Support of the Development Process Chain by Manufacturing Features

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Abstract

The feature based design environment of FESTEVAL supports the users during the design process through a manufacturing feature based design interface. The instantiated manufacturing features are automatically 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 FESTEVAL identifies the shape and technological interdependencies. All the determined manufacturing feature interdependencies are managed by the system and represented in a Common Data Model. These interdependencies are necessary for the determination of the manufacturing operations sequence and for the automatic generation of the NC program. 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 Common Data Model, consisting all information of design and planning, including the interdependencies among 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

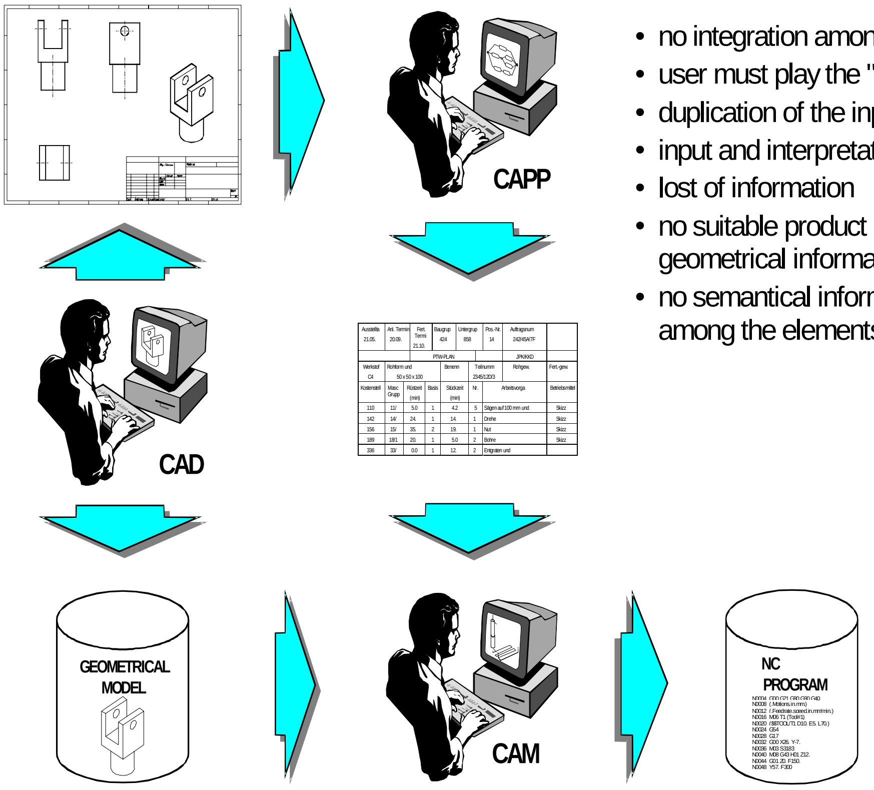
Due to the increasing need for computer systems support during all phases of the product life cycle, a lot of computer aided systems have been developed and used during the last years [1]. They are usually specialised to support a specific application and are designed based on their own individual information model representing their particular application domain view on the product. As a consequence, these application systems build islands of automation and as such do not allow the joint use of the product data described by those information models.

Especially considering the current situation, that the activities within the process chain of product development become more and more distributed not only among several companies but also among companies working in different locations all over the world, the information flow among these activities needs to be improved in order to be more competitive in the future [2].

Most actual CAx-Systems (CAD, CAPP, CAM, CAQ, etc.) offer only local solutions and support for the users in their application area (detailed design, process planning, NC programming, etc.). In the case of most commercial CAD-Systems, e.g., the designer will be aided to model the geometric shape of a product only; the semantical and technological information, such as thread information or shape and positional tolerances, surface conditions, etc., are not represented in the geometrical model and, as a consequence, are treated as text or annotation in technical drawings only. The resulting lack of semantical and technological information within the geometrical model is the reason that computer integration with subsequent CAx - systems in the process chain of product development such as CAPP-systems cannot be supported [3, 4, 5].

In the case of CAM-systems the situation is very similar. Initially the user must re-define all the information that is missing in the geometrical model with the risk of wrong interpretations or typing mistakes [6]. At the end of the repetitive process of identifying manufacturing regions, getting tolerance specifications from drawings, etc. the planner will generate NC-codes that are sent to the shop floor to manufacture the part.

This situation forces the system user to play the role of an integration function by himself (see figure 1). He must redefine information which is necessary for his phase of the product development although this information was already available in the systems of earlier phases. Also the current architecture does not support the contribution of the various expertise available along all phases of the process chain of product development in order to improve the product and to correct mistakes in the earlier phases. As a result this situation hinders the implementation of simultaneous engineering concepts.



- no integration among the systems
- user must play the "integration interface"
- duplication of the inputs, data and models
- input and interpretation mistakes
- lost of information
- no suitable product model (only geometrical information)
- no semantical information and relationship among the elements in the part model

Figure 1: Conventional process chain of the product development

2. Requirements to an integrated process chain from the shop floor

Down at the shop floor, the situation is even worse. The machine operator does not have efficient support to operate and optimise this NC-code according to his expertise. The only resource of optimisation consists of the NC Program. 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. Thus optimisation possibilities are limited to the modification of cutting parameters; more complex optimisation such as the changes of the cutting strategy are usually not feasible (see figure 2).

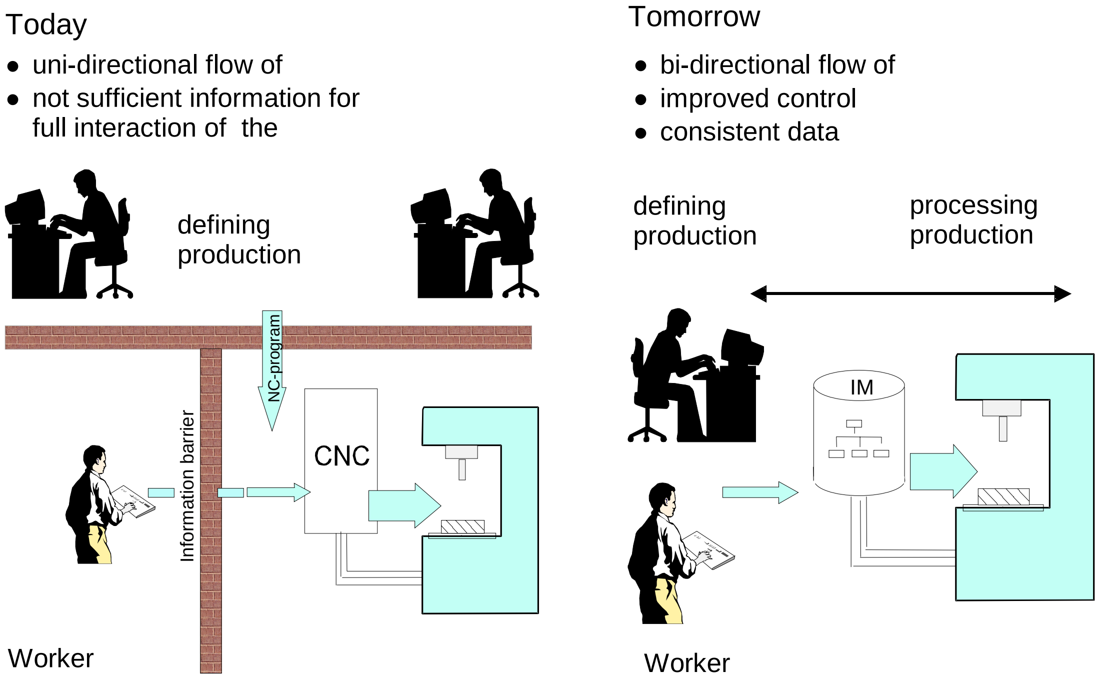


Figure 2: Information flow between shop floor and preliminary areas.

These changes of the NC-code are done by the operator in an expensive, manually way. Furthermore there is no possibility to provide feedback to the planning department in order to avoid the repetition of this process [7, 8, 9]. 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 [6]. However, to enable the skilled worker flexible to react 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 allow to identify the following typical critical situations in which the skilled worker is given insufficient support [9]:

- 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);

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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“

- scheduled machining sequences in the NC program are not the 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 provision 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.

In order to overcome these limitations the shop floor has to be integrated in the product development chain. In this way the worker gets the possibility to use all information of the preliminary areas at the machine tool.

3. Common Data Model

The approach taken in *FESTEVAL* is to define the process development chain by a Common Data Model, which serves all related areas. This Common Data Model contains all information of the design, planning and manufacturing related to a workpiece. The design determines the geometry of the workpiece, the planning department defines all necessary machining operations and organises the optimal workplan and down at the shopfloor the manufacturing is done using the same Common Data Model.

In order to handle this amount of data in an effective way an object oriented approach is chosen. This is realised by the use of manufacturing features. A manufacturing feature is a data object of a portion of the workpiece with a specific semantical meaning, like a Hole or a Pocket. The definition of a manufacturing feature consists of the geometrical description, the interdependencies to other manufacturing features, and the machining operations with the related tools, and the NC-Codes in form of CLDATA (see figure 3). The description will be based on the STEP Protocol AP214 and 224 [10, 11].

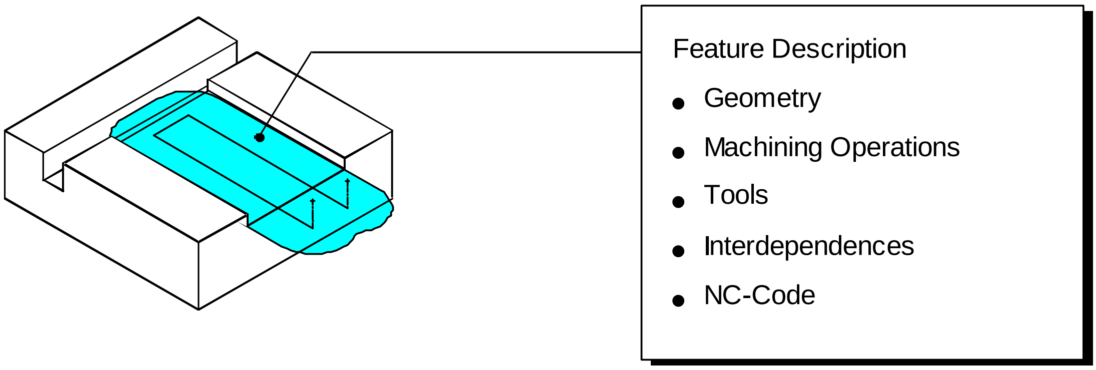


Figure 3: Description of a manufacturing feature according to FESTEVAL

In *FESTEVAL* a feature based design environment will be developed on the basis of Unigraphics Solutions. It will be based on the results of the former European research program FIRES [12] with its prototypes FINDES and FINPLAN and the German research program WesUF [13]. The design environment will supply an active support to the designer by the automatic recognition, validation, representation and management of the interdependencies among manufacturing features. This means that already in a very early stage of the design the manufacturability of the workpiece can be checked. Further on the designer not only describes the shape of the workpiece, but supplies other related tasks with semantical information of the instantiated manufacturing features. Also the technological data of the features like tolerances or roughness are added to the feature description. All information is saved in the Common Data Model (figure 4).

These information are essentially important for the automated planning of the operations. The description of interdependencies between features allows the calculation of possible tools be used. With the semantical meaning of the feature instances, the interdependencies in between them and the tool description it is possible to calculate an optimal sequence of the machining operations with a CAPP System, which contains no geometrical kernel. The optimised sequence is also included in the Common Data Model by the partial machining model.

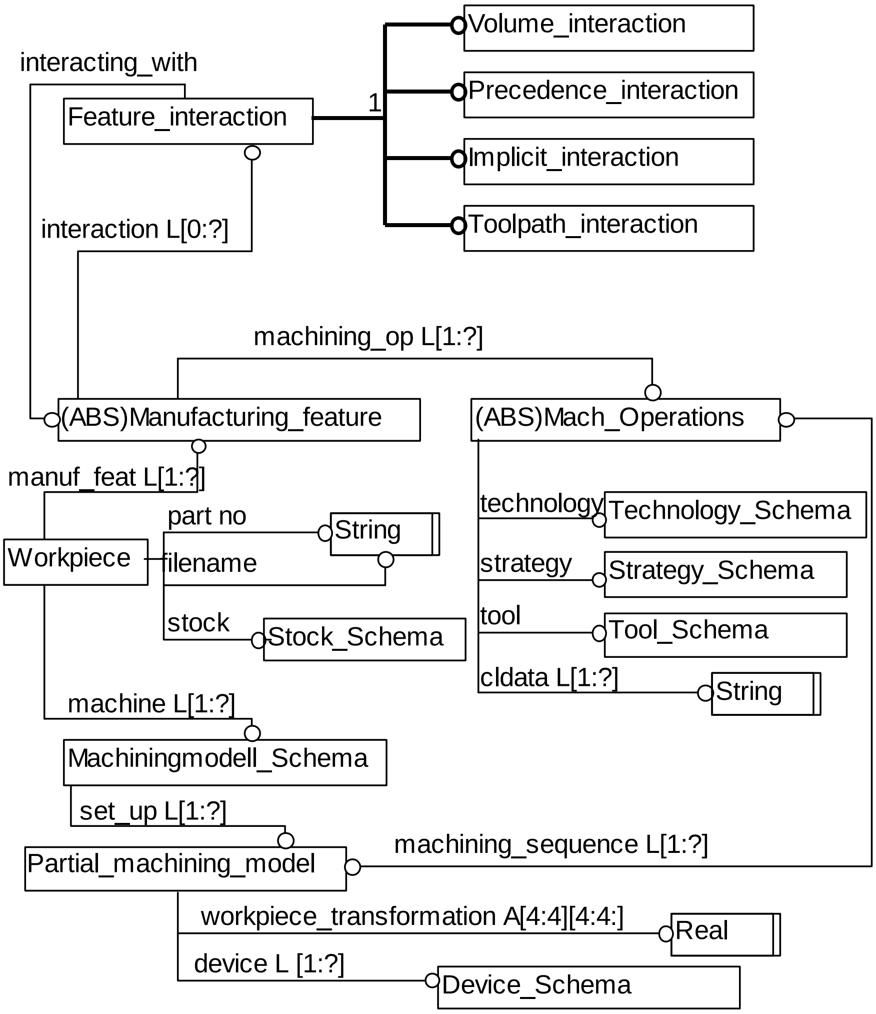


Figure 4: Common Data Model of FESTEVAL in EXPRESS-G [14]

4. Technological and Shape Interdependencies

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 [3, 4]. 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 7 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.

Most CAPP systems do not have a geometric core. Therefore, it is necessary that the feature based design environment supports the CAPP, if some kind of geometric reasoning is necessary to take a machining decision; for example, in choosing the size of the tools. Figure 5 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.

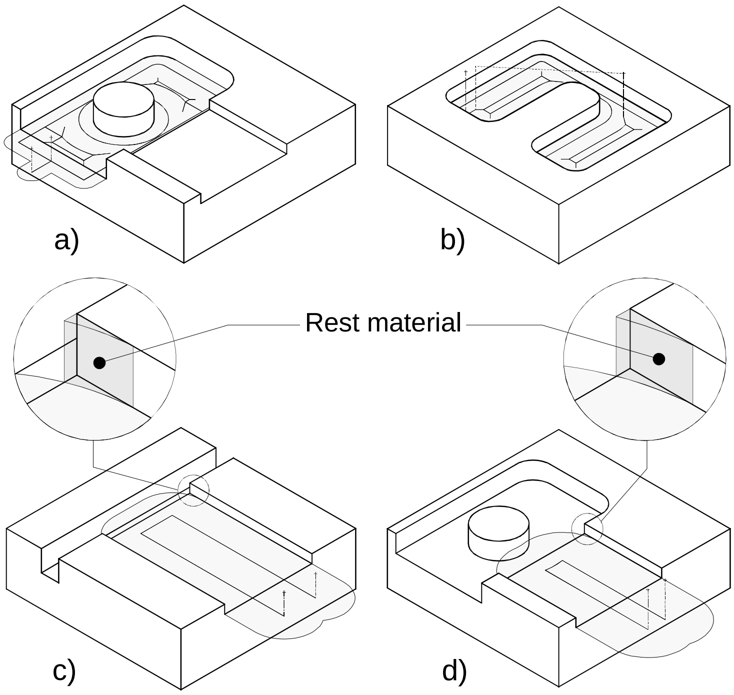


Figure 5: Examples of machining constraints: a) volume interaction; b) concave pocket; c) precedence interdependence; d) implicit technological interdependence

Therefore, the recognition, validation and representation of the interdependencies among manufacturing features by a feature based design environment is the prerequisite for an automatic generative process planning system. Taking that in consideration the feature based design will be developed to prove these concepts.

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 8).

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 [3]:

- 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 7 c);
- implicit interdependencies: are the interdependencies that result from an implicit constraint among manufacturing features (see figure 8).

4.1 Technological Attributes and Technological Interdependencies

The feature based design environment 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 from 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 [3].

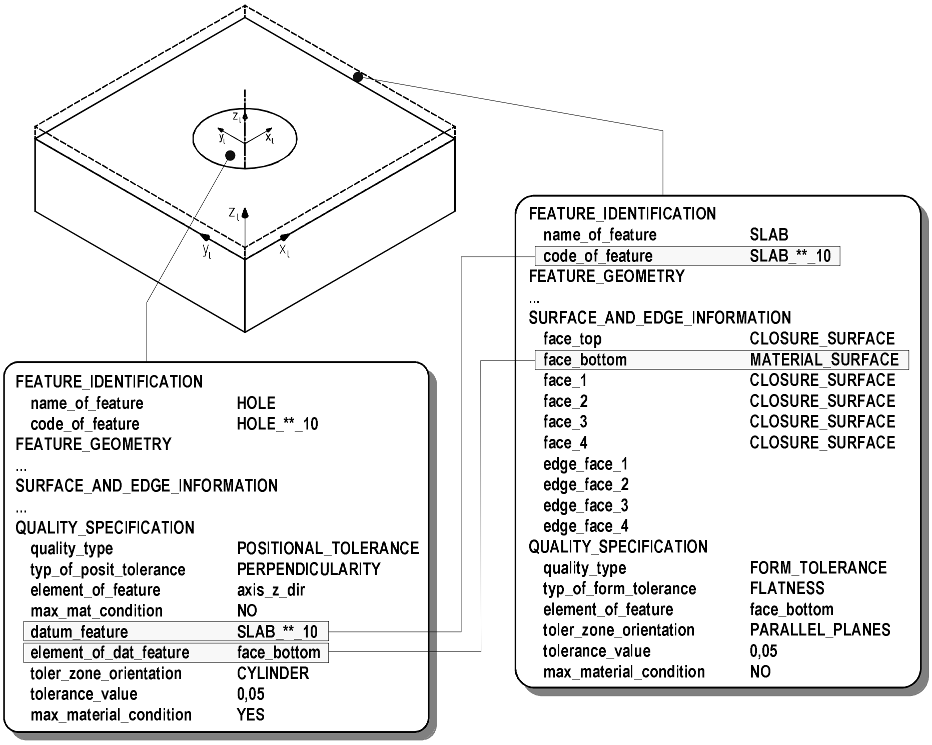
The feature based technological attributes will be divide into two groups, considering the structure of the Common Data Model (see topic 3). In the first group are the technological attributes, that are related to a parameter or to an element of only one manufacturing feature. In the second group are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

Considering this classification it is necessary to distinguish two 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 Common Data Model (see figure 4).

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 other manufacturing feature instances, therefore, they result in technological interdependencies that will be automatic recognised and managed by the design environment. The system will verify, according to the available intern tolerance knowledge, that the feature elements and the tolerance specification are coherent, as, for example, by the definition of a perpendicularity. In this case *FESTEVAL* will verify that the tolerated element and the referenced element are really perpendicular and that the tolerance value is coherent to the used values. The figure 6 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 Common Data Model (figure 4).



FEATURE_IDENTIFICATION	
name_of_feature	HOLE
code_of_feature	HOLE_**_10
FEATURE_GEOMETRY	
...	
SURFACE_AND_EDGE_INFORMATION	
...	
QUALITY_SPECIFICATION	
quality_type	POSITIONAL_TOLERANCE
typ_of_posit_tolerance	PERPENDICULARITY
element_of_feature	axis_z_dir
max_mat_condition	NO
datum_feature	SLAB_**_10
element_of_dat_feature	face_bottom
toler_zone_orientation	CYLINDER
tolerance_value	0,05
max_material_condition	YES

FEATURE_IDENTIFICATION	
name_of_feature	SLAB
code_of_feature	SLAB_**_10
FEATURE_GEOMETRY	
...	
SURFACE_AND_EDGE_INFORMATION	
face_top	CLOSURE_SURFACE
face_bottom	MATERIAL_SURFACE
face_1	CLOSURE_SURFACE
face_2	CLOSURE_SURFACE
face_3	CLOSURE_SURFACE
face_4	CLOSURE_SURFACE
edge_face_1	
edge_face_2	
edge_face_3	
edge_face_4	
QUALITY_SPECIFICATION	
quality_type	FORM_TOLERANCE
typ_of_form_tolerance	FLATNESS
element_of_feature	face_bottom
toler_zone_orientation	PARALLEL_PLANES
tolerance_value	0,05
max_material_condition	NO

Figure 6: Tolerance attribute and the resulted technological interdependence

4.2 Shape Interdependencies

In the literature it is possible to find references to shape interdependencies among features [15]. 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 7 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. *FESTEVAL* will validate each feature instance considering its parameters, elements and manufacturability.

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 instantiated in dependence on the elements of an explicit manufacturing feature, i.e., an implicit surface feature as a marking (Knurl) can be instantiated 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 7 b).

Those interdependence and the parameters of the implicit manufacturing feature will be represented in the Common Data Model linked to an element instance of an explicit manufacturing feature (see figure 4).

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 7 c, d and e. The pattern of manufacturing features (figure 7a) 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 [3]. 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“.

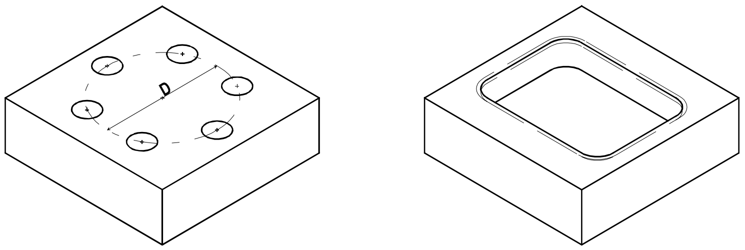
The shape interdependencies defined in figure 7 c, d and e are defined through a surface or a volume interaction.

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 Common Data Model to be used by the process planner.

The *FESTEVAL* prototype will have 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 Common Data Model for the following integration with a CAPP system.

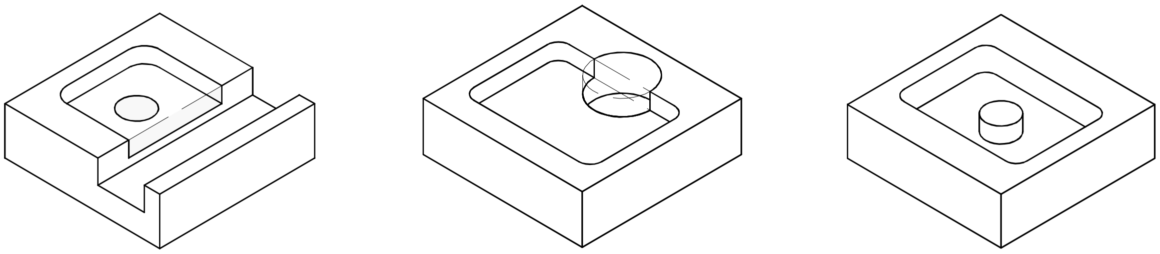
The volumetric interaction among subtractive manufacturing features does not define a precedence interaction, however the recognition and representation of this interdependence can be very useful for the process planning system. Taking this information in consideration the CAPP system can combine both canonical feature volumes [3, 16] 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 7 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.



a) Pattern of manufacturing features

b) Implicit manufacturing features (fillet, chamfer, etc.)



c) Precedence interaction

d) Volume interaction (subtractive manufacturing features)

e) Volume interaction (island manufacturing features)

Figure 7: Types of shape interdependencies

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, *FESTEVAL* will inform the occurrence to the designer and will ask for a decision.

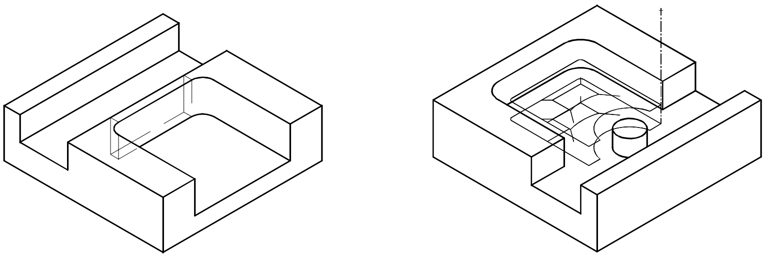
4.3 Implicit Interdependencies

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 8 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 8 b.

This kind of interdependence can also have influence on other 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 Common Data Model. This is the case of interdependencies resulted from interactions of the NC toolpath. By the verification of the manufacturability of each manufacturing feature *FESTEVAL* will be able to 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 8 b. However, the prototype will not be able to recognise all kind of implicit interdependencies, therefore the system will offer to designers the necessary support to identify those interactions and to represent them in the Common Data 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.



a) Implicit interaction (thin walls, etc.)

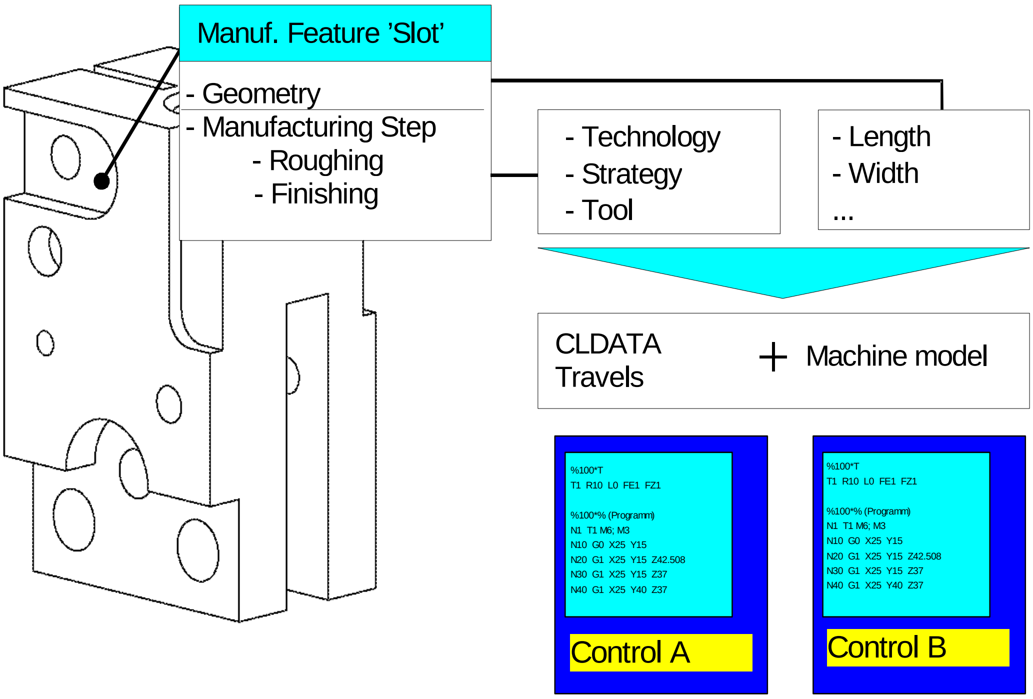
b) NC toolpath interaction

Figure 8: Implicit interdependencies

5. New Capabilities in the Shop Floor

In *FESTEVAL* the NC Code of the workpiece is not anymore transferred to the machine control in form of a specific NC Program but is included directly in the Common Data Model. The machine operator loads the Common Data Model at the machine tool in a specific feature based application, which will be developed in *FESTEVAL*. This will run at the machine control.

Since nowadays machine controls are only able to interpret NC code as per DIN 66025, this code has to be generated from the information for each manufacturing feature and the related machining operations and transferred to the numerical control (see figure 9). In order to keep the partial program independent of specific numerical controls, the travels are stored in the Common Data Model as CLDATA. For each set-up a continuous NC Program in DIN 66025 is generated at runtime out of the CLDATA programs of each manufacturing feature. Also the transformation of the zero offset of the set-up according to the workpiece origin is taken into account. 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.



```
%100*T
T1  R10  L0  FE1  FZ1

%100*% (Programm)
N1  T1 M6; M3
N10  G0  X25  Y15
N20  G1  X25  Y15  Z42.508
N30  G1  X25  Y15  Z37
N40  G1  X25  Y40  Z37
```

```
%100*T
T1  R10  L0  FE1  FZ1

%100*% (Programm)
N1  T1 M6; M3
N10  G0  X25  Y15
N20  G1  X25  Y15  Z42.508
N30  G1  X25  Y15  Z37
N40  G1  X25  Y40  Z37
```

Figure 9: Machining on the basis of manufacturing features.

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 steps 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 steps. This way it can be ensured that the data of the Common Data Model remain consistent.

5.1 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 Common Data 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 explorative 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.

5.2 Structured representation of the machining program

The object-oriented description of the machining program by a Common Data 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 7 c).

5.3 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 [9]:

- 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 Common Data 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 5 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 Common Data 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.

5.4 Transfer of experience values

The studies [9, 17] 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 needed 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 the 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 Common Data Model.

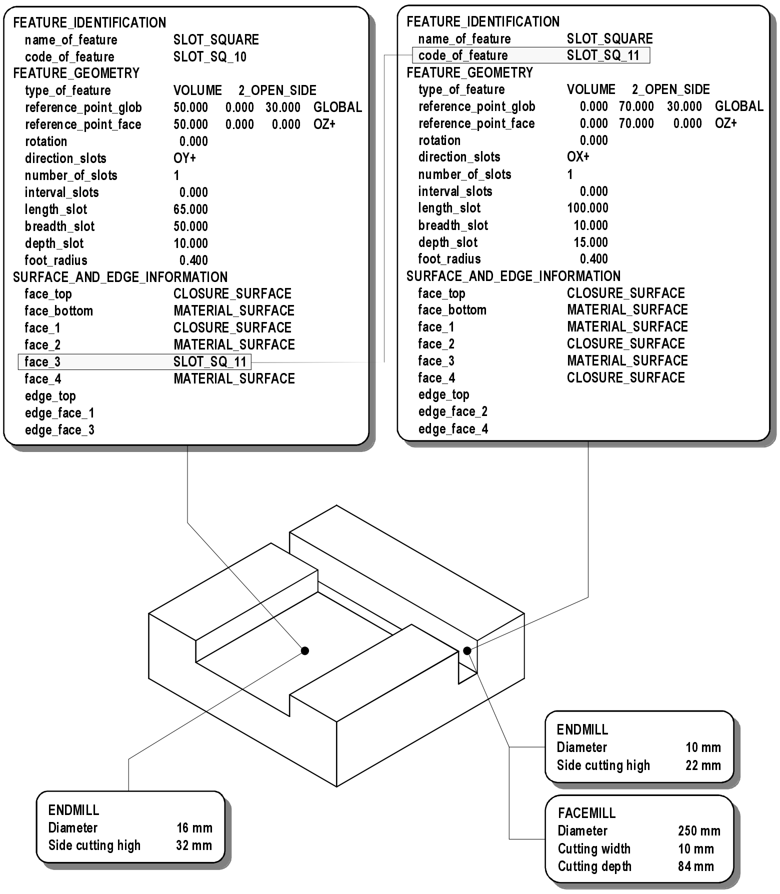
5.5 Short paths between programming, running and documenting

An important requirement of action orientation is to maintain short paths between the various operating areas of programming and running the program [8]. This is the direct way of making the link between planning and performance become reality. The object-oriented structure of the Common Data 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 makes it possible 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.

6. Results and Conclusions

FESTEVAL is using the design by feature methodology based on manufacturing features. This improves the design methodology and is 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. *FESTEVAL* 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.

Figure 10 shows the additional support provided by *FESTEVAL* to the process planning system. Considering the manufacturing features interdependencies *FESTEVAL* 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.



```
FEATURE_IDENTIFICATION
   name_of_feature          SLOT_SQUARE
   code_of_feature          SLOT_SQ_10
FEATURE_GEOMETRY
   type_of_feature          VOLUME    2_OPEN_SIDE
   reference_point_glob     50.000    0.000   30.000   GLOBAL
   reference_point_face     50.000    0.000    0.000   OZ+
   rotation                  0.000
   direction_slots          OY+
   number_of_slots          1
   interval_slots            0.000
   length_slot              65.000
   breadth_slot             50.000
   depth_slot               10.000
   foot_radius               0.400
SURFACE_AND_EDGE_INFORMATION
   face_top                 CLOSURE_SURFACE
   face_bottom              MATERIAL_SURFACE
   face_1                   CLOSURE_SURFACE
   face_2                   MATERIAL_SURFACE
   face_3                   SLOT_SQ_11
   face_4                   MATERIAL_SURFACE
   edge_top
   edge_face_1
   edge_face_3
```

```
FEATURE_IDENTIFICATION
   name_of_feature          SLOT_SQUARE
   code_of_feature          SLOT_SQ_11
FEATURE_GEOMETRY
   type_of_feature          VOLUME    2_OPEN_SIDE
   reference_point_glob       0.000   70.000   30.000   GLOBAL
   reference_point_face       0.000   70.000    0.000   OZ+
   rotation                   0.000
   direction_slots          OX+
   number_of_slots          1
   interval_slots             0.000
   length_slot              100.000
   breadth_slot              10.000
   depth_slot                15.000
   foot_radius                0.400
SURFACE_AND_EDGE_INFORMATION
   face_top                 CLOSURE_SURFACE
   face_bottom              MATERIAL_SURFACE
   face_1                   MATERIAL_SURFACE
   face_2                   CLOSURE_SURFACE
   face_3                   MATERIAL_SURFACE
   face_4                   CLOSURE_SURFACE
   edge_top
   edge_face_2
   edge_face_4
```

```
ENDMILL
Diameter              10 mm
Side cutting high     22 mm
```

```
FACEMILL
Diameter             250 mm
Cutting width         10 mm
Cutting depth         84 mm
```

```
ENDMILL
Diameter              16 mm
Side cutting high     32 mm
```

Figure 10: Information to the process planning: manufacturing features, interdependence, tool type and maximal tool size

Additionally, *FESTEVAL* has the advantage that a Common Data 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 significant.

The information along the NC process chain can be exchanged bi-directionally. By representation in the Common Data 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. The Definition and documentation of machining are made in a Common Data Model and thus are associated.

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Support of the Development Process Chain by Manufacturing Features

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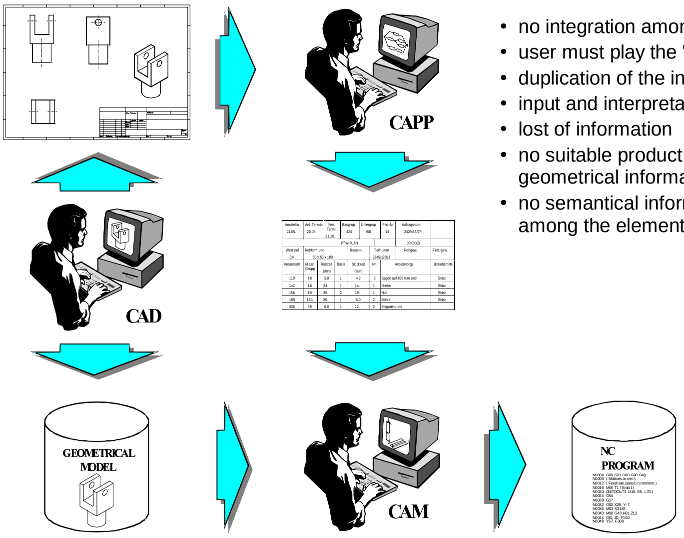
Dipl.-Ing. Erik Claassen, DiK - TU Darmstadt, Germany

1. Introduction
2. Objectives
3. Interdependencies of Form Features
4. Support of the NC Process Chain

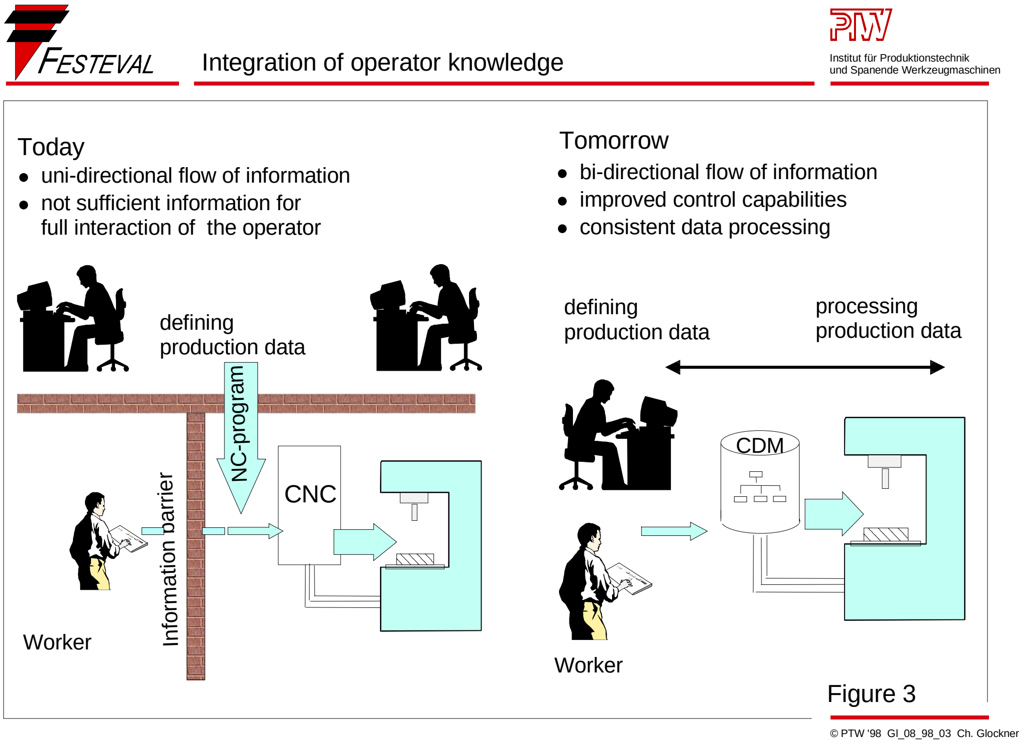
Figure 1

Conventional process chain of the product development



- no integration among the systems
- user must play the "integration interface"
- duplication of the inputs, data and models
- input and interpretation mistakes
- lost of information
- no suitable product model (only geometrical information)
- no semantical information and relationship among the elements in the part model

Figure 2



FESTEVAL

Integration of operator knowledge

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Today
- uni-directional flow of information
- not sufficient information for full interaction of the operator

Tomorrow
- bi-directional flow of information
- improved control capabilities
- consistent data processing

Figure 3

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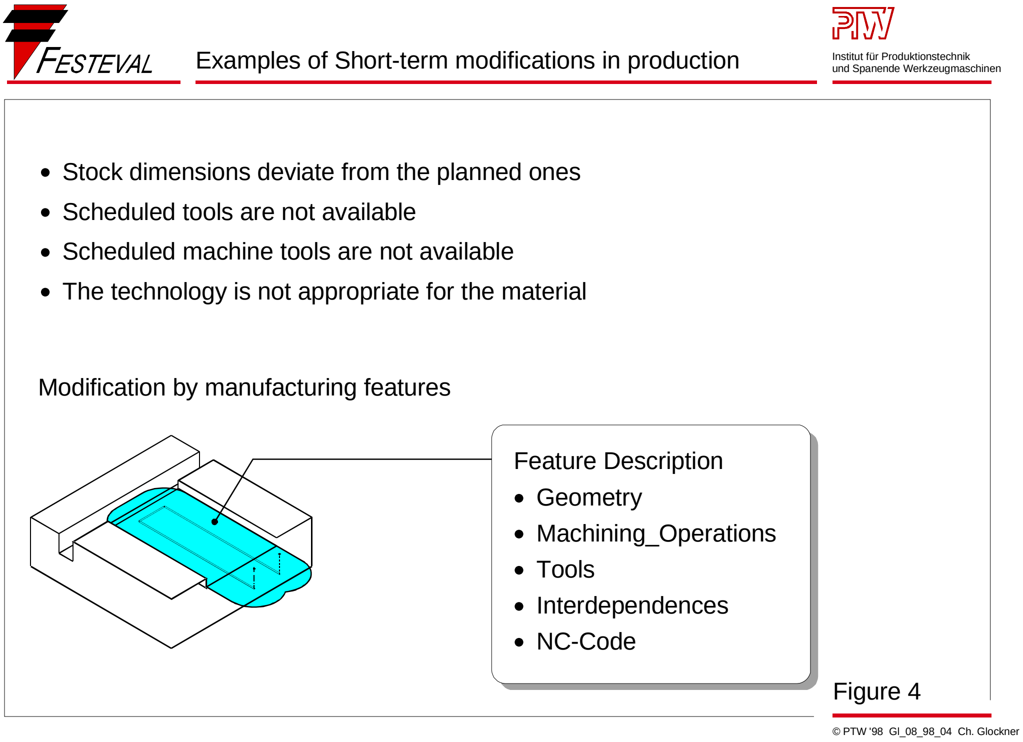

FESTEVAL

Examples of Short-term modifications in production

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- Stock dimensions deviate from the planned ones
- Scheduled tools are not available
- Scheduled machine tools are not available
- The technology is not appropriate for the material

Modification by manufacturing features

Feature Description
- Geometry
- Machining_Operations
- Tools
- Interdependences
- NC-Code

Figure 4

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FESTEVAL

Common Data Model of FESTEVAL

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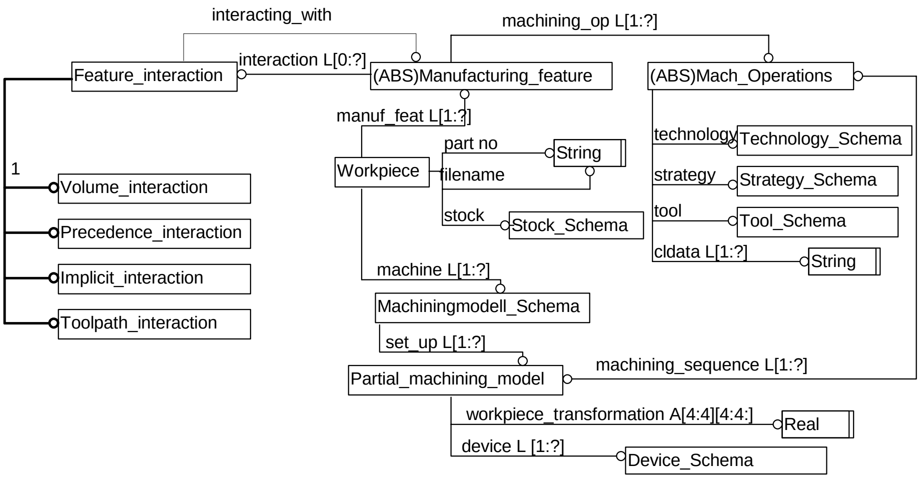

interacting_with
machining_op L[1:?]
interaction L[0:?]
Feature_interaction
(ABS)Manufacturing_feature
(ABS)Mach_Operations
manuf_feat L[1:?]
technology
Technology_Schema
part no
String
Workpiece
filename
strategy
Strategy_Schema
1
Volume_interaction
stock
Stock_Schema
tool
Tool_Schema
Precedence_interaction
cldata L[1:?]
String
Implicit_interaction
machine L[1:?]
Toolpath_interaction
Machiningmodell_Schema
set_up L[1:?]
machining_sequence L[1:?]
Partial_machining_model
workpiece_transformation A[4:4][4:4:]
Real
device L [1:?]
Device_Schema

Figure 5

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FESTEVAL

Overview of the interdependencies

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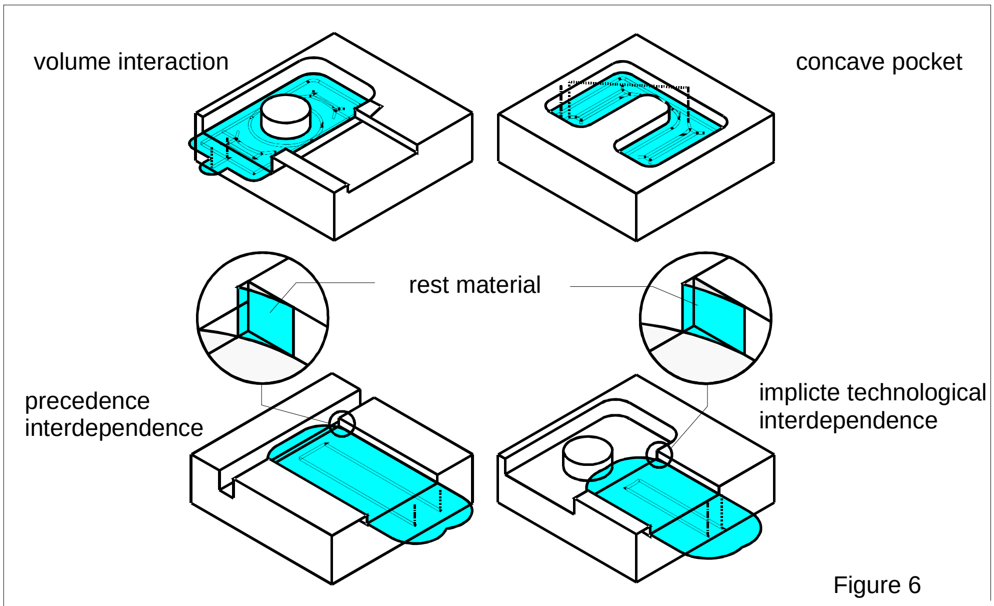

Figure 6

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FESTEVAL

Objectives of the Integrated Design Environment

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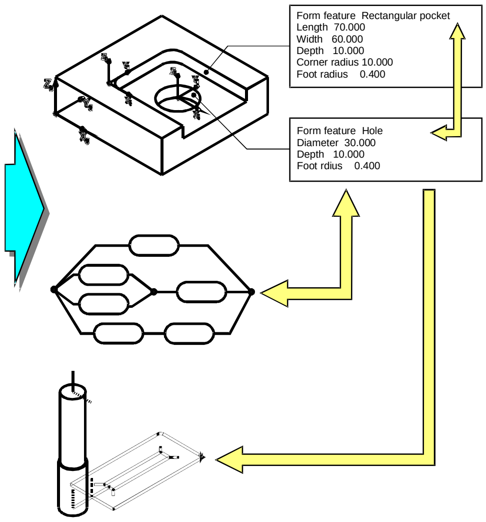
- active support to the designer during the design process and input of technological attributes
- semantical, geometric and technological representation of the part through form features
- recognition, validation, representation and management of the interdependence among form features
- Integration with a CAPP-System in two directions
- integrated and automatic NC-programming



Form feature Rectangular pocket
Length 70.000
Width 60.000
Depth 10.000
Corner radius 10.000
Foot radius 0.400

Form feature Hole
Diameter 30.000
Depth 10.000
Foot rdius 0.400

Figure 7

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FESTEVAL

Support of the process planning activities

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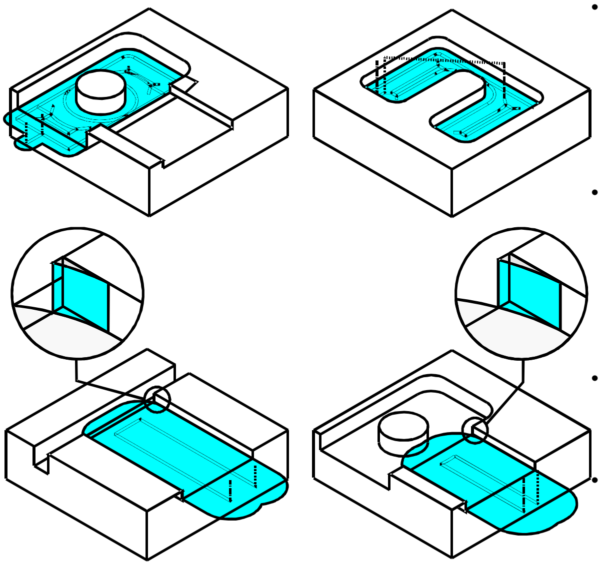

- **Part model based on manufacturing features including:**
  - manufacturing based semantic
  - geometric information
  - technological information
- **Representation of interdependencies relating the manufacturing features**
  - technological interdependencies
  - shape interdependencies
  - implicit interdependencies
- **Determination of the tool type and maximal tool dimensions**
- **Determination of the material to remove and rest material**

Figure 8

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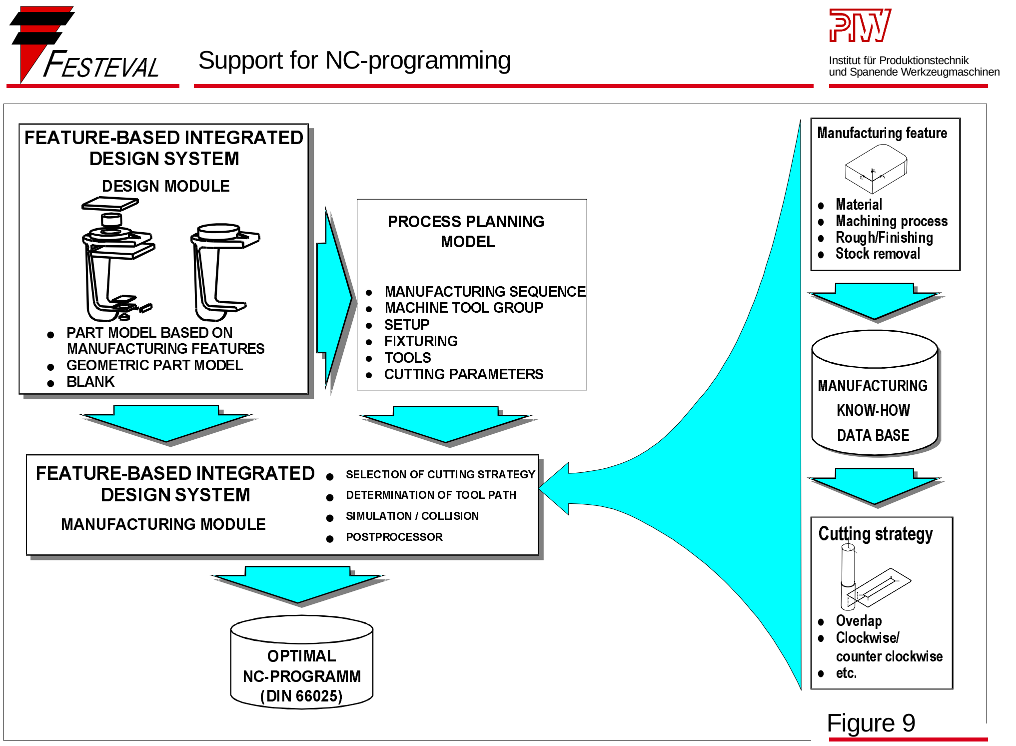

FESTEVAL Support for NC-programming

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FEATURE-BASED INTEGRATED DESIGN SYSTEM

DESIGN MODULE

- PART MODEL BASED ON MANUFACTURING FEATURES
- GEOMETRIC PART MODEL
- BLANK

PROCESS PLANNING MODEL

- MANUFACTURING SEQUENCE
- MACHINE TOOL GROUP
- SETUP
- FIXTURING
- TOOLS
- CUTTING PARAMETERS

FEATURE-BASED INTEGRATED DESIGN SYSTEM

MANUFACTURING MODULE

- SELECTION OF CUTTING STRATEGY
- DETERMINATION OF TOOL PATH
- SIMULATION / COLLISION
- POSTPROCESSOR

OPTIMAL NC-PROGRAMM (DIN 66025)

Manufacturing feature

- Material
- Machining process
- Rough/Finishing
- Stock removal

MANUFACTURING KNOW-HOW DATA BASE

Cutting strategy

- Overlap
- Clockwise/ counter clockwise
- etc.

Figure 9

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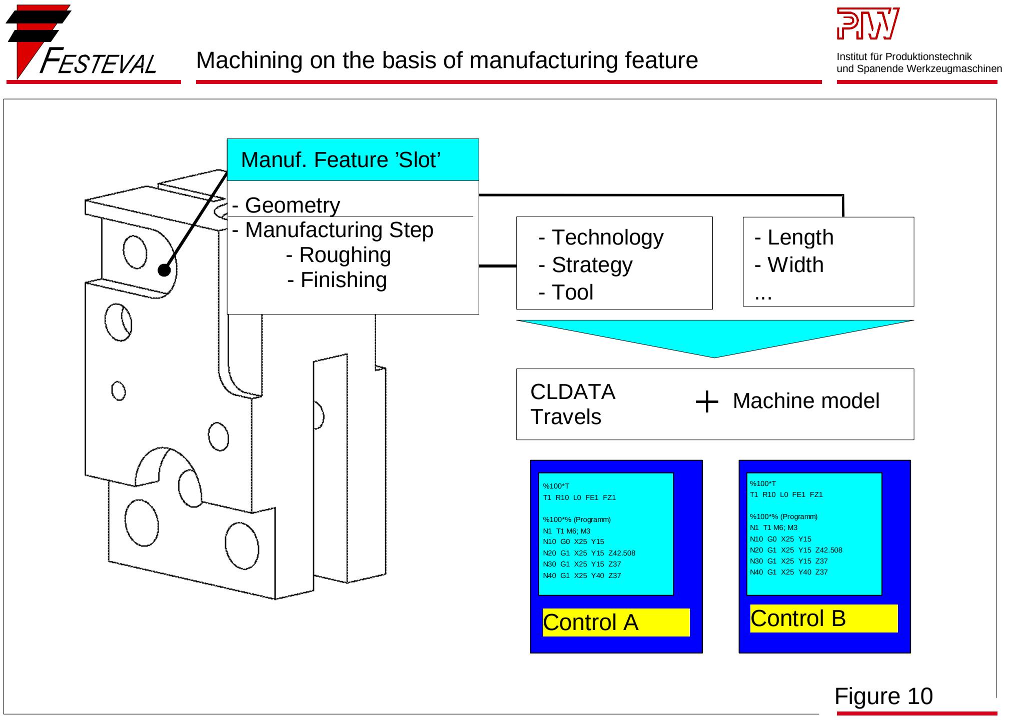

FESTEVAL Machining on the basis of manufacturing feature

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Manuf. Feature 'Slot'

- Geometry
- Manufacturing Step
  - Roughing
  - Finishing

- Technology
- Strategy
- Tool

- Length
- Width
- ...

CLDATA Travels + Machine model

```
%100*T
T1  R10  L0  FE1  FZ1

%100*% (Programm)
N1  T1 M6; M3
N10  G0  X25  Y15
N20  G1  X25  Y15  Z42.508
N30  G1  X25  Y15  Z37
N40  G1  X25  Y40  Z37
```

Control A

```
%100*T
T1  R10  L0  FE1  FZ1

%100*% (Programm)
N1  T1 M6; M3
N10  G0  X25  Y15
N20  G1  X25  Y15  Z42.508
N30  G1  X25  Y15  Z37
N40  G1  X25  Y40  Z37
```

Control B

Figure 10

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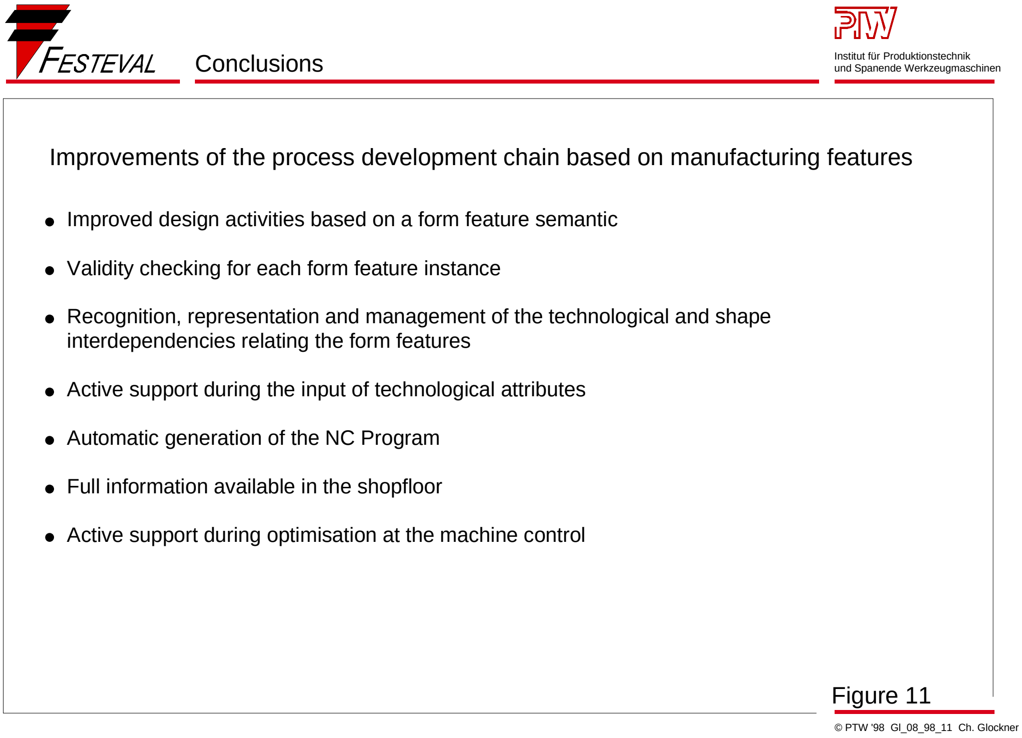

FESTEVAL

Conclusions

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Improvements of the process development chain based on manufacturing features

- Improved design activities based on a form feature semantic
- Validity checking for each form feature instance
- Recognition, representation and management of the technological and shape interdependencies relating the form features
- Active support during the input of technological attributes
- Automatic generation of the NC Program
- Full information available in the shopfloor
- Active support during optimisation at the machine control

Figure 11

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