Integration of machine operator know-how in a feature based environment - CAD/CAPP/CAM/CNC

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Abstract

The feature based design environment, FINDES, support the users during the design process through a manufacturing feature based design interface. The instantiated manufacturing features are validated by the system considering feature parameters, feature elements and manufacturability according to the available production means. For a valid manufacturing feature according to these criteria, FINDES identifies the shape and technological interdependencies. FINDES supports the user during the tolerancing process and the definition of other technological attributes. All the determined manufacturing feature interdependencies are managed by the system and represented in the feature based part model. These interdependencies are necessary for the determination of the manufacturing operations sequence and for the automatic generation of the NC program by FINDES. Down at the shop floor still the machine operator needs the possibility to optimise the NC program according to the actual situation of production means. In order to integrate his knowledge, the feature based process chain has to be defined consequently down to the machine control. This is realised by a central feature based part model, consisting all information of design and planning, including the interdependencies among the features. Since in this case in the machine tool all information related to the part, tools used and existing and the planned strategy are available, modifications can be made on the spot at the machine. In this way the experience of the machine operator can be integrated. The represented interdependencies between the features support the machine operator for selecting possible tools and identifies necessary recalculations of cutting volumes of single features.

1. INTRODUCTION

The research for CAPP systems started in the middle of '60s [1]. In the '70s the most of the developed CAPP systems are based on the concepts of variant process planning and group technology. The generative and knowledge based approaches for process planning began to be applied only later in ‘80s [1, 2]. Today, the trend is towards an automated and intelligent process planning systems looking for integrated solutions in CAD/CAPP/CAM systems [3-5].

While in the variant approaches a feature based representation of the part did not play an important role, but the part family; in the generative process planning the feature based part model are together with the manufacturing databases and the decision making logic or reasoning mechanism the main components [1]. Therefore, the way towards to integrated CAD/CAPP/CAM systems demands the full representation (geometrical and technological) of a part in terms of manufacturing features, being these objects the common semantic for all these systems [3, 4].

During the development of the process planning one of the main activities is to determine and to optimise the machining operations sequence. For this task it is fundamental not only to obtain a manufacturing feature representation of the part, but also the interdependencies among them. Only considering these interdependencies it is possible to determine the correct machining sequence. A typical example is a Hole positioned in the bottom surface of a Pocket (see figure 3 c). There are different machining sequences to manufacture both features, but the process planning system needs the information about the interdependence between both features to take the correct decision.

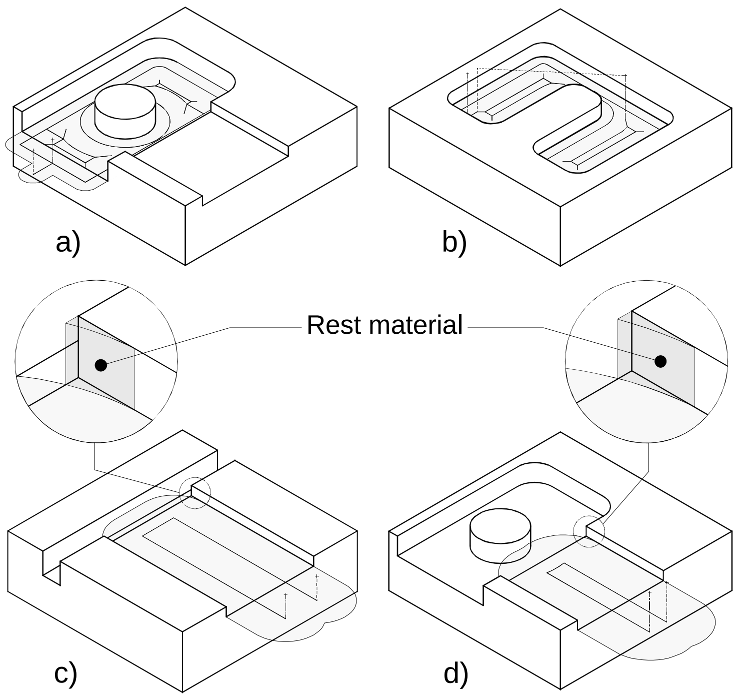

Figure 1: Examples of machining constraints: a) volume interaction; b) concave pocket; c) precedence interdependence; d) implicit technological interdependence

The CAPP systems do not have a geometric core. Therefore, it is necessary that the feature based design environment supports the CAPP when some kind of geometric reasoning is necessary to take a machining decision; for example, in choosing the size of the tools. figure 1 shows some of these problems that the process planning must solve; note that many of those situations are also related to the interdependence among features. In case a) and b) the CAPP is confronted with a narrow passage that must be taken in consideration to choose the correct tool diameter. In case c) and d) there are two other cases of feature interdependencies and the CAPP needs the full information about the features including the tool diameter constraints to avoid a collision with the wall of the second feature and the uncompleted machining of the first feature.

Therefore, the recognition, validation and representation of the interdependencies among manufacturing features by a feature based design environment is the pre-requisite for an automatic generative process planning system. Taking that in consideration the feature based design prototype, FINDES [4, 6], was developed to prove these concepts. Some of the results will be presented in the following topics.

2. TECHNOLOGICAL AND SHAPE INTERDEPENDENCIES

An initial analyse of the technological and shape interdependencies among manufacturing features permits to classify them in two main groups: explicit and implicit interdependencies.

An explicit interdependence has a technological or a topological explicit constraint relating to two or more manufacturing features. A typical example for a technological interdependence is a position tolerance of concentricity between two holes for ball bearings in a gear box. This technological attribute results in an explicit technological constraint for the machining of the part, that must be taken in consideration during the process planning task.

An implicit interdependence considers the case where the related manufacturing features do not have any explicit technological or topological constraint, however due to the design or the machining of the part a constraint was established (see figure 4).

Taking in consideration the conceptual differences among an explicit technological and a topological constraint, the interdependencies among manufacturing features will be subdivided in three groups [4]:

- technological (explicit) interdependencies: are the explicit interdependencies resulted from the technological attributes of the part, as in the case of a position tolerance relating two manufacturing features;
- shape (explicit) interdependencies: are the explicit interdependencies resulted from the shape of the part and the topological relationship among the manufacturing features, for example, when a Hole is positioned in the bottom surface of a Pocket (see figure 3 c);
- implicit interdependencies: are the interdependencies that result from an implicit constraint among manufacturing features (see figure 4).

2.1. Technological Attributes and Technological Interdependencies

The feature based design environment, FINDES, supports the designer by the input of the following technological attributes and recognises automatically the resulted technological interdependencies:

- general technological attributes: material, general tolerance and heat treatment for the whole part;
- feature based technological attributes: dimensional tolerance, form tolerance, position tolerance, surface quality, heat treatment applied to a manufacturing feature.

The first kind of attributes is defined to the whole part and does not result on specific interdependencies among manufacturing features, therefore it will be not considered in this paper. The whole concept and implementation of this kind of attributes can be found in [4].

The feature based technological attributes will be divide in two groups, considering the structure of the Feature Based Part Model (see topic 3). In the first group are the technological attributes, that are related to a parameter or to an element of only one manufacturing feature. In the second group are the technological attributes that define a relationship among elements of two or more manufacturing features.

Considering this classification it is necessary to distinguish to kinds of dimensional tolerance. The first kind, internal dimensional tolerance, will be applied to a parameter of a manufacturing feature. The second kind, external dimensional tolerance, will define the tolerance for a measure between two parallel elements of two different features and, therefore, defining an interdependence.

Resulting from the above considerations, the first group of technological attributes will include: internal dimensional tolerance, form tolerance, surface quality and heat treatment to a manufacturing feature element. These information are referred to a parameter or to an element of a manufacturing feature instance in the Feature Based Part Model (figure 5).

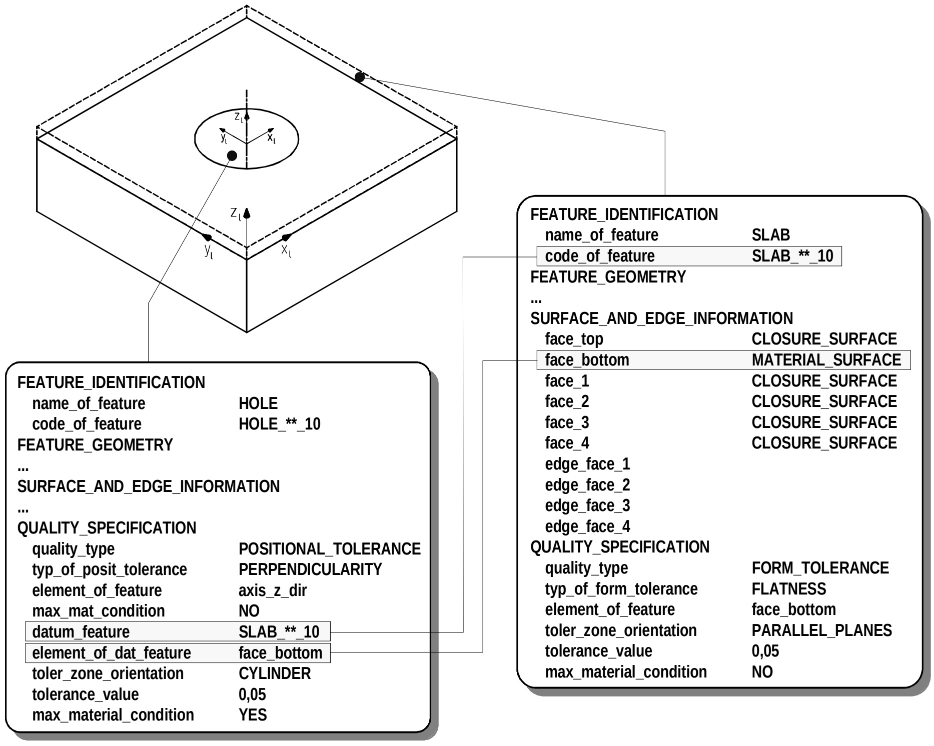

Figure 2: Tolerance attribute and the resulted technological interdependence

The technological attributes of the second group are: external dimensional tolerance and position tolerance. These attributes tolerate an element of a manufacturing feature instance in relationship to one or more elements of others manufacturing feature instances, therefore, they result in technological interdependencies that will be automatic recognised and managed by

FINDES. The system will verify, according to the available intern tolerance knowledge, if the feature elements and the tolerance specification are coherent, as, for example, by the definition of a perpendicularity. In this case FINDES will verify if the tolerated element and the referenced element are really perpendicular and if the tolerance value is coherent to the used values. The figure 2 shows an example of a technological attribute and the representation of the resulted interdependence.

This information is fundamental for the process planning systems to decide about the correct machining sequence and it is represented in the Feature Based Part Model (figure 5).

2.2. Shape Interdependencies

In the literature it is possible to find references to shape interdependencies among features [7]. However, the main focus of those works is the topology of the part. They consider problems as the split of faces and the generation of new edges, as in the case of the intersection of two perpendicular Slots or the intersection of a Hole with a Pocket as shown in figure 3 d. However, the focus of this work is the recognition, the representation and the management of interactions from the machining point of view. The decision about the positioning of the manufacturing features during the design process belongs to the designers. FINDES will validate each feature instance considering its parameters, elements and manufacturability [4].

The shape interdependence is originated during the design process by the instantiation of the manufacturing features available in the feature library and refers at least to two feature instances. In this work they are classified into two groups according to the type of features involved in the interaction.

♦ ***Interdependence among implicit and explicit manufacturing features***

The implicit manufacturing features will be instanciated in dependence on the elements of an explicit manufacturing feature, i.e., an implicit surface feature as a marking (Knurl) can be instanciated in dependence on a surface element of a manufacturing feature, or an implicit edge feature (fillet, chamfer) in dependence on an edge element (see figure 3 b).

Those interdependence and the parameters of the implicit manufacturing feature will be represented in the Feature Based Part Model linked to an element instance of an explicit manufacturing feature (see figure 5).

This kind of interdependence will be recognised by the instantiation of the implicit manufacturing feature in dependence on an explicit feature. Therefore, it will not demand any other recognition procedure.

♦ ***Interdependence among explicit manufacturing features***

The possible interdependencies among explicit manufacturing features are shown in figure 3 c, d and e. The pattern of manufacturing features (figure 3 a) can as well define a shape interdependence. However, in the concept developed by the authors, the pattern features will be treated as an individual manufacturing feature [4]. Hence the parameters that define the relative distance and positioning of each basic object, also a manufacturing feature, will be considered as parameters of the „pattern manufacturing feature“.

The shape interdependencies defined in figure 3 c, d and e are defined through a surface or a volume interaction.

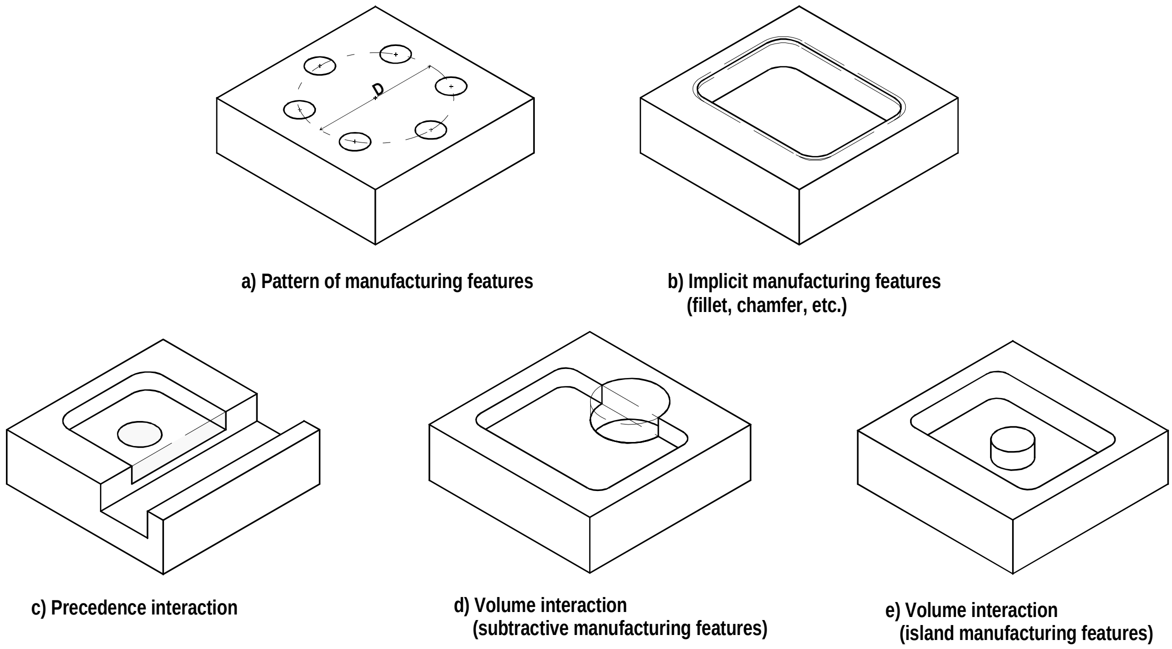

Figure 3: Types of shape interdependencies

The interaction among surfaces elements of subtractive manufacturing features will be always among a virtual surface element of a dependent manufacturing feature and a real surface element of a precedent manufacturing feature. This kind of interdependence defines a precedence interaction that must be considered by the process planning system to determine the correct machining sequence. Therefore, they must be recognised by the system and represented in a feature based part model to be used by the process planner.

The FINDES prototype has procedures to verify this kind of interaction among the virtual and the real surfaces for each instantiated or modified manufacturing feature. This interaction will be managed during the whole design process and represent in the Feature Based Part Model for the following integration with a CAPP system.

The volumetric interaction among subtractive manufacturing features does not define a precedence interaction, however the recognition and representation of this interdependence can be very useful for the process planning system. Taking this information in consideration the CAPP system can combine both canonical feature volumes [4, 8] and calculate the resulting material to remove, that can be machined in a shorter time.

Considering the machining constraints of a 3-axis machine the interaction among an additive (protrusion) and a subtractive manufacturing feature will be initially considered valid only when the protrusion feature is positioned in the bottom surface of a subtractive feature as shown in figure 3 e. In opposite to the surface interaction presented above, this kind of interdependence also does not define a precedence interaction by the NC machining; the protrusion feature will be treated as an island object in the subtractive feature that represents the material to be removed.

During the recognition process of the interdependencies among features the manufacturability of each individual manufacturing feature is also verified. When due to modification or instantiation of a new feature an existing manufacturing feature can no more be completely machined with the available production means, or the semantic of this feature was modified, FINDES will inform the occurrence to the designer and will ask for a decision.

2.3. Implicit Interdependencies

The implicit interdependence is defined by an implicit relationship among two or more manufacturing features. The related features do not have any kind of topological relation, therefore the automatic recognition is very complex and demands high computing time.

This kind of interdependence can, for example, be defined through a characteristic of the shape, that is the case of the thin wall between the Slot and the Pocket in the figure 4 a, as well as through a technological characteristic, that is the case of the interaction produced during the generation of the NC toolpath to machine the pocket in the figure 4 b.

This kind of interdependence can also have influence of others non geometrical attributes. This is the case of the mentioned thin wall, which critical value depends on the material and on the machining conditions. As well as the interaction of the NC toolpath that can be eliminated by choosing a very small tool diameter.

Some of the implicit interdependencies can be automatically recognised and represented in the feature based part model. This is the case of interdependencies resulted from interactions of the NC toolpath. By the verification of the manufacturability of each manufacturing feature FINDES can identify a collision between the tool and the part. This is the case of the Boss placed in front of the virtual surface of the Pocket in the figure 4 b. However, the actual FINDES prototype can not recognise all kind of implicit interdependencies, therefore the system offers to the designers the necessary support to identify those interactions and to represent them in the feature based part model. The designers identify the related features through the graphical interface and afterwards choose the type of the implicit interdependence to be assigned to the interaction.

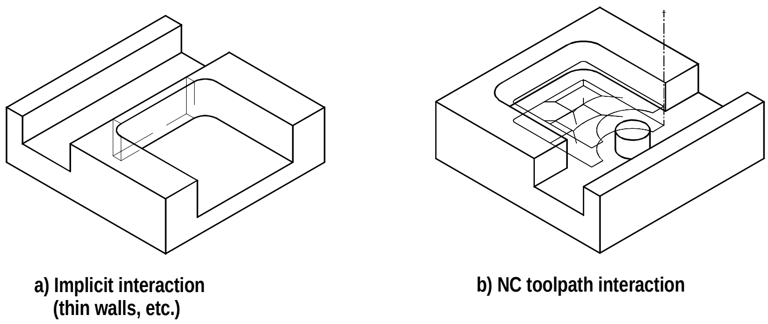

Figure 4: Implicit interdependencies

3. REPRESENTATION OF TECHNOLOGICAL AND SHAPE INTERDEPENDENCIES

The FINDES prototype utilises an external geometric modeller for all the geometric modelling functions. The available geometric modeller by the implementation of the system did not offer an object oriented data base, that could be used to implement the planned Feature

Based Part Model. Therefore, the adopted solution was to work with two data base: one for the geometrical representation and one for the feature based representation of the part. Both data basis are managed simultaneously providing always the actual representation of the part in design.

Considering the good and reliable programming language interface of the CAD/CAM system EUCLID3 of Matra Datavision, this system was chosen for the implementation of the actual FINDES prototype.

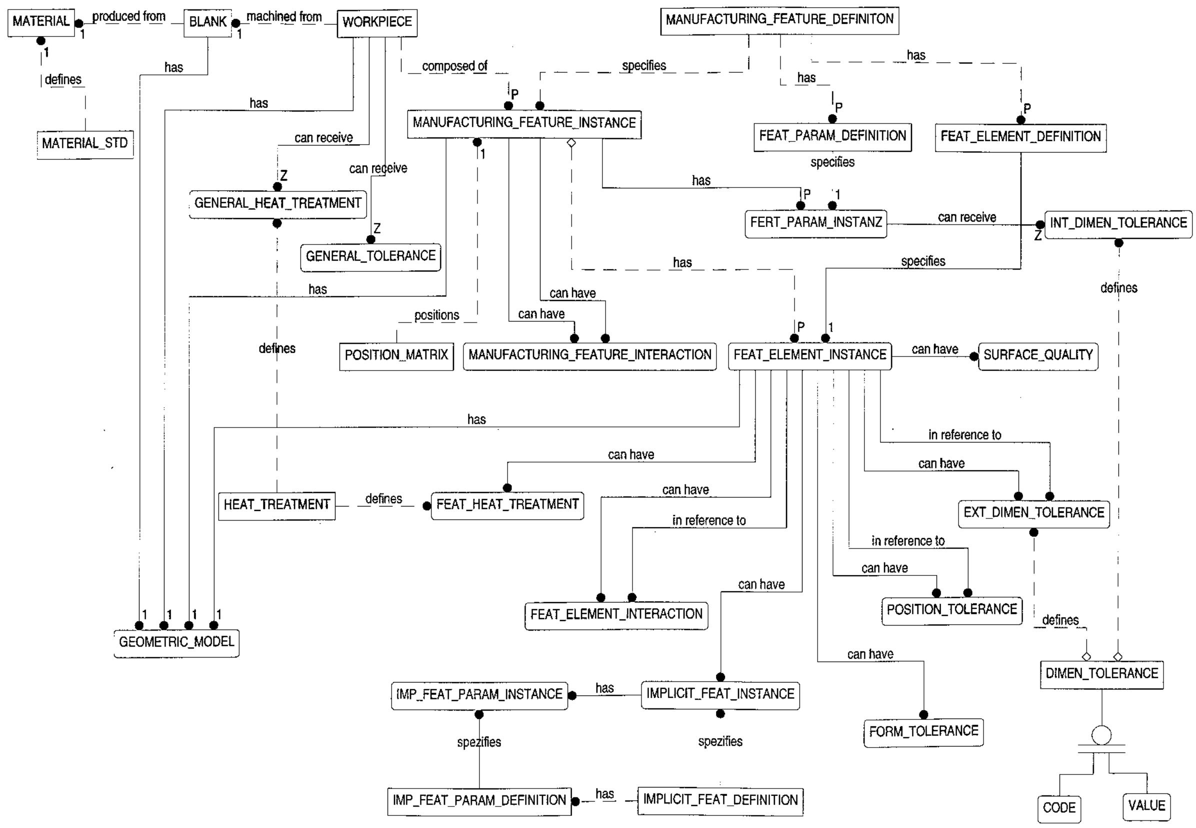

Figure 5: Feature Based Part Model (IDEF1X Diagram)

One of the essential issue of this work is the integration of the design (CAD) with the following CAx systems (CAPP/CAM) and the core of this integration is the Feature Based Part Model. Based on the requirements for this integration the Feature Based Part Model (see figure 5) includes the following information:

- the representation of the blank and the material specification;
- the general attributes of the part as general tolerances and heat treatment for the whole part;
- the representation of the part based on the explicit and implicit manufacturing features;
- the representation of the technological attributes based on the manufacturing features;

- the representation of the technological, shape and implicit interdependencies among the manufacturing features;
- the relationship to the geometric model of the blank, the final part, the manufacturing features and their feature elements.

The figure 5 shows the entity level of the Feature Based Part Model. The definition of the manufacturing features, together with the definitions of their parameters and elements are represented at the highest level. These definitions specifies the feature instances during the design process. Entities for the representation of the technological attributes based on features and the interdependencies among manufacturing features are connected at the level of the feature instances.

The technological interdependencies (external dimensional tolerance and position tolerance) as well as the shape interdependencies (interaction among surface elements) define a relationship among feature element instances and a precedence interaction. Therefore, in the part model they will be assigned to the related instances of manufacturing feature elements. This concept is also applied to the implicit manufacturing features, which will be instantiated in relation to a feature element.

Finally, the volumetric interaction among manufacturing features and the implicit interdependence, as already mentioned, does not define a precedence interaction and is not related to a feature element, therefore it will be represented through an entity relating two or more manufacturing feature instances.

The concept of the Feature Based Part Model supports additionally the representation of the initial state of the part (blank) and all the intermediate states of the part during the manufacturing process. In this way this information can easily be used for the fixturing planning and for the documentation of the process planning.

4. INTEGRATION OF OPERATOR EXPERIENCE KNOW-HOW

The various approaches of feature based planning and design systems are characterised by a strict division of labour between the planning departments and the manufacturing (Figure 6). In the preliminary areas preceding manufacturing, all required geometrical, technological and strategic data are prepared and furnished to manufacturing in the form of NC programs as per DIN 66025[9]. In the NC program, geometrical data and strategic information are merely contained implicitly in the form of distances to be travelled. The transition from the defining data to an NC program results in heavy losses of information.

The NC program is no longer generally valid, but rather is generated for a particular control system or machine. The opportunities of making modifications are thus heavily restricted and can be made only with a lot of effort [9]. However, to enable the skilled worker to react flexibly to unforeseen situations and to bring his experience know-how to bear, he needs to have access to all planning data from the preliminary areas. The studies conducted within the WesUF[1] project allowed to identify the following typical critical situations in which the skilled worker is given insufficient support [10]:

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[1] WesUF = German research project „ action-oriented solutions for machine tool control systems to support experience-guided and team-susceptible skilled labour“

- assimilation of machining programs as per DIN 66025 is time-consuming and cumbersome due to lack of transparency and structure;
- modification of machining programs before or during the pre-production stage is frequently necessary due to deviations from predetermined features (such as different positioning of clamping elements, non-availability of tools scheduled, variations of cast blanks);
- scheduled machining sequences in the NC program are not optimum for manufacturing, but cannot be adapted in the short term due to lack of structure;
- short-term rescheduling on other machines involves great effort and therefore is made in rare occasions only since NC programs are generated for a particular machine in each case;
- quality assurance is complicated by the great effort involved with the adaptation of measuring protocols and machining programs;
- work documentation is inadequate due to increased complications in protocolling of machining and process data and to the difficulties involved with their situation-specific evaluation;
- modified NC programs can be fed back to the preliminary areas with great difficulty only.

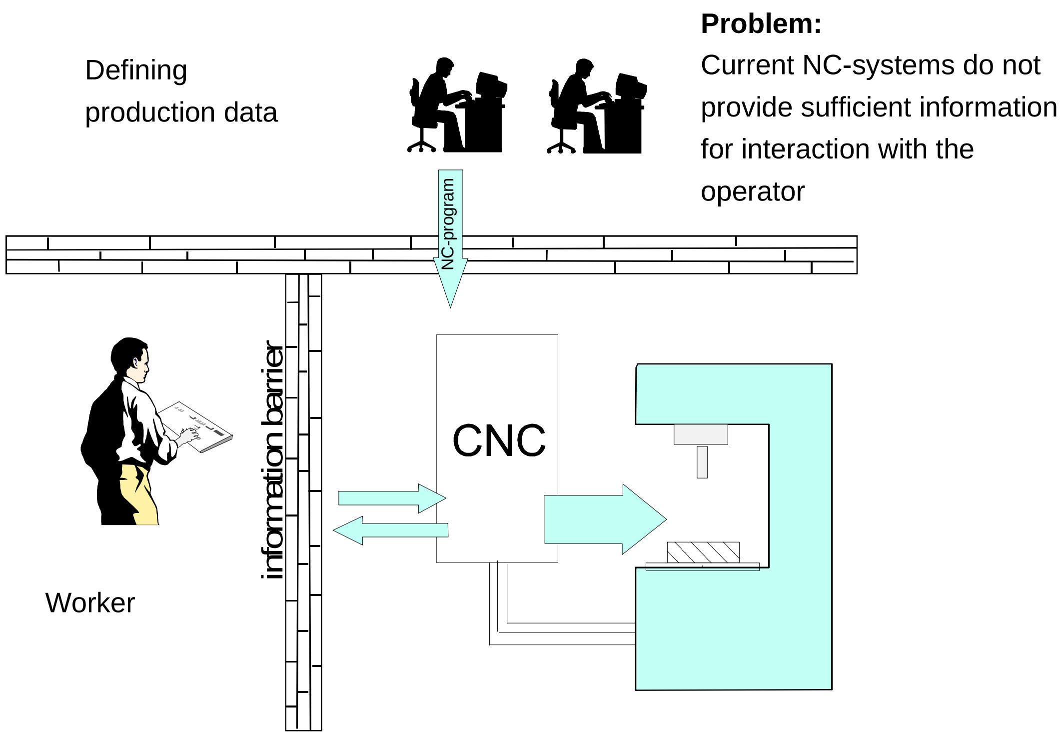

Figure 6: Classic NC process chain with barriers

Skilled workers have to put in considerable effort to cope with such critical situations. However, they are barred from making decisive interventions, so that there is no opportunity for benefiting from their experience know-how and competence. In order to eliminate this deficit, it is necessary to integrate the manufacturing in the feature based process chain.

4.1. Concept of free handling of work at the machine

Since the interface between preliminary areas, worker and process always is the control system, improvement of the NC process chain must be made exactly at this point. In place of the data flow in the form of a „one-way passage“ from the planning areas to manufacturing, a feature based part model as shown in figure 5. for all areas involved must be installed. In this event, the preliminary areas furnish the basic input in the form of geometrical data and work schedules. The skilled worker will then modify and optimise this information in the machine or will add missing information (Figure 7).

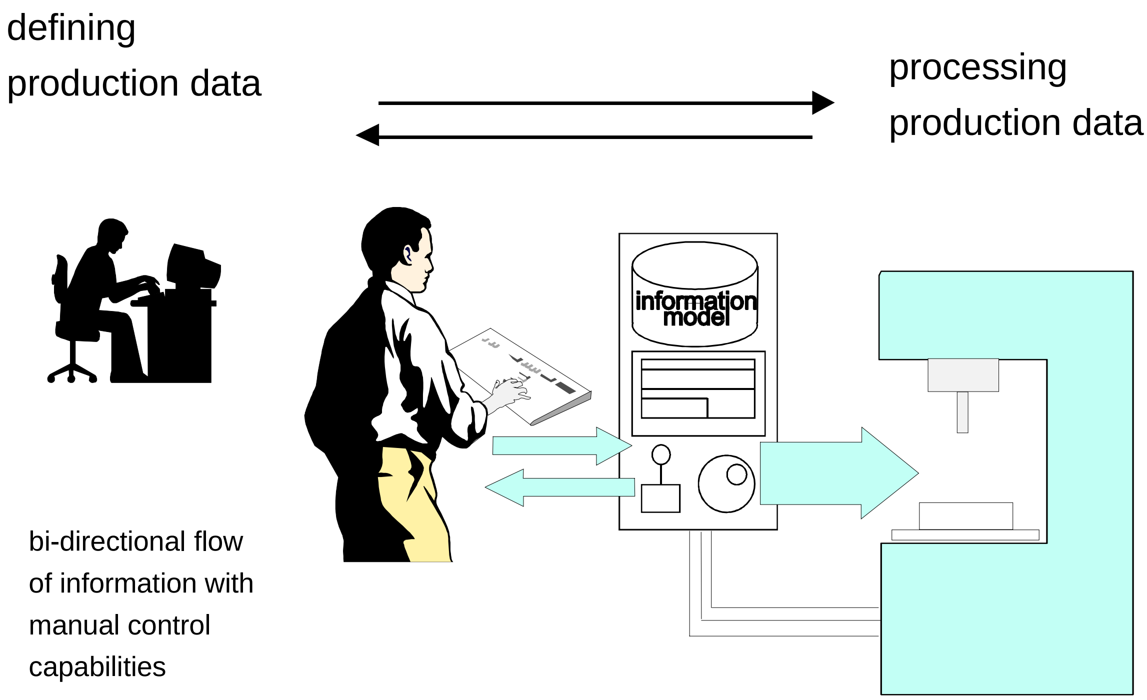

Figure 7: NC process chain with central feature based part model

His action-oriented and experience-guided intervention in product generation must be supported without allowing any restriction from rigid predetermined data or from technology.

4.2. Structure of the feature based part model of WesUF

The feature based part model developed in the WesUF project is based on machining objects combining individual machining areas to form encapsulated units. Machining objects thus are constituted by a geometrical description, the technological and strategic information for machining, and the tool used.

Existing approaches to the description of features in STEP [11] have been included in the development for defining the machining objects used. As in STEP, the feature based part model is made up in EXPRESS or in EXPRESS-G for its graphic representation and is available as a C++ classification library. The choice of the objects defined here is restricted to prismatic elements such as bores and pockets.

For calculating the metal removal volume, the volume balance between blank and finished product is calculated for the area of the machining object. The basis used is the three-dimensional geometry model established in design engineering which does not yet include any feature elements. The definition basis used is a selected surface of the finished product. Starting from this, the limiting lateral surfaces of the product geometry are searched automatically, or in the case of open pockets the metal removal volume is extended up to the blank boundary.

One or more machining operations are assigned to each machining object. A machining operation is composed of the technology, the strategy and the tool data for a machining operation performed by a single tool. In conjunction with the geometrical description of the machining object and with the machine-specific data, this information is used for generating travels (see Figure 8).

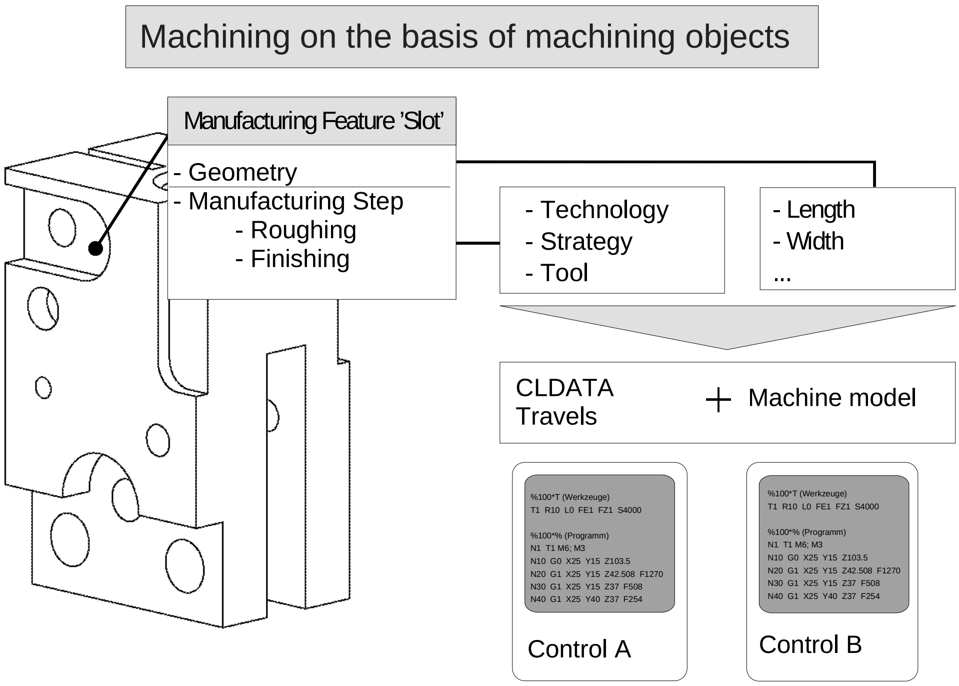

Figure 8: NC machining on the basis of machining objects

Since the machining operations are not run in the sequence of the machining objects, but rather according to sorting criteria such as particular machines, tools or short travels, the feature based part model is structured by further schemes of order (see Figure 9). All machining operations to be run on a machine are compiled in the machine model. In addition, such machine-specific parameters as thermal correction values or drag errors can be included in this model. The partial machine model includes all of the machining operations to be run in a single set-up. This partial machine model therefore contains transformation vectors for correct definition of the geometrical description of the machining object.

Since nowadays control systems are only able to interpret NC code, a migration solution currently used is to generate NC code in the background as per DIN 66025 from the information for machining objects and operations and to feed this to the control system. Due to the fact that these partial programs are no longer independent from the machine, they are only generated from travels during machining and are deleted again after machining.

In contrast with the classic process chain, the manipulation media available to the machine operator are not the travels, but he rather has direct access to the machining objects and operations mentioned. The coded form of travels, on the other hand, remains concealed from the user and is processed only internally within the control system. For the purpose of checking, the operator can have the travels displayed to him in graphic form. However, modifications are made only in the machining objects or operations. This way it can be ensured that the data of the feature based part model remain consistent.

4.3. Interlinking of planning and performance

Combining the advantages of modern NC technology with the principles of action orientation permits the previous separation between planning and performing to be eliminated. The feature based part model offers the skilled worker new and requested opportunities of intervention during machining. The need for opportunities of manipulation is particularly high during the running-in phase of new programs. This allows the skilled worker to test the predefined strategy of a machining operation and to optimise it freely as required. In order to support the worker in choosing tools or cutting strategies the representation of interdependencies between features are necessary. In this way only changes are possible, by which other features are not concerned. While conventional systems at best permit speed and feed to be modified easily, it is now possible to modify the entire strategy or technology for a machining object. Skilled workers can thus verify or define machining in an explorativ manner by consecutively defining and running the machining operations for a machining object. The experience gathered from machining operations already run can be transferred into the operations to be newly defined.

4.4. Structured representation of the machining program

The object-oriented description of the machining program by an feature based part model provides an excellent basis for representing the program to the user in a structured manner. This involves representation of machining features and machining operations in a priority graph (such as the structure tree under Microsoft).

Variation of the sequence of one or more machining operations can then be made simply by moving various objects within the tree. Interdependencies incorporated in the definition of the machining operation prevent illogical arrangements (such as „drilling“ before „centering“) or force the system to recalculate the cutting volumes in case that they are dependent on the sequence (see Figure 3 c).

4.5. Short-term modifications in production

Deviations of a planned machining situation from the situation actually found on site are everyday occurrences on the shop floor. Such situations become critical in conventional systems due to the fact that both recognition of the difference and subsequent adaptation of the manufacturing situation described in the NC machining program to the actual situation are complicated. Relevant deviations are as follows [12]:

- Clamping fixtures are located on the workpiece in places different from those scheduled. Since the location of the clamping fixtures and the travels adapted to these are not interlinked in the NC program, a deviating location cannot be recognised and in particular cannot be corrected by means of a simple text editor as normally available in control systems. In contrast with this, the feature based part model provides a representation of clamping fixtures for each set-up (partial machine model). The clamping elements are described both geometrically and in location (transformation). Inasmuch, they can be represented at the graphic level of the control system and can be modified in number, location and position. During generation of the travels, the clamping elements are specified as contours not to be violated. For the modified set-up, the appropriate machining operations must then be recalculated.
- Using different tools as planned in the CAPP the recalculation of rest material like shown in Figure 1 is necessary. This is assured by the representation of the interdependencies.
- Scheduled tools are not available or not optimally suited for the case involved. Due to the lack of searching mechanisms in control systems, the machining locations in which a tool will be used do not become apparent. In contrast with this, the object-oriented structure of the feature based part model provides for tool-related aspects listing all machining operations for the tool involved. This list can also be established to encompass all set-ups for the machine.
- The workpiece dimensions used in the machining program deviate from those actually required. Updating the NC program requires a lot of adaptation effort since the dimensions are coded and are available only as co-ordinate data for the travels. With access to the geometrical data of the blank, these can be corrected with ease. The new blank dimensions can be used for recalculating the metal removal volumes for the machining objects and for redefining the cut distribution correspondingly. This also permits additional cuts to be introduced into machining without any problem.

4.6. Filing of experience values

The studies [13] have shown that, depending on quality requirements and manufacturing situations, skilled workers specify machining processes and technology values deviating from those scheduled. These experience values comprise a great amount of know-how needing to be documented. Filing and transfer of experience values, for instance between colleagues in a shift but also within preliminary and subsequent departments, have hardly been supported by existing control systems. These rather used to involve „pencil and paper work“. By adding documentation components to the features and machining operations, such experience values are associated directly with the case involved. Commented machining operations or objects are then graphically marked. This permits critical areas to be identified faster during application of the programs.

This support of information transfer also means an improvement of co-operation encompassing all departments along the NC process chain. Improving the co-operation, for instance, between design engineering and shop floor is considered to be a necessity. A barrier is constituted here by different ways of thinking and acting. While design engineers primarily hold a vision of the function a component will have to fulfil later, it is the technology of manufacturing the component that is in the foreground during production. This discrepancy has in the past even been cemented by the use of different tools. For instance, design engineers work with CAD systems which differ widely from the NC programming systems. A consistent language is therefore urgently required, and this can be established by a jointly used feature based part model.

4.7. Short paths between programming, running and documenting

An important requirement of action orientation is to maintain short paths between the various operating areas of programming and running the program [14]. This is the direct way of making the link between planning and performance become reality. The object-oriented structure of the feature based part model allows this requirement to be accounted for. As soon as an individual object is fully defined, it can be run in production. Correspondingly, the control interface is such that it is possible both to access the data of the machining operations and to perform the machining operations themselves from one user level. Similarly, the comments from the same user level are called up in the priority graph by selection of the machining operation involved.

5. RESULTS AND CONCLUSIONS

FINDES was implemented using the design by feature methodology, being its features library based on manufacturing features. This combination and all the additional design and manufacturing support provided by the system has been proved to be a tool that shows the possibility to improve the design methodology and a decisive step in the direction of the integration of CAD/CAPP/CAM systems.

The designer does not need anymore to deal with low level geometry. FINDES supports the design with a new semantic based on the elements used to produce a real part, which are related to a high level geometry. The design modifications will also be realised through those elements resulting in the reduction of the design time. The definition of technological attributes will also be assisted by the system and the resulted part model based on a manufacturing feature description can be transferred to a CAPP system without any additional treatment.

The figure 9 shows the additional support provided by FINDES to the process planning system. Considering the manufacturing features interdependencies FINDES identifies the appropriated tool types and determines the maximal size of the tools for the complete machining of the feature without collision with other manufacturing features.

The tests that have been done designing real part using FINDES and using the standard tools of a CAD system resulted in a significant time reduction [3, 4]. Additionally, FINDES has the advantage that a feature based part model is generated eliminating completely the necessity of feature recognition or further input of the technological attributes to the process planner. Considering the whole integration - design/planning/manufacturing - the time reduction provided by the system is still more significant. This encourages further developments of FINDES.

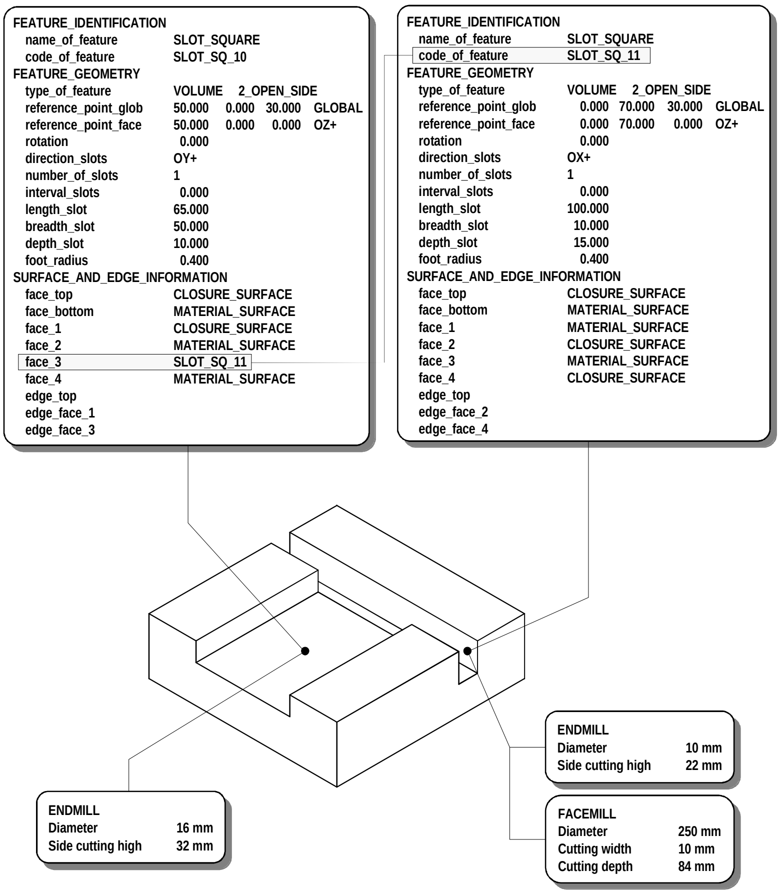

Figure 9: Information to the process planning: manufacturing features, interdependence, tool type and maximal tool size

The new method of machining description of WesUF on the basis of features and machining operations permits considerably better handling of machining programs and uncomplicated integration of experience know-how of skilled workers.

The essential benefits are as follows:

- information along the NC process chain can be exchanged bi-directionally. By representation in a common data model (feature based part model), the know-how introduced from the experience of skilled workers can now also be made available to the planning departments via feedback;
- due to clear information structure, the skilled worker can concentrate better on critical situations (such as fast tool changing in case of tool failure) and thus can improve process control decisively;
- based on their experience, skilled workers can without difficulty modify NC programs fast and with ease;
- modifications or redefined machining sections can be evaluated immediately, so that experience gathered can be introduced into subsequent machining sections;
- access to planning data is considerably facilitated due to the structure into machining objects and operations;

- working jointly on the basis of a data model also creates a consistent and redundancy-free description of the machining tasks;
- definition and documentation of machining are made in a single data model and thus are associated.

By the integration of both systems the support of the machine operator will be increased dramatically. By identification of the interdependencies the common system of FIRES and WesUF will offer only such variations of the workplan, which are possible according to means of machines and tools.

6. ACKNOWLEDGEMENT

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