Integration of CAD/CAPP based on the process planning working space to support design for manufacturing

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Abstract

In order to improve the communication and co-ordination between CAD and CAPP, a concept called "process planning working space" is proposed in this paper, which is used to integrate CAD and CAPP and to support design for manufacturing.

Based on the design methodology, a concept of design working space has been used in the early product design stage. A bi-directional connection between design working space and process planning working space is established to make it possible for designer and process planner to share the information in design domain and in process planning domain, so that the product structure that is suitable for manufacturing can be generated supported by the information from process planning domain.

The process planning working space possesses a hierarchical structure. With its decomposition operation the object of process planning can be simplified. A case-based reasoning method is used to generate manufacturing solution for each sub-object that is contained in process planning working space.

Keywords

CAPP, design for manufacturing, CAD/CAPP integration.

1. INTRODUCTION

CAD/CAPP techniques have been employed in industry for a long time, and extensively automated design and manufacture. However, the traditional CAD and CAPP systems are isolated with some weaknesses:

Lack of system integration

Traditional computer aided design aims at creating, modifying, and documenting the geometrical model of a product, although only geometric information is provided in the model. But as a subsequent phase of design, process planning requires not only the geometric information of an object, but also some semantic information, so that the

M. J. Pratt et al. (eds.), *Product Modeling for Computer Integrated Design and Manufacture*

output of CAD can not be directly used as an input for CAPP, this will result in duplication of modelling work and may result in inconsistency.

Lack of information exchange

The communication between CAD system and CAPP system is limited. A decision of designer can not be supported by the information from manufacturing domain, so that he is usually not aware of the constraint of manufacturing and may define some structure which is not suitable for manufacture or even can not be machined by available manufacturing resources, This will result in unoptimal product structure.

Sequential system relationship

A traditional CAPP system follows CAD sequentially. The process planning phase is started only after the design phase is finished and the result is generated. If some improper product structures which are not suitable for manufacturing exist, they can only be found in process planning phase, and must be returned to the design field to be modified. This process will result in the waste of product development time.

In order to overcome these shortcomings a new concept called Process Planning Working Space is put forward in our research work to integrate CAD system and CAPP system, and to support design for manufacturing.

According to design methodology, an integrated knowledge based design system was developed at RPK in University Karlsruhe (Grabowski 1995). A concept called Design Working Space was proposed (Rude 1991), which aims at reducing the complexity of sub-tasks, structuring design process knowledge, and limiting the available design space. The concept of design working space can support all design stages and connect all models of early design stages, such as requirement model, function model, physical principle model and geometry model. It will be also beneficial to the CAD/CAPP integration, if the concept of working space is used in process planning phase. With the help of process planning woking space a bi-directional connection between CAD and CAPP can be established and design for manufacturing can be supported.

2. PROCESS PLANNING WORKING SPACE (PPWS)

Process planning working space is defined according to the following baselines:

• The model structure of PPWS is hierarchical, more exactly it is a tree structure, whose nodes can be divided into sub-trees.

• The root as well some sub-nodes of a PPWS tree is respectively connected to the corresponding root or nodes of design working space tree, so that there is a direct connection between design and process planning.

• Initially the geometry for which the process plan should be generated is contained in the PPWS.

• After the execution of process planning system the elements contained in a process planning working space are the generated process planning information for the geometry contained in this PPWS, they are

- Manufacturing methods,
- Manufacturing resources,
- Manufacturing parameters, and
- Process plan.

• A PPWS possesses a geometric boundary which envelops all the geometry to be dealt with.

Figure 1. illustrates the contents of a process planning working space and its connection with a design working space. The following models are linked to process planning working space model:

Manufacturing features: which are contained in the selected process planning working space and are generated by design feature mapping.

Manufacturing methods: with which the geometric shape of a certain manufacturing feature can be generated and its accuracy demand should be satisfied.

Manufacturing resources: which includes cutting tool and machine tool selected from database to perform the required manufacturing operation for a certain geometry.

Manufacturing parameters: which includes cutting condition, cost and time to be calculated according to the generated manufacturing methods and manufacturing resources.

Process plan: which is generated by collecting all of the manufacturing resources and methods and arranging in an optimal sequence.

Design working space: the pointer to the design working space is also an attribute of process planning working space model to establish a connection between them.

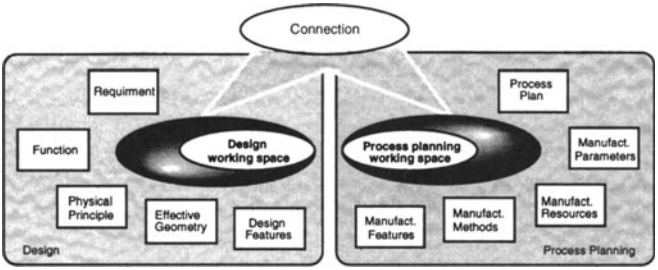

Figure 1. Elements in process planning working space

The Process planning working space is used to support design for manufacturing and support process planning. These are realised by three steps:

• First step: establishing the root of process planning working space and the connection between design working space and process planning working space.

In CAD system which is based on the concept of design working space, the sub-geometry is contained in sub-design working space. During design phase, if designer wants to confirm whether the designed shape that is contained in a design working space is suitable for manufacturing, whether the machining cost and time is acceptable, whether the required resources are at hand, the designer can start the process planning system based on the process planning working space to find a manufacturing solution to support his decision.

When a process planning system is started in the CAD phase, an object of process planning working space, which is corresponding to the selected design working space, is generated at first, and a connection between the two working spaces is established immediately. Then through this connection the geometric model can be transmitted in process planning working space.

• Second step: starting the process planning system to generate manufacturing methods, manufacturing resources and manufacturing parameters for the geometry contained in the process planning working space.

A case-based CAPP method is used to generate manufacturing solution. Before the case-based CAPP system is started the design features generated by CAD system will be mapped into manufacturing features to be used in process planning.

In case-based CAPP system the manufacturing knowledge is organised in such a way that all of the manufacturing methods for frequently used features or feature groups are treated as a case and stored in a case base. The solution should be searched in the case base according to the object status. If no appropriate solution exists in the case base the process planning working space will be decomposed to simplify the object to be planned, and the solution for the sub-geometry in sub-process planning working space will be searched in case base once more. The decomposition and searching process will be repeated till the solution can be found in the case base or the minimum geometry appears. The minimum unit in sub-process planning working space is a manufacturing feature, if there is no manufacturing solution for the minimum unit exists, an interactive input is needed. This procedure is shown in figure 2.

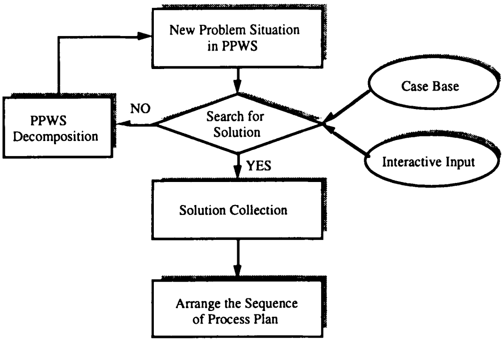

Figure 2. Search for the manufacturing solution

Figure 3 illustrates the decomposition of PPWS, which can be performed in two ways:

The first way is that the decomposition will be carried out with the help of the structure of the design working space. The structure of the process planning working space, which is generated in this way, is the same as the structure of the design working space. The advantage of such a decomposition is that each sub-geometry in the sub-process planning working space possesses certain sub-functions, because sub-geometry in the sub-design working space relates to certain sub-functions. With application of the system the geometry in old case is then connected with certain functions.

The second way is rule based decomposition. At a leaf of the design working space tree, geometry will be divided into frequently used features or feature groups according to rules of decomposition, which are related with the old cases in the case-base. That is, the geometry is decomposed into such feature groups that exist in the case-base at first. If a solution is not found in the case-base the decomposition will be performed continually, till minimum unit appears.

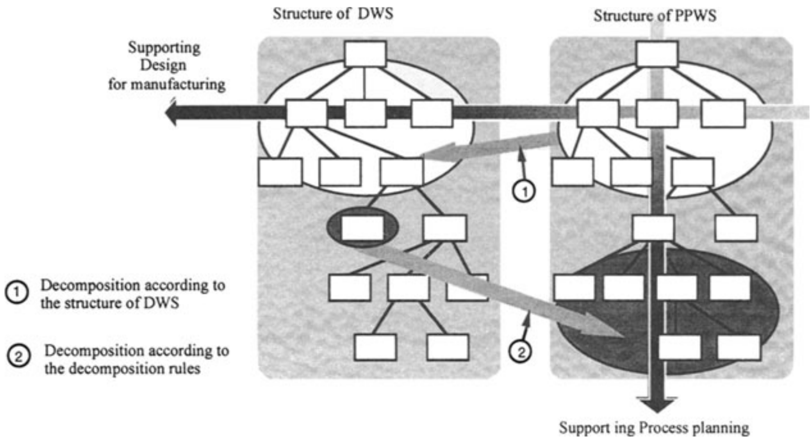

Figure 3. Decomposition of process planning working space

In order to generate a process plan, a top level process planning working space is selected from the tree of process planning working space, and all sub-nodes of it are interrogated to collect all of the solutions for the top level geometry. The start point of generating a process plan can be any node in the tree. If the generated process plan is a new one, which does not exist in case base, it will be stored in case base for future use.

With use of the system the contents of the case base will increase steadily. Instead of decomposing and searching for basic manufacturing method, the solution for some kinds of complex shape, which are frequently used, can be directly obtained from the case base.

• Third step: The manufacturing solution will be fed back to the design working space to support the decision of the designer . Figure 4.

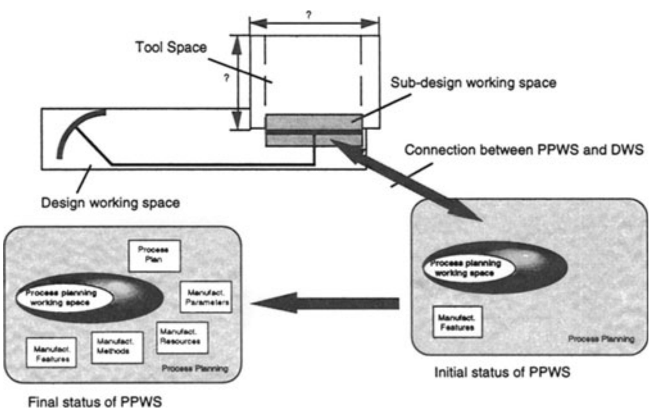

Figure 4. Initial and final status of process planning working space

3. PROTOTYPE CAPP SYSTEM BASED ON PROCESS PLANNING WORKING SPACE

To demonstrate the function of process planning working space, a prototype CAPP system called ProCAP has been developed and is being implemented at RPK in the University of Karlsruhe. This system addresses the generation of the process plan for the general metal cutting methods. Figure 5.

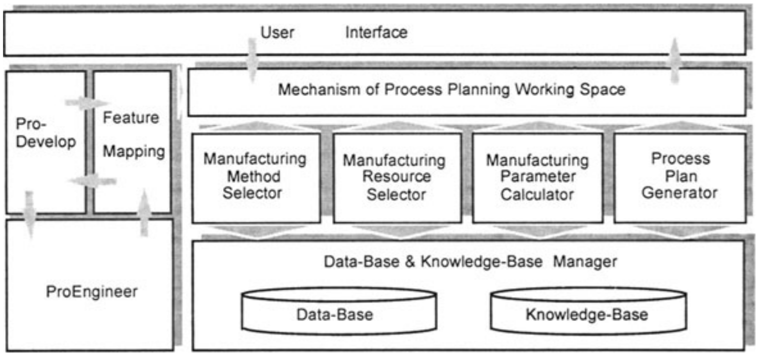

Figure 5. System structure of ProCAP

User interface

By the user interface of ProCAP the commercial CAD system ProEngineer, the object oriented data base system and the case-based CAPP module are connected. Figure 6.

The user interface allows to control the system operation. The structure of the design working space for different products, which are stored in the integrated data based can be selected and displayed on the user interface. A node in the design working space tree can be selected, if a manufacturing solution for the geometry contained in it needs to be found. The process planning working space generation process can also be displayed on this interface, such as the generation of the root of the process planning working space, and its decomposition. After the operation a complete structure of the process planning working space is displayed. The solution for each sub-geometry contained in a sub-node of the process planning working space tree is searched automatically in the case base. At the end a top level node can be selected interactively to generate process plan for the geometry contained in it.

Manufacturing feature generation

Feature technology is generally regarded as an effective method to support the integration between CAD and CAPP. Features provide a means of describing the engineering attributes and relationships between product definition entities and are considered as the entities at higher semantic level than the pure geometric elements typically used in geometric solid modelling systems. A commercial CAD system called ProEngineer is selected as a tool of creating the geometric model in the design system which is integrated with ProCAP. ProEngineer is a feature based modelling system, a component in ProEngineer is constructed by design features.

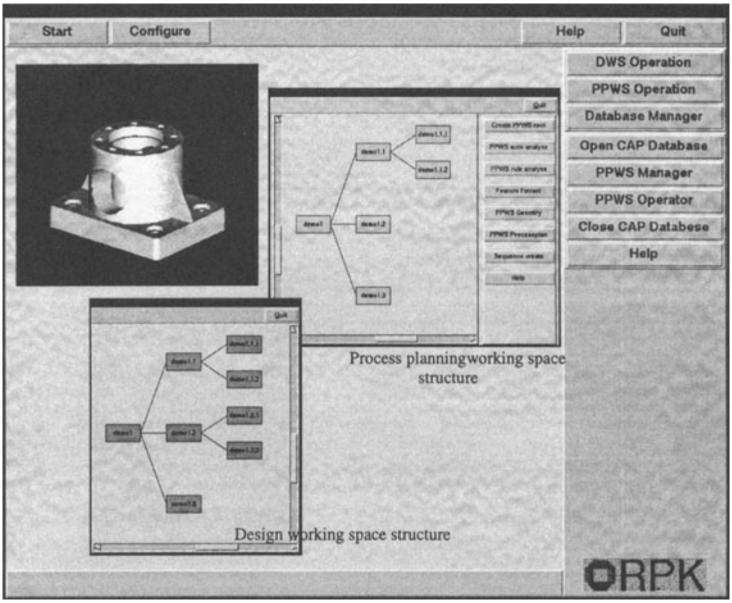

Figure 6. User interface of ProCAP

Before the CAPP system is started design features should be mapped into manufacturing features which are used in the CAPP system. Generally, the mapping from design features into manufacturing features is realised in such a way that the delta volume to be removed is obtained by a Boolean subtraction calculation between the stock and the desired part first, then this delta volume is decomposed by different kinds of methods to generate the manufacturing feature (Krause 1990 and Shah 1994). However, the situation of the component made from a casting blank is not the same as a general component made from a stock. Because the shape of a casting blank must be determined with the help of a process plan, such as the cutting thickness, the Boolean subtraction calculation between casting blank and desired part can not be performed before the process plan is generated, so that the mapping method for the component from casting blank should be adapted.

In our CAPP system the manufacturing feature includes form features, such as hole, slot, pocket and so on, and surface features, such as plane and cylinder. Each feature is described by its parameters, machinable direction and located surface explicitly, some semantic information is also included in the data structure of the manufacturing feature, such as feature relations, and functional surfaces of a feature.

There are two steps to generate the manufacturing feature, one is to generate the feature identity, the other is to generate the feature parameters. Figure 7.

first step: generate feature identity

Three feature mapping methods are employed in the ProCAP system to generated the feature identity of a manufacturing feature.

Direct mapping: some design features can be directly converted into manufacturing features, if the design feature and manufacturing feature is the same.

Decomposing mapping: multiple manufacturing features are generated from one design feature. The relation between design features and manufacturing features is 1:n.

For example, a plane is regarded as a manufacturing feature in ProCAP, but it can not be directly obtained as a feature in ProEngineer, so that a decomposition will be performed to generate the feature plane from the basic body, which is called "Protrusion" in ProEngineer. The plane from the decomposition of Protrusion can be distinguished into surface feature and sub-surface of a feature, for example if the Protrusion exists in a pocket.

Composing mapping: one manufacturing feature is generated from several design features. The relation between the design features and the manufacturing features is n:1.

For example, in order to establish the structure of an axis in detail a manufacturing feature axis is defined, which consists of cylinders and planes in sequence. But with a different modelling method in ProEngineer the basic body of an axis may be made up of a different number of design features. To generate the feature axis, all of these surfaces of the design features must be composed sequentially.

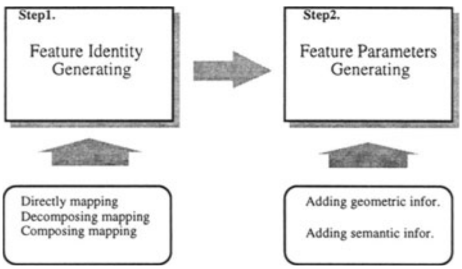

Figure 7. Feature mapping in ProCAP

second step: generate the parameters of the manufacturing feature

After the manufacturing feature's identity is generated, it is necessary to add the geometrical and semantic information in the manufacturing feature, because it is important for the manufacturing feature to be described explicitly. With the explicit description of manufacturing feature, the manufacturing knowledge can conveniently be connected with it.

For example, a manufacturing feature is defined with locating surface and main direction, through which the relative position and machinable direction are determined, but this information is hidden in the topological and geometrical model of ProEngineer. To describe this information explicitly it must be extracted from topological and geometrical model.

Another example, all sub-surfaces of a pocket, from which a pocket is made, can be got through the topological structure of a design feature "cut", and all parameters of these sub-surfaces can also be got through the corresponding geometric model. However, it is impossible to identify the bottom and the wall of a pocket directly. For the process planning this information should be extracted and added.

Case-based CAPP system

With the development of artificial intelligence techniques some problems have been met in knowledge-based systems, such as knowledge elicitation and maintenance of such systems. Meanwhile, case-based reasoning (CBR) method has increasingly attracted more and more attention.

Based on the observation of human problem solving methods a case-based reasoner solves new problems by adapting solutions that were used to solve old problems. It has the following outstanding advantages:

- CBR does not require an explicit domain model and so elicitation becomes a task of gathering case histories.
- Implementation is reduced to identifying significant features that describe a case, an easier task than creating an explicit model.
- By applying database techniques large volumes of information can be managed, and
- CBR systems can learn by acquiring new knowledge as cases and can be maintained easily. (Watson 1995)

The case-based reasoning method is used in the sub-CAPP modules "manufacturing method selector" and "process plan generator" in ProCAP, which was developed conceptually and is being implemented.

All the cases used to solve the old problems are stored in case base, and these cases are indexed with several parameters, the case for manufacturing method is indexed according to

Object name: which is the name of one manufacturing feature or a list of manufacturing features that belongs to a manufacturing feature group. The object can be dealt with by the manufacturing methods contained in this case.

Input status: that is the status of the object before the manufacturing methods are performed on it. It includes the geometrical dimension, the accuracy, the surface quality such as surface finishing, surface hardness and surface heat treatment.

Output status: that is the status of the object after the manufacturing methods stored in this case are performed. The same information is included as in the input status.

The case for the decision of set-up is indexed as following:

Set-up surface: which described the surface type and the main direction of the surface. The set-up surface is used as the main surface in set-up method contained in the case.

Machine tool type: which includes all possible machine tool types that are suitable for set-up method contained in the case.

Machinable direction: that describes the directions, in which the part that is set up with the method in the case can be machined.

Degree of freedom to be fixed: which describes how many degrees of freedom can be fixed with set-up method contained in the case.

The case based CAPP module is illustrated in figure 8.:

1. A new problem situation will be analysed and the index for problem is generated, which has the same structure as the index of a case in the case base.
2. According to the index of the new problem a list of cases which match the new problem situation are selected from the case base.
3. The cases will be reused to the new problem in turn. In order to match the new problem better, the case will be adapted and then a solution is generated.

4. The generated solution will be evaluated, if it is not successful the solution must be repaired.
5. The final solution will be stored in the case base for future use.

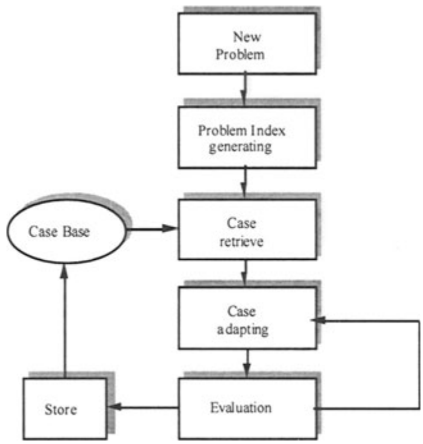

Figure 8. Case-based system

Integrated database

An integrated object oriented database is used to save the manufacturing resource data, manufacturing knowledge and manufacturing solution. All of the design model and process planning model can be queried in this database. The database manager is integrated with the user interface to perform the interactive operation in the database.

The whole CAPP database can be divided into the following sub-databases:
• Machine tool database
• Cutting tool database
• Cutting condition database
• Cost and time database
• Process plan database

The data in the sub database of manufacturing method, machine tool, cutting tool, and cutting condition are organised in two levels.
• Static data

All manufacturing methods and manufacturing resources at hand are stored as static data. It reflects the manufacturing capability of a manufacturing system.
• Dynamic data

It is selected by the process planning system as an actual data from static data or calculated based on static data for certain geometry shape. This data is connected with the process planning working space, in which the geometry exists.

4. CONCLUSION

In this paper a concept of process planning working space is proposed. By establishing the connection between process planning working space and design working space a new way is provided to integrate CAD and CAPP. Based on the integration of CAD and CAPP information can be exchanged between design domain and process planning domain. When the execution of CAPP system is guided by process planning working space, the design model and process planning model can be simultaneously accessed by designer and planner during design and process planning process, so that design for manufacturing is supported.

On the basis of process planning working space a CAPP prototype system called ProCAP is developed. The mechanism of process planning working space plays a central role in this system, and all of the functions of the system are organised according to the structure of process planning working space. With the guidance of the process planning working space process planning is carried out, and the process planning results are generated.

Further research is undergoing to implement all of the system functions, which have been conceptually built up already , and to expand database and knowledge base.

5. REFERENCES

Grabowski, H., Lossack, R.S. and Weis, C. (1995) Supporting the design process by an integrated knowledge based design system, *Advances in formal design methods for CAD*, (ed. Gero, John S. and Sudweeks, Fay), Key Centre of Design Computing, University of Sydney.

Krause, F-L, Ulbrich, A. and Vosgerau, F.H. (1990) Feature based approach for integration of design and process planning, *Product modelling for computer aided design and manufacturing*, (ed. Turner J.), North-Holland.

Rude, S. (1991) Rechnerunterstützte Gestaltfindung auf der Basis eines integraten Produktmodells, Diss. RPK Universität Karlsruhe.

Shah, Jami J, Mäntylä, Martti and Nau, Dana S. (1994) *Advances in feature based manufacturing*. Elsevier.

Watson, I. (1995) An Introduction to case-based reasoning, *Progress in case-based reasoning* (ed. Watson, Ian D.), Springer.