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Simultaneous Engineering System for Applications in Mechanical Engineering

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2. Abstract

This paper presents a CAD/CAPP/CAM - System developed using an open-architecture solid modeller. The main characteristics of the CAD - System are its object-oriented approach, feature definition via a set of parameters and a set of procedures, a hybrid CSG/B-rep data structure to accommodate features and a mechanism allowing specification of inter-feature relationships. The concept of process planning is divided in three possible steps, which will complement one another. The first step will automatically generate, based on genetic algorithms, an optimized process plan depending on the manufacturing facilities available in a database. With the Interactive Feature Planner manufacturing methods can be added, which are not yet part of the technical database and the Manual Process Planner gives the possibility to change particular process plan information, without rerun the whole planning process. The integrated NC - Programm generator calculates the toolpaths automatically, based on the information from the process plan.

Feature technology supports detailed design efficiently through parametric modelling and can make post-design knowledge available at the design stage and gives the following processes the chance to use design information for the manufacturing process without regeneration of redundant data. Algorithms mapping between dissimilar application feature sets, *would achieve company-wide unified product modelling.*

3. Introduction

One of the recent and most significant trends in manufacture is *to link* automation with flexibility, in order to balance management of technological evolution and market requirements with fast pay-back of investment. Integration of Design, Process Planning and Part Program Generation would increase company competitiveness. This is particularly true for firms, such as the ones to which the project is addressed, involved in the manufacture of mechanical goods, e.g. machine tools, automobiles, aircraft, with batch production of a complex product mix.

Although the system available at the end of the project could also be used simply as a design tool or simply as a process planning tool, it is mainly aimed at the users concerned with both design and process planning / manufacture.

Potential user product analysis has shown that in most cases components are mainly prismatic and also rotational, without free-form surfaces. These components are produced on milling/drilling machines (machining centre category) and on lathes. Machining operations used are 2-1/2 D. This does not mean that other machines and the corresponding processes should be outside the

capabilities of the system, but it is a necessary assumption for reducing the scope of system implementation.

Judging by the amount of research publications and also by the way the results have been taken up in the computer software industry, it appears that the concept of feature-based modelling is the next step in the right direction.

Based on the feature technology [1,2, 3,4,5] and the above mentioned user profile, the Sesame Project aims at developing an integrated system for designing, process planning and NC programming (Figure 1) mechanical components involving metal cutting operations on machining centres.

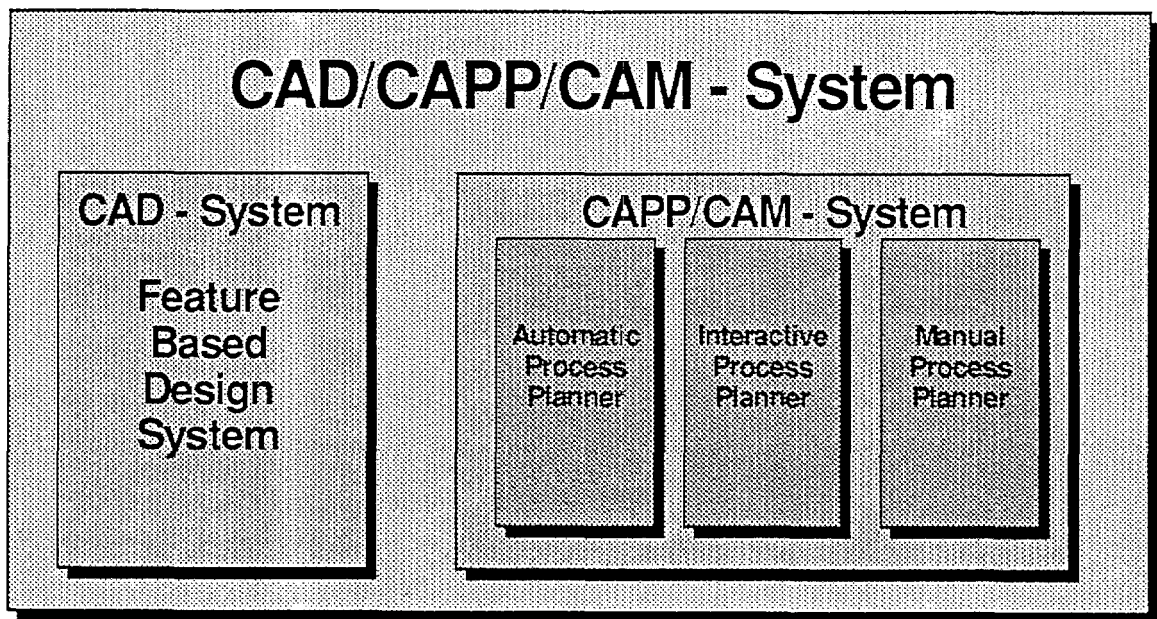


Figure 1: SESAME End Product

The SESAME system consists of several modules, which are completely integrated based on a common model. The CAD/CAPP/CAM - prototype consists of two main modules (Figure 1). One main interactive component represents the feature - based CAD - System.

The second main component is the CAPP/CAM - system, which is divided into three modules.

These modules represent the possibility of generating process plans and NC - programs. The automatic process planner generates an optimized process plan, depending on the quality of the technology database. If complete generation fails, because of new design features or missing technology information from the database the process plan will be completed using the interactive feature planner, where the feature selection, the manufacture methods selection and the replacement in the process plan will be decided by the user. At the end it is possible for the user to make some slightly changes in the result using the manual process plainer, which is a process plan editor. With this architecture the user will be able to produce process plans in every case, which is important to his daily business.

After completion of the process plan the toolpath calculation for the NC-programs for the part are generated automatically.

4. Technical description

4.1 The Feature Based Design System

The philosophy of the FBDS presented, largely resulting from the considerations outlined in [11], [4], [13] and [12] is the following:

A B-rep **modeller** is necessary, as it is advantageous to have an explicit description of feature boundaries, both for **manipulation within the modeller** and for use by other applications subsequently.

A feature **should** be represented as a volume and not as a collection of faces, because **volumetric** bodies are easier to manipulate in the **modeller** (Through **Booleans** etc.), and also because otherwise problems due to undetermined ('closure') faces may arise.

It is natural to define features in generic templates (implicit definition). Then, every time a feature instance needs to be input, an instance of the appropriate **template** is created and integrated with the rest of the model i.e. the feature is evaluated (explicit definition).

Finally, a feature **model** external to the **modeller** precludes any parallel processing of both feature and solid geometry and is thus not desirable, **unless** accessibility to the kernel is poor.

A design feature in SESAME is seen as consisting of:

- Morphology expressed in a coordinate system, e.g. a volume, a symbol etc.
- A set of parameters, a subset of which uniquely determines the **morphology**. Parameters may have constraints attached.
- A set of rules constraining the definition **and/or** application of the feature
- Additional **information**, usually related to manufacture

In addition, a design feature can also be seen as part of a **hierachy** or feature structure. In accordance to the above, a feature template **consistes** of the following elements:

- A **unique** name
- . A type
 - Type can be of the following :
 - . BASE, denoting the seed feature of the **workpiece**,
 - ADD /SUB, denoting an additive / subtractive volume,
 - . LOC, denoting a local operation that does not procedure a new volume, but **modifies** an old one (e.g. blend, chamfer etc.) and
 - GRP, denoting logical grouping of features into a pattern.
- . A parent feature class
- A set of parameters
- Procedures attached to each parameter
- . An evaluation procedure
- A symbol definition procedure
- . Procedures dealing with feature rules

An overview on the internal **FBDS** architecture is shown in Figure 2.

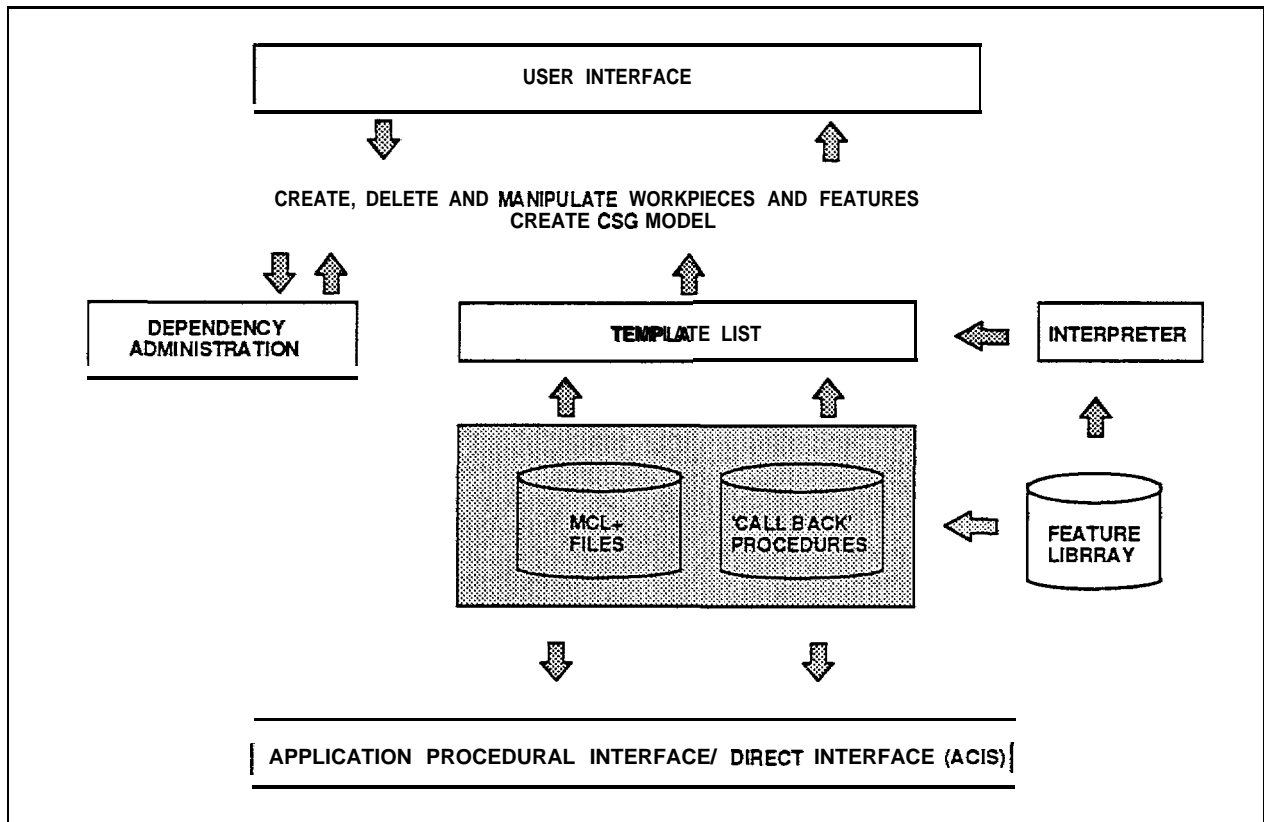


Figure 2: Architecture of the FBDS

The feature templates are defined according to the **frame** concept in the feature template file, which is a simple ASCII file. When loading the system this file is read and interpreted in order to set-up the data structures for feature representation. During a **modelling** session feature frames are instanced and features evaluated and (the volumetric ones at least) combined with the already existing body into a new B-rep body. A hybrid model is used for feature representation. The individual feature-bodies are stored as the primitives of a **CSG-type** tree maintained in parallel to the main B-rep representation. The **CSG tree** in effect provides a history of the **modelling** steps taken. This arrangement ensures that changes in **volumetric** feature parameter values can be made easily, the model being updated very quickly, and at the same time that the evaluated boundaries are always available **without** considerable computational load. After completion of the **modelling** session both the implicit feature model and the (explicit) boundary solid model are stored in a file, from where this data can be **retrieved** again when needed. An important characteristic of the system is the introduction of dependencies between parameters within the same feature or between different features. In effect parameter chains can be built in this way. The effect of changing a parameter is propagated along the chain and the model is automatically updated to reflect the changes.

The most important feature manipulation commands are as follows :

- provide a list of the **workpiece** features
- perform model evacuation after input of a feature
- select a feature either by name or by picking
- input a feature

- miscellaneous, e.g. save/load, generation of a B-rep solid out of the feature model, enabling keyboard command input mode etc.

The key to definition of new features is the Macro Command Language (MCL+). This is a programming language, but also a programming environment including interpreter, that can be integrated easily in any application. Functions and data types of the application can be installed in the language and used as if they were the language's own.

The user interface is based on 'MOTIF'. According to the current version, the screen looks as in Figure 3.

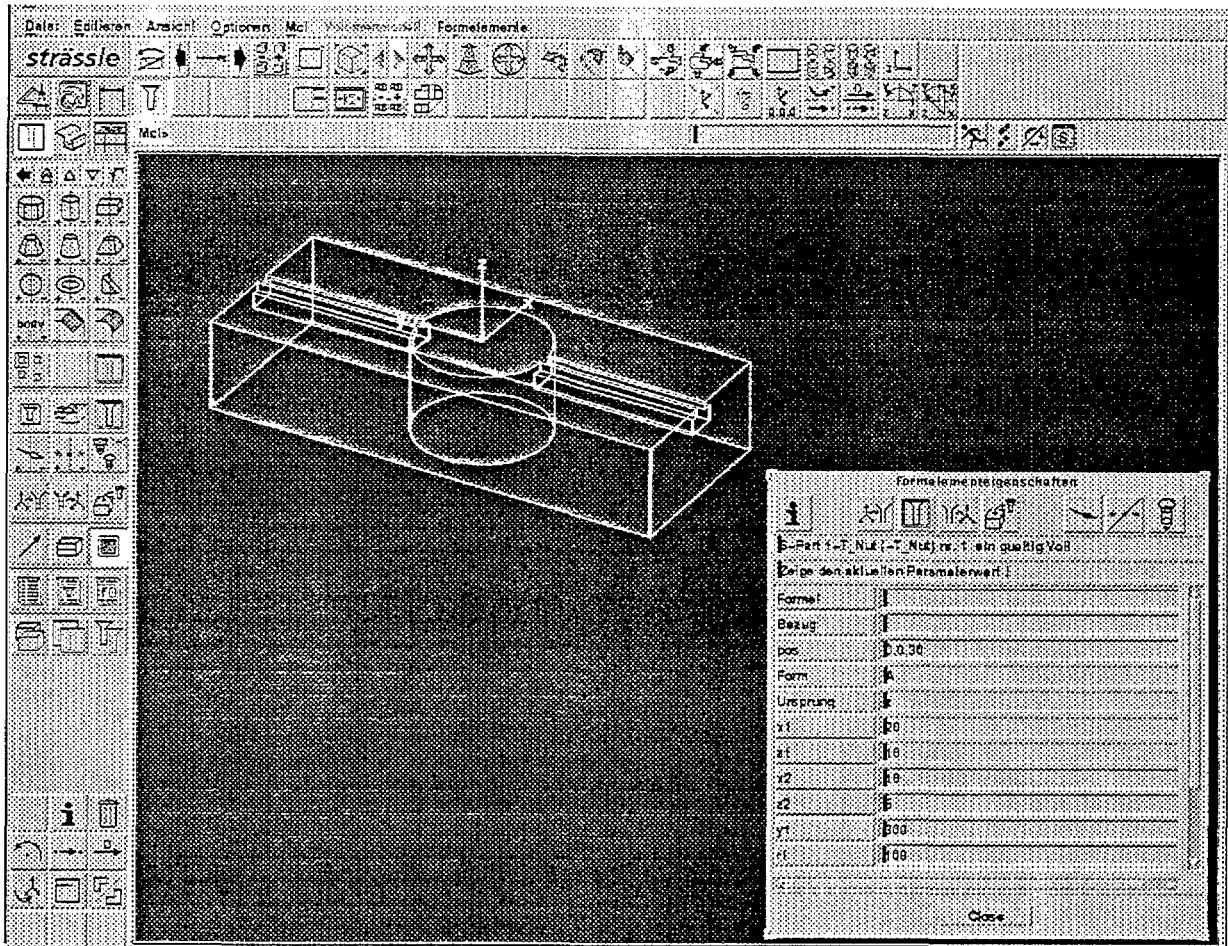


Figure 3: User Interfaces of the FBDS

There are two categories of commands represented by icons: In the top rows are Coordinate system manipulation commands and Display manipulation commands, e.g. zoom, shade, autoscale etc. These commands are permanent available in all strässle applications. The column of icons left on the screen are dependent on the module the user selects (2D profiling, solid modelling, feature modelling, sheet metal processing, etc.)

When input of a feature is selected, the user is presented with a feature definition window, through which all feature parameters should be entered, either through the keyboard or through the picking

device, as appropriate. A feature is displayed along with its coordinate system, whose origin is used to position the feature.

In addition, the mechanism recording the **modelling steps (CSG-tree)** and the **ACIS roll-back facility** ensure that the principals of conceptual **modelling** are supported in a practical way. Roll-back till allow branching of alternative **model configurations**, so that the current state of a model does not need to be altered in order to try a different design. Implementation of feature transformation and **modification** was expected in [4] to reveal interesting **problems**. One problem worth considering is that of **blends**. Blends are features of type **LOC modifying edges**. In the slotted block of **Figure 4a** two collinear edges have blends of different radii. If the slot feature is rotated by **90 degrees**, the two edges are joined into one, and the **blend** that was made first will extend over the whole of it. If the **slot** is rotated again by an angle other than 90 degrees, the two blends reappear, as the should, see **Figure 4c**.

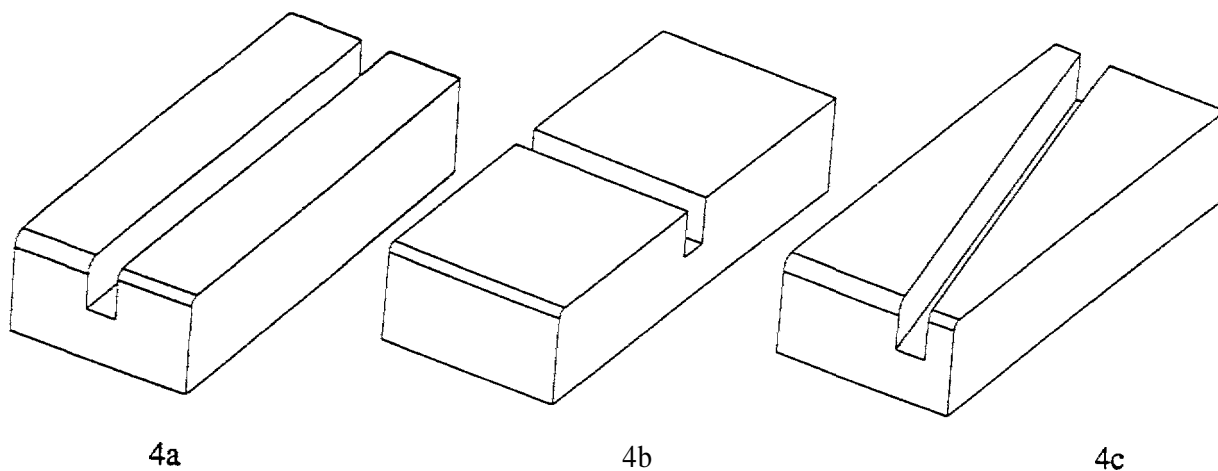


Figure 4: Slotted block with two colliner edges

A major benefit the system is **likely** to bring to a company employing it is the structuring of a company's design experience, especially when rules/constraints are attached to features and to their parameters. Design features can be structured in a number of **libraries**, according to their application sector, e.g. sheet **metal** work features are quite different from those used in volumetric components. Such a practice would reduce redundancies in design **and**, as a **result**, would also reduce the load that alternative designs put downstream on process planning, **fixturing** and inspection procedures. The essence of features is their **pecularity to applications**, to **companies** and even to individual **designers**. Therefore only a few can be with certainty said to be universal and thus hard-coded in the system. Most importantly, new ones should be easy to define and incorporate **in** feature libraries. This is the main bottleneck in feature-based design being fully accepted for day-to-day work in an **engineering** company. More precisely the main issue is definition of the functions that generate the **volume** representing the feature. The **API** interface of **ACIS** possesses **all** these characteristics. **In** addition, **programming** of new features has to be **performed in** some language, which will be **simple** for the programmer (usually the designer) to use.

4.2 The Automatic Process Planner

The automatic process planning system consists of three modules, the geometric reasoning module, the planning space generator and the optimiser. The geometric reasoning process reads feature based workpiece descriptions as a CODL file generated in the Feature Based Design System. After implicit feature interactions are recognized, a network of manufacturing possibilities for the features of the component is generated by relating technologically possible microcycles to each feature. Explicit and implicit feature interactions are performed in consideration of feature parameters as well as the assignment of microcycles. Depending on feature dimensions, tolerances, anteriority constraints and implicit feature interactions, tables have been produced where technologically possible microcycles can be selected. After the definition of microcycles, tools are attached for each microcycle and the finally cutting parameters are related to each type of operation. Rules stated by the end-user makes the whole process company dependent. The network of manufacturing possibilities generated by the planning space generator serves as input for the optimizer. An optimized process plan considering costs, number of set-ups, machining time, toolchange time and machine transfer time is generated by the optimizer using genetic algorithms [10].

4.3 The Interactive Feature Planner

The feature planner is a flexible interactive process planning system and is used for the interactive generation of process plans in a graphical environment [9]. The process plan generation is carried out using a manufacturing feature based workpiece description, which is derived out of the design feature workpiece model by means of a feature mapping process. The feature mapping information can be represented and stored in the feature library which is used for the initialization and configuration of the system. The architecture of the Feature Planner is presented in figure 7.

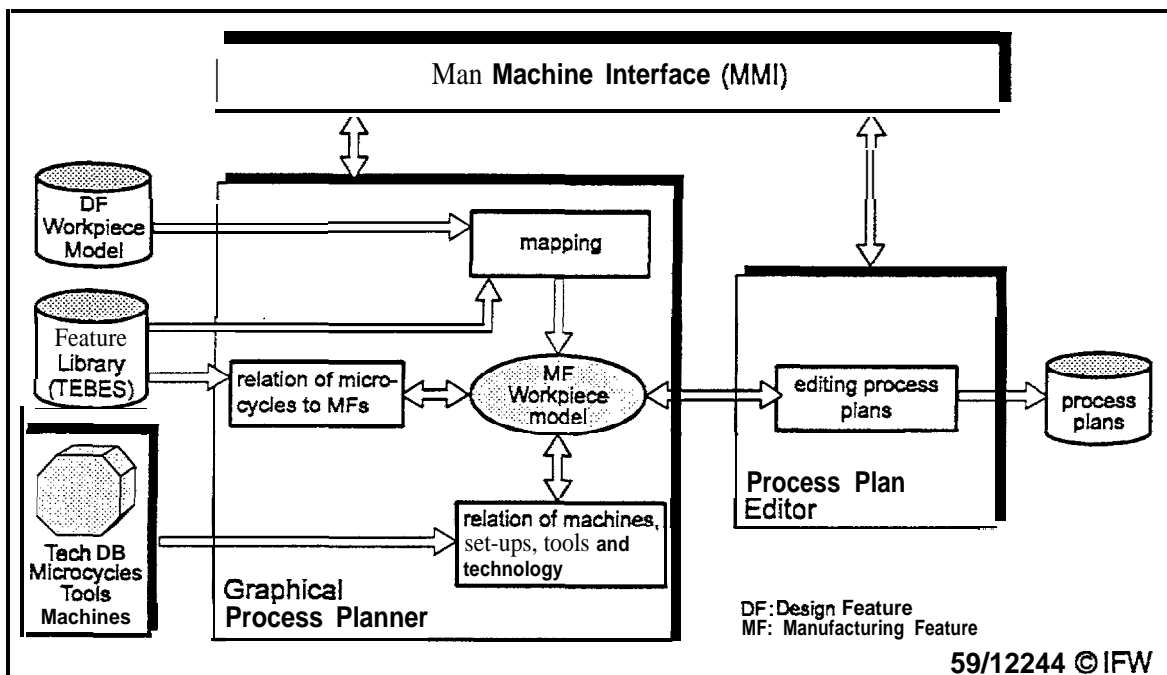


Figure 7. Architecture of the Feature Planner

Figure 8 presented an example for feature mapping. Two mapping alternatives for the design feature **counterbore hole** are available. This feature can either be manufactured using a **special tool** (combination drill and **counterbore**) which is capable to manufacture the feature in one operation or the alternative is to drill for hole and then manufacture the **counterbore**.

When there is more then one mapping alternative, user interaction is requested. Otherwise, the mapping is performed automatically. After completion of the mapping process , interactive process planning can start based on a manufacturing feature **workpiece** model.

After the machine and set-ups have been selected, the operation sequences for the manufacturing of each manufacturing feature have to be specified.

Each manufacturing feature has a related set of **microcycles**. One microcycle is the operation sequence for manufacturing the feature (figure 8). The set of **microcycles** describes the different individual and company dependent technological approaches for the manufacturing process. The applicability of a **microcycle** is influenced by the current dimensions and explicit and implicit feature interactions. Explicit interactions are those explicitly stated by the designer such as tolerances and surface finish. Implicit feature interactions are relationships between features not explicitly defined by the designer, but which have to be considered when selecting manufacturing methods. Examples are the intersection or the proximity of features [14,15]. After the assignment of **microcycles** to features, tools and technological data have to be related to each operation.

The **microcycles**, **teds**, and technological data are defined in a database which is accessible by the feature planner.

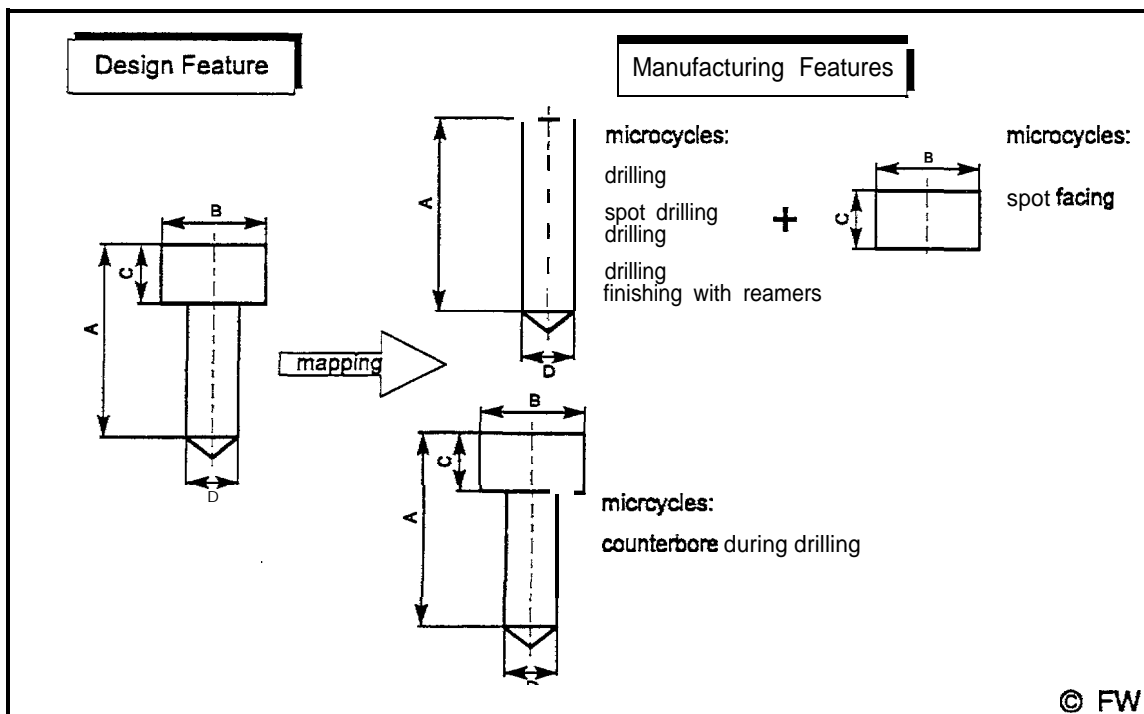


Figure 8. Mapping and microcycles

In order to close the loop from process planning back to design, problems arisen in process planning can be marked and commented on in the manufacturing feature workpiece model. The remarks have to be transferred into the design feature model which is then transmitted back to the

design system. The transfer of these remarks into the design feature model is possible because in each manufacturing feature the corresponding design feature is noted.

The comments in the design feature model transmitted back to the design system give hints to the designer making it easier for him to improve his design according to manufacturing demands.

4.4 The Manual Feature Planner and the NC - System

The Manual Feature Planner (MFP) and the NC - System (NCS) really means the CAM -System. The MFP stands for the generating and/or modifying a process plan, its operations and technology information. The NCS stands for a NC-algorithm machine, that calculates the toolpaths depending on the parameters, which are stored in each operation. The architecture of the system contains four main modules: The User Interface, the APM Interface, the NC data structures and Strata as NC-algorithm machine, which includes the 3D modeller ACIS.

The user interface in its main functions (e.g. graphical functions, Manipulation of the coordinate system) is corresponding to the FBDS. According to the geometric model a list of operations shows the status of the process plan (figure 9).

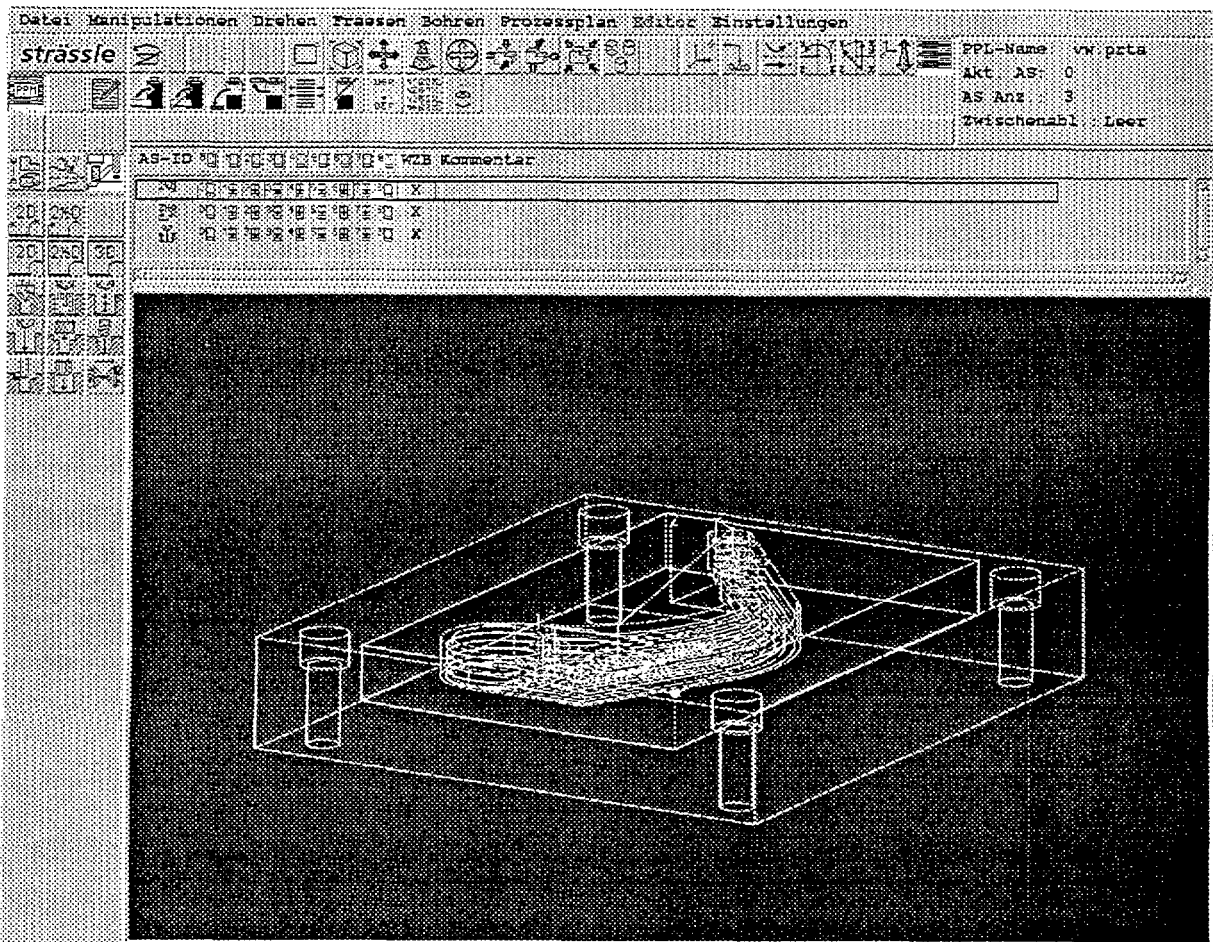


Figure 9: User Interface of the CAM -System

Each row of the list characterizes one milling operation or method, e.g. roughing, finishing or drilling. With edit functions a couple of manipulation possibilities are available for the end user.

One can delete and/or add operations or change the order of the operations and therefore optimise the process pkm to the specific needs of the manufacturing problem. Each operation exists of seven categories of information groups, which contains all parameters necessary to calculate a toolpath (e.g. geometry classification, tool information, entry/exit method, etc.). The process plan matrix allows the user to make particular changes like a single feedrate manipulation, without waking through the whole process plan. Dependencies between the operations let the system know, which of the operations have to be evaluated.

All operations of the user and the system are done via the APM Interface. Using a defined command language it performs all necessary actions for the CAPP modules to get its results. This means on one hand to build up hierarchical structures for the whole work plan, on the other hand to start toolpath calculation using STRATA (Figure 10). As the Automatic Process Planner as well as the Interactive Feature Planner uses the APM -Interface to generate the process plan data structure, there is no redundancy in data handling.

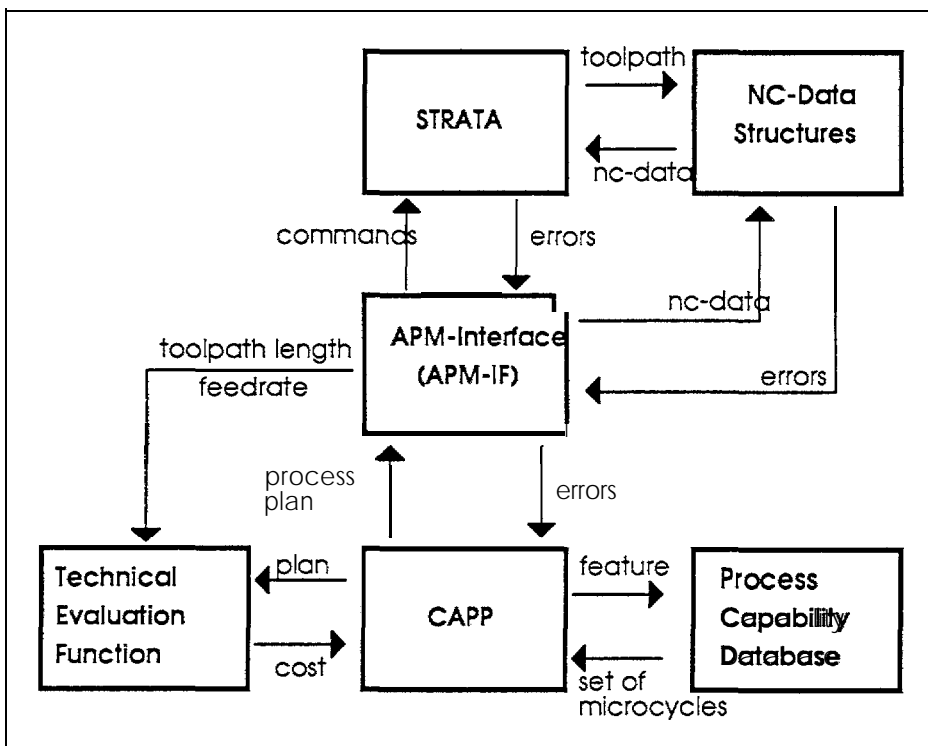


Figure 10: CAPP System Architecture

5. Results

The first experiences with using the FBDS to model real components pointed out strongly that such a system has the potential for changing design practices. Solid modellers have so far been supporting detailed, as opposed to conceptual design, for two reasons :

- Design primitives offered are simply geometry primitives, e.g. cubes, spheres, cones etc., not all representative of engineering functional shapes. The designer in the majority of cases thinks in terms of

- shapes fulfilling a function in the working component, e.g. cooling channel, bearing seat, stiffening rib etc.
 - standard shapes defined in engineering catalogues and handbooks, e.g. keyway, pulley, flange etc.
 - less 'concrete' features, but still with a functional significance, e.g. cylindrical groove, rectangular pocket, chamfer etc.
- Even assuming that the design primitives offered are appropriate, it is usually cumbersome to make changes in the model after its initial input. This typically involves several Boolean operations on several solid modelling primitives in order to delete old bodies and input new ones, every single step being specified by the user. This is a very important discrepancy, given that engineering design is by definition an iterative process.

Provision of higher-level, design focused primitives and of a mechanism to express inter-feature dependencies and constraints in the FBDS, supports to a good extent the principle of conceptual modelling. However, the main constraints in conceptual design are logical ones, and therefore what is really necessary is a general-purpose constraint management mechanism.

The experience with the CAPP/CAM system pointed out, that future work in the manufacturing departments will change. The old fashioned way of producing process plans depends on the rules and technological information in the individual company dependent database. As material, tools, machines and production methods change, the database has to change to the new environments as well. The process planner will have more time to optimise rules and methods, while the routine work will decrease. This leads to a more efficient way of using production resources.

6. Conclusions

The reduction of the process and product development time are objectives of simultaneous Engineering. Processes, which are carried out in parallel during the development phase can achieve this goal. The present integrated CAD/CAPP/CAM system use as a basis feature techniques and a common geometric modeller.

The SESAME system consists of modules for design, process planning and NC-programming. These engineering tasks can be performed partly in parallel causing a decreased development lead time. Feedback loops from process planning to design and from NC-programming to process planning have been established. The process planner and the designer are encouraged to work closer together and therefore they are able to produce a more sophisticated workpiece design. Future work will have to address additional technological processes as manufacturing of sculptured surfaces, turning and the selection of fixtures in process planning.

7. Acknowledgments

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