11. CONCLUSIONS

11.1 Feature Extraction & Recognition

Attempt has been made to extract machining features by boundary loop method. Since it has not yielded satisfactory results for complex, and compound features formation of MAAM and feature coding method has been attempted. The methodology has been tested for some typical CAD model and has yielded satisfactory results.

11.1.1 Quantitative Analysis of Feature Extraction

Quantitative analysis for the components tested have been discussed earlier. The present analysis is limited to number of features, feature types and feature groups. For each component, drawing and features are shown in figures and quantitative details about the features are tabulated. The table gives the details of features extracted, in-groups, types and numbers. It is to be noted that the present analysis may not cover all the machining features.

11.1.2 Comparison with Boundary Loop Method

The present method compared to that of boundary loop method has the following advantages:

- The principle of formation of MAAM will reduce the task of forming the boundary loop as each feature can be identified easily from the Object-MAAM
- The unique string code for each feature is easy to compare which increases the speed and reduces the complexity
- Curved Feature Extraction can be done easily and V slots and complex slots, which can not be extracted by boundary loop method, can be extracted.
11.1.3 Conclusion

From the tests conducted on various components, some of the points concluded are as follows:

- The extraction of polyhedral features of simple machining regions and compound machining regions with nested type are successful from the components.
- Writing feature interpretation routines can do the extraction of complex features.
- The extraction of some of the curved features is done, which can be extended to include more number of curved feature instances.

Though the present work is carried out for CAPP, this could be extended or modified to integrate various other activities of manufacturing. Some of them are given below:

- Time and Cost Estimation of the component:
  The time to machine each feature can be estimated by considering the feature parameters, material of the component and cutting tool material. And the time of machining can further be used to estimate the cost of manufacturing.

- Scheduling:
  A scheduling software can be developed where the machine selection is based on the descending order of maximum number of operation with minimum set-up time. Automatic retrieval of set-up time, unit time, work centers required and sequence of operations.

- Automated NC code generation:
  The path of cutting tool can be parameterized for a feature considering the machines, tools, etc. These parameters and geometrical details can be used to generate NC code automatically.

- Near Net Shape Manufacturing:
  The extracted features can be used as input for deciding the feasibility of Near Net Shape Manufacturing (NNSM) process and to automate the die-manufacturing etc.
Group Technology:

The extraction of features could be used for classifying and coding the components. This coding could be used for various computerized processes.

DFM:

Each feature can be verified for ease of manufacture based on the expert rules formed from manufacturing experience and redesign if necessary.

11.1.4 Suggestion for Future Work

A program can be developed using CVMAC (macro programming in CADDS5), which would highlight the feature extracted by the software by linking with C program. By doing this manufacturing details (feature tolerance, surface finish) of the component could be entered by viewing the feature, thus reducing the ambiguity. The implementation of this methodology is presently limited to polyhedral features, circular holes and some curved features of prismatic components. The concept can be extended to all types of surfaces. Further research is to be conducted to resolving intersecting features (Complex machining features). This software has to be made compatible with all modeling packages by writing a simple routine which will take IGES file as input and converts the information into linked lists of Faces, Edges and Vertices.

Feature grouping is to be carried out. This will reduce the manual intervention to input the manufacturing details (such as feature tolerance, surface finish, etc.) that are not available in the CAD database.
11.2 Process Plan Generation

A software package has been developed successfully for the feature based process generation system of the prismatic components. Generation of process plans for missile components has validated this. The results are found to be adequately correct.

11.2.1 Observations

The system developed uses the part and feature data files, which are in fixed format. Then the software automatically orders the features depending on the feature type, classes, and tolerance & finish. The user can change the order depending on the feature precedence, which he feels appropriate. The software generates operations (processes, machines, cutting tools) for a number of features like Cut, Round / Ogival, Rib, Boss, Chamfer, Fillet, Step, Slot, Circular hole, Noncircular hole, Negative dome, Negative cone for different classes. After all the features have gone through Feature process correlation module, selected operations are sequenced automatically by the software to reduce tool changing time and number of setups. Integration with oracle database for selection of blank, machine, and tool information has been carried out.

The output of the software has been compared with that of manual process plans. The generated process plans are easily understandable. The output was nearly constant even though the order of the data was changed. The output is consistent for the same set of input data. But the software generates the process plans for typical components only. The components having the cut features without predefined shape creates difficulty in generating the process plans. Another limitation has been found out that the raw part is assumed as either rectangular block or circular rod. But it may not be always i.e.; it may cast or forge part of typical shape. Thus the process knowledge base has to be updated to get reliability in process plans. However, the CAPP presently available cannot completely supplement the expert process planner since his years of experience enables him to plan effectively for the specific part. Hence during the course of the process plan generation, the user is provided with the option to interact with the knowledge base so as to include his ideas in the process plan. Thus
CAPP can be used effectively as a tool for automatic process plan that complements the experience of the user in process plan generation.

11.2.2 Manual input method

A software package has been developed in Oracle and Visual C++ which runs in Windows 95 / NT environments. The purpose of developing the software in VC++ is to meet the requirements of the sponsors of the project. Initially around 125 flat features are identified and the required dimensions for each feature were documented. Provisions have been made in the software to include dimensional tolerances, References, Positional/form tolerances and surface finish. Also the software facilitates the user to specify the grinding allowance which varies depending on the process capability of the machine. The software generates operations for a number of base features like Cut, Round, Boss, Chamfer, Fillet, Step, Slot, and almost all Hole features from which several sub-features have been derived. After generating operations for all the features, the Feature Process Correlation module selects the machines, tools and quality operation for each operation. Here, the user is provided with the option to change any of the parameters to suit his needs by interacting with the knowledge based system, thus making the software very flexible. The provision of human touch to the software gives the results that are very encouraging and optimized. Generating the process plans for missile components has validated the software.

11.2.2.1 Scope for further work

This work can be extended to suit the growing needs of the dynamic changes in this field of process planning. The software developed to generate the process plan can be suitably modified to suit any industry and also it can be generalized for any part. The upgradations that can be done to the software are discussed below:

> As more and more new features gets identified during feature identification, the decision rules for the identified features can be suitably incorporated in the Knowledge Base giving details about the process, machine and tooling required for the manufacture of that feature.
Presently, the software generates the process plan only for raw blanks of rectangular or circular cross-sections. The software can be suitably modified to include other cross-sections also so that the blanks obtained from casting and forging can be directly given as the raw blank in the software.

The process plan generated for the parts only include basic metal removal operations like milling, drilling, boring, grinding, etc. Suitable modification can be done on the software to include other operations like casting, welding, plating, etc and including the decision rules for the same in the knowledge base.

The software does not take into consideration the time of each process like set-up time, machining time, etc. These can be incorporated in the knowledge base where required so that the cost of making the part can be calculated based on the machine hour rate of the machine.

11.2.2 Future Work

Presently the software has been developed for a limited number of materials. The software can be further developed to support all kinds of materials. Though the software gives the machining face and adjacent faces of each feature, optimized setup planning has to be done. Calculation of manufacturing time can also be implemented.

11.3 Database Design and Development

The data retrieval of tools, cutting parameters, machines etc., for various processes to be carried out on different features have been tested. The necessary reports for transactions have been generated. Apart from using as an integrated module in CAPP, this centralized database can also be used as a stand alone in any manufacturing environment to save time for the data lookup and technical decision making text and document preparation. This database can be easily updated to adopt the new changes. Adding new databases to the existing tool, cutting parameters and machine libraries can further strengthen the database.
11.4 Integration of different modules

This automated process planning system generates process plans for material removal operations in prismatic components. The issues encountered during implementation of the integrated system from source codes written by different programmers due to individual programming style, use of importable library functions being specific to a compiler or a piece of hardware, inadequate comments in the source codes, and recursive source code inclusion have been successfully solved. Process plan archival facility presently stores the process instructions as a continues string while the better approach is to store only the pertinent process data from which the instructions could be constructed. Nevertheless, the work is an integrated modular approach to process planning which is easily modifiable, improvable, and extendible.

11.5 Conclusion

The present work can be further extended to include operations other than machining like casting, welding, plating, etc. The software can be further developed to support all kinds of materials. The software can be suitably modified to suit any industry and also it can be generalized for any part. Further more number of features can be identified and the rules to generate process for them can be formulated and updated in the database. The software needs to be made to generate process for raw blanks of any cross section. Process optimization can be included in the software to improve its efficiency. The software does not take into consideration the time of each process like set-up time, machining time, etc. These can be incorporated in the knowledge base.

Thus an expert system for process planning for curved features has been developed. There is lot of scope for enhancing the project. Although the expert system appears to be intelligent, they ultimately depend upon the human expertise for their knowledge base. The aim of the expert system is not to replace the humans but to assist them in problem solving and decision making. Lastly I would like to point out that though expert system do not tire out, take breaks and devoid of all human shortcomings, they do make mistakes.