON, 0.0 , 0.0, -1.0,   15.000
THICK/0,    0.295,0.000
GO/TO,LN     4,TO,SPL,   TO    ,LN    2
GO/TO,LN     4,TO,SPL,   PAST  ,LN    6
THICK/0,    0.590,0
GO/TO,LN     4,TO,SPL,   TO    ,LN    6
GO/TO,LN     4,TO,SPL,   PAST  ,LN    2
THICK/0,    0.000,0.000
GO/TO,LN     4,TO,SPL,   TO    ,LN    2
GO/TO,LN     4,TO,SPL,   PAST  ,LN    6
GOTO/ PT 9
TOOL NO/ 2
LOADTL/ 2
CUTTER/    1.500
FROM/STPT
FEDRAT/ 255.7235
SPINDL/2700.0000
CYCLE/ ON ,    4.500
GOTO/PT    1
CYCLE/ OFF
TOOL NO/ 3
LOADTL/ 3
CUTTER/    3.500
FROM/STPT
FEDRAT/ 250.4166
SPINDL/2103.2310
CYCLE/ ON ,  12.000
GOTO/PT    1
CYCLE/ OFF
TOOL NO/ 4
LOADTL/ 4
CUTTER/  12.000
FROM/STPT
FEDRAT/ 168.5467
SPINDL/ 681.6026
CYCLE/ ON ,  12.000
GOTO/PT    1
CYCLE/ OFF
 RAPID
 GOTO/STPT
 FINI
```

Figure 7

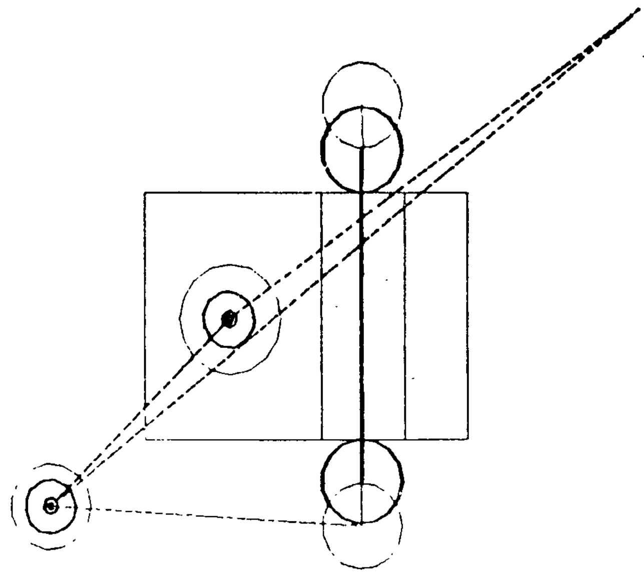


Figure 8

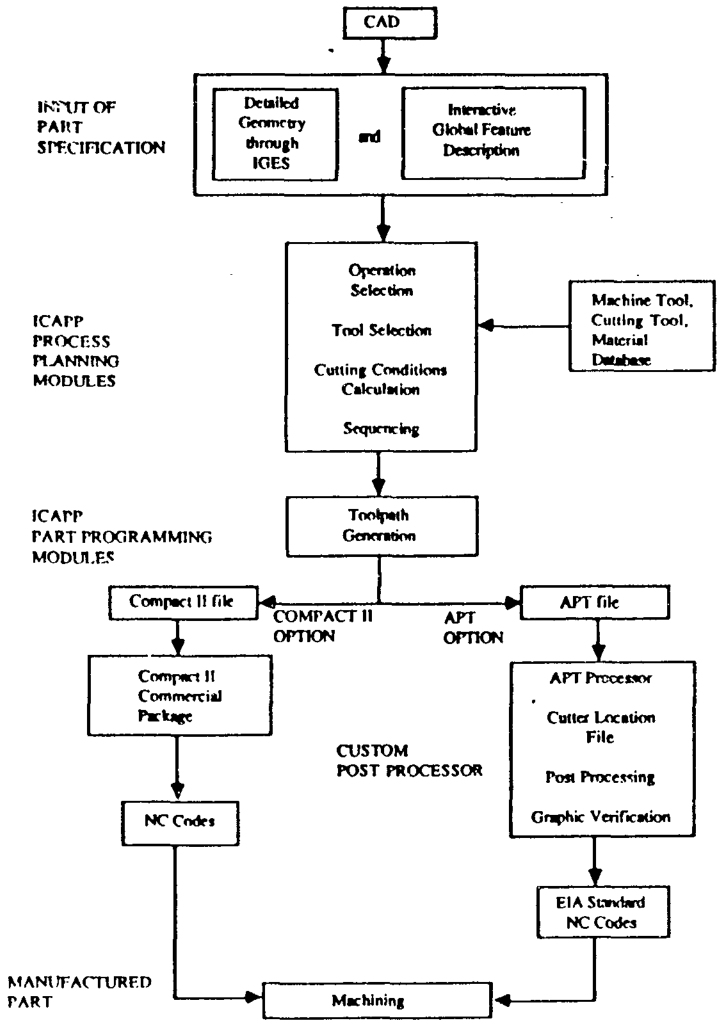

CAD
INPUT OF PART SPECIFICATION
Detailed Geometry through IGES
and
Interactive Global Feature Description
ICAPP PROCESS PLANNING MODULES
Operation Selection
Tool Selection
Cutting Conditions Calculation
Sequencing
Machine Tool, Cutting Tool, Material Database
ICAPP PART PROGRAMMING MODULES
Toolpath Generation
Compact II file
COMPACT II OPTION
APT OPTION
APT file
Compact II Commercial Package
CUSTOM POST PROCESSOR
APT Processor
Cutter Location File
Post Processing
Graphic Verification
NC Codes
EIA Standard NC Codes
MANUFACTURED PART
Machining

Figure 9