From CAD through manufacturing to quality control of microstructures

K.P. Scherer, H. Eggert, P. Buchberger, P. Stiller, U. Stucky
Forschungszentrum Karlsruhe, Institut für Angewandte Informatik (IAI), Postfach 3640, D-76021 Karlsruhe, Germany

Abstract

In the Institute of Applied Computer Science (IAI) in the Forschungszentrum Karlsruhe (FZK) information technologies are developed and applied to support the manufacturing process for micromechanical structures, based on LIGA (German Acronym for Lithographie, Galvanik, Abformung) technique, developed in the Institute for Microstructure Technique (IMT) of the FZK. The information related kernel of the computer integrated manufacturing consists of different semantic clusters. In the first step, at the beginning of the whole manufacturing process, the designer has to construct the microstructure. These 3-dimensional microstructures are designed with a CAD system for mechanical construction. After application of design checks and design rules, based on heuristics from human experts, these constructions are the references for the quality control of the real fabricated structures. To guarantee an efficient construction and fabrication, on the logical top level of application an expert system is developed, which correlates the different manufacturing semantics and which is responsible for diagnoses of intermediate and final products and instructions to the designer.

1 An Information Concept for Manufacturing Micromechanical Structures

In a first approach, the design step, the closed manufacturing process and quality control methods are logical separate domains, but a powerful method to get an integrated manufacturing process is to correlate semantically these three knowledge domains [1].

The quality of the intermediate and final products concerning geometrical and topological features has to be validated, for example with optical quality control methods based on digital image processing techniques. Special knowledge, how

to compare the inspected real structures with the designed reference models is essential to find out failures and defects in the manufacturing process in a very early stage. This aim can be reached only if all aspects like design, fabrication and inspection are considered in a common integrated way, which needs a unique object oriented database as fundamentals for a consistent and persistent information processing. The knowledge, necessary to construct a microstructure relates to a lot of geometrical and topological features. In reality, not all geometrical forms are possible because of constraints coming from the manufacturing process, the mounting conditions and the desired functionality.

This requires first a formal representation of the knowledge domains including methods to combine the knowledge. This representation is supported by a knowledge based system where the knowledge domains are structured in an object oriented manner. The object oriented structures concern the product knowledge of the intermediate and final microstructures, the process knowledge to fabricate these products, the geometrical knowledge which correlates with the CAD generated structures, and the knowledge about the instantaneous plant stage. For integrated information processing a consistent and correct data exchange is a necessary condition for information transfer. The geometrical information included the specification of critical measures, generated in the CAD system and given by a IGES file, must be converted into an object oriented representation, also the bidirectional information exchange between the digital image processing system COSMOS-2D [2], developed in our department and the knowledge bases. The expert system itself consists of two layers, a **basic model** of different knowledge domains and an **application level**.

2 Knowledge base with different partial models

For manufacturing of complex systems or structures, knowledge of different domains and of different depths must be available. The solution is a concept of different **knowledge layers**, containing special **partial models**. In our case there is developed a two layer concept (see Fig. 2). On the first level there is information about all basic process elements, product related knowledge and geometrical and topological product features. This level is important for detailed information requirements to the human experts to understand for example physical relations of the process behaviour. It can be understood as a explanation part within a complex information system. The different partial models on this layer are given as semantic clusters with weak bindings to the other knowledge layer of the expert system.

On the next higher layer, application related knowledge must be available. The user needs support for construction, regarding different logical aspects. These can be subdivided into different constraints. A special constellation of product components, process conditions and geometrical features of the product guarantee a fabrication related useful structure. That means, the constraints concerning the fabrication of a useful structure are given by a combined information

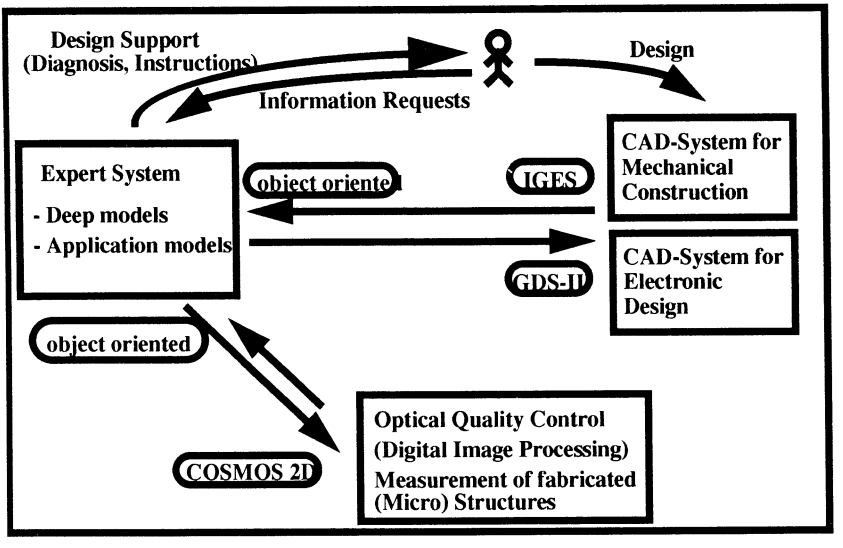

Figure 1 Different Information Processing Techniques

of objects in the deeper level. Especially this fact is the kernel to produce cost efficient because distinguishing between possible and impossible structures in a very early stage of manufacturing. The same situation for constraints is given in the field of mounting the partial product components. Furthermore the functionality of the planned final product or system must be regarded on the application level.

2.1 Man Machine Interface

The man machine interface of the expert system consists of a dialogue component, an explanation part for diagnoses and needs also a knowledge acquisition component. The explanation operates on the two described levels, on the deeper level as information system and on the application level as support by using design rules concerning different constraint clusters. The knowledge acquisition part must be developed to guarantee expert controlled extension of the knowledge bases. The transfer of the human semantics into a formal computer environment is realized by a data interface, which is responsible for a correct image of the domain dependant data format in an integrated information structure.

The activation of the inference engine can be made interactively by requirements of the user and also full automatically by designing a structure in the CAD system. After the design step an algorithmic preprocessing step, which generates the geometrical features, gives the input for the knowledge base and the forward driven production system matches these inputs with the rules in the application level.

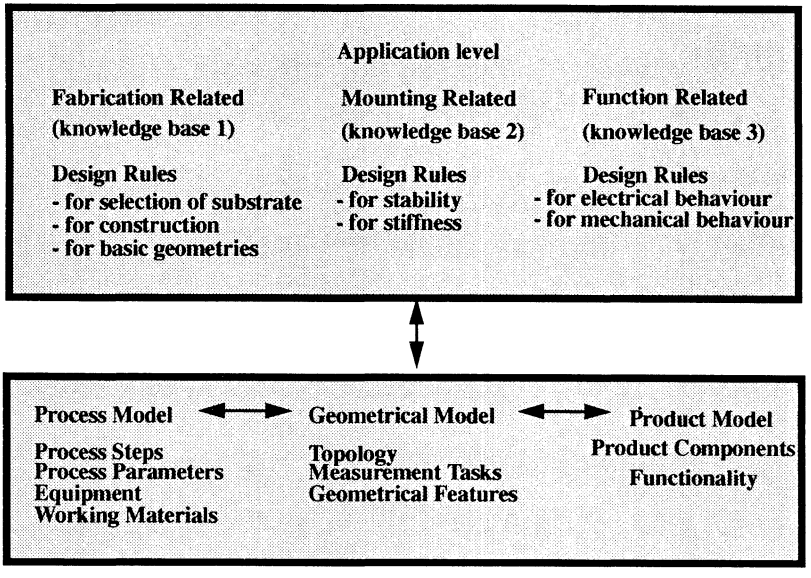

Figure 2 Two Layer Concept with Partial Models

3 Basic Models

For giving instructions and explanation to the designer or the experts responsible for the manufacturing process, knowledge on the deeper level must be available. On this level dependencies between the main features of the intermediate product must be given.

3.1 Process Model

Each special process step is defined as the transition of one state to the next state for a partial intermediate product. Often, a special process step can be subdivided into several finer process steps. This is realized by the so called object-subobject relation **consists of** respectively the inverse relation **belongs to**. Such a process step on a finer level belongs to the process step of the higher level. The result of this hierarchical relation structure is called **refinement**. The advantage is to have every time information about each process step on a self defined abstract level in the given data base. A further very important aspect concerning the information about the process steps is the well defined sequence of them to reach a final product. That means, the system has knowledge about successor and predecessor of all process steps. This fact (after, during, before) is performed on a relational mode of time logic.

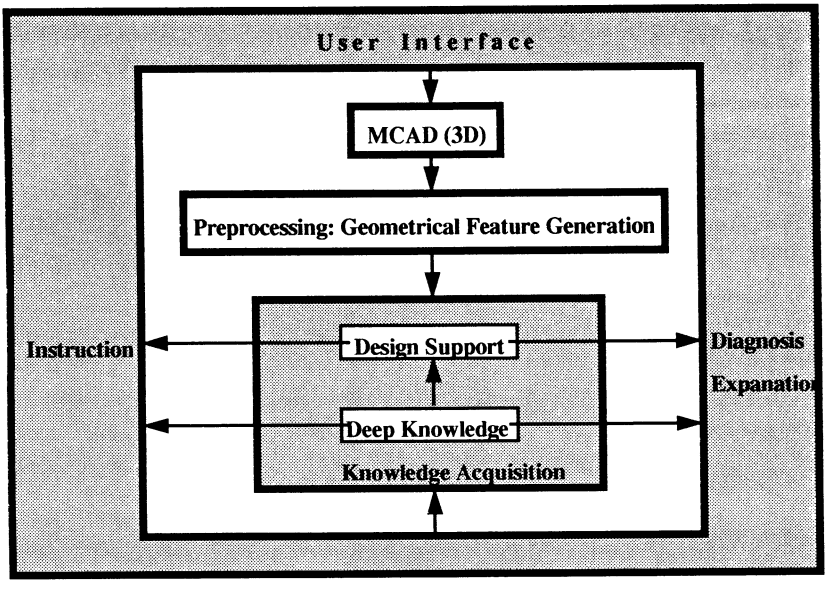

Figure 3 User Interface

The third dimension of the hierarchical process step model is the possibility to substitute a partial process by an alternative process or a chain of processes. That can be necessary because of special constraints. The result of these three aspects is a three dimensional information structure of this hierarchical process step model as shown in Fig. 4 for an example in the LIGA microsystem technology.

One very important advantage of the object oriented structure is the flexible extension to generate, to modify and to delete such classes, attributes and the objects in the classes. From the other point of view, it is absolutely necessary to have such formal mechanisms to handle a complex manufacturing process.

From semantics, not only the set of process steps is important, but also the set of all process parameters belonging to the processes, the set of working materials and the set of equipment. In a formal representation, there is generated the class of **process steps**, the class of **process parameters**, the class of **working materials** and the class of **equipment**.

All elements (objects) of a special class have the same attributes, filled with special values, also each subclass of class (subset of a set) has the same attributes. This fact is known as **inheritance**. This mechanism guarantees as well a comfortable access to special features of a special object, as well as a comfortable generation, information processing and deletion of attributes for a lot of special objects. The object oriented structure of the process model is based on the four above mentioned classes, the inheritance and the refinement mechanism.

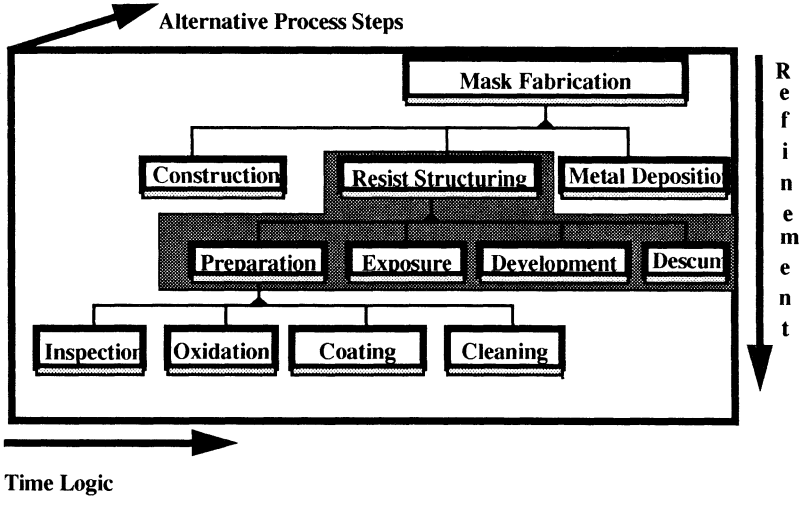

Figure 4 Three Dimensional Process Model

The power of the process model is given by the mixture of objects belonging to different classes in the object-subobject relation, i.e. a special process step has as subobjects any further process steps, as well any process parameters, belonging to this process as well as any equipment objects.

3.2 Geometrical Model

One essential part of the quality control of the fabricated (micro)structures is the strong verification and measurement of the intermediate and final structures, related to the designed geometries. A lot of possible defects, based on any fabrication process steps, can be detected immediately by comparison between the predefined CAD-geometries and the inspected geometries of the real structure. This is performed in the measurement system COSMOS 2D, developed in the FZK [2]. The measurement system, based on digital image processing techniques, is responsible for the verification and validation of the real fabricated geometrical and topological features like edges, corners and polygons including their measures in form of distances, radii and other curve parameters. Detected defects of the product refers to these basic topological and geometrical cell elements. For comfortable handling of this information, also an object oriented representation of the geometrical and topological information is useful. For send a final measurement order to the measurement system, a knowledge based configuration of basic measurement tasks is performed. Each task of them belongs to a set of geometrical objects (i.e. a distance measurement needs for example two points or corners, a line verification needs one line and so on).

Each of the geometries specified in the CAD-system is represented as a well known collection of primitives. The information (as well the geometrical and also the specification of measurements) generated by the CAD-process is represented in a special data format IGES [6]. The designed microstructures may have any complex geometry, and a structure is a combination of several so called cell elements, where a cell is a basic geometrical figure element. The transfer of the geometrical information from the CAD system to the knowledge based system is shown in Fig. 5.

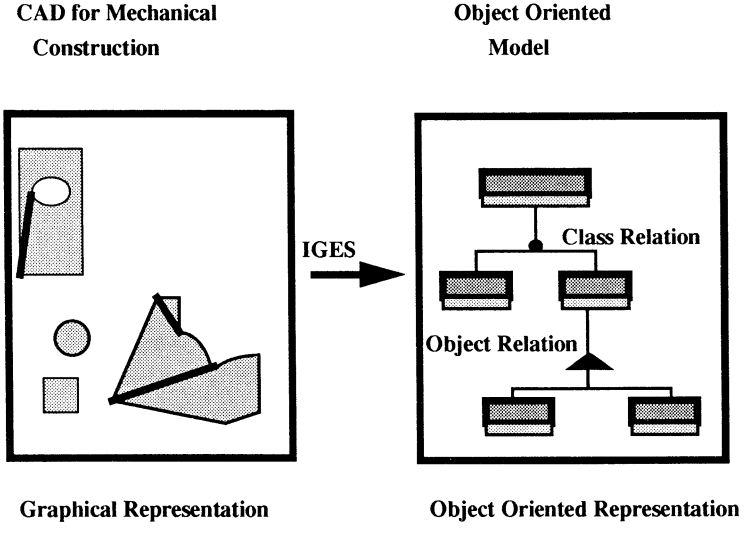

Figure 5 CAD Interface

4 Realisation

The different knowledge atoms are basically represented by C++ objects and classes. The software for the knowledge based information is implemented under UNIX on a SUN Sparc Station. For the design step of the 3-dimensional mechanical microstructures, ME10 / ME30 as CAD-system is available, running on the hardware platform HP 720 / PVRX. The information, generated in the CAD system and given in IGES-format, is converted by a special developed IGES-parser into the object oriented structure of the common data base of the expert system.

The measurement system for performing the inspection step needs also a special input data format, which must be generated from data of the common data structure. The measurement system is based on digital image processing techniques, running at time on an ELTEC transputer farm. The man machine interface is implemented on a SUN Sparc Station. The architecture of the whole

computer network is a server client concept, where the different computer systems are connected via a Local Area Network (LAN) with the TCP / IP protocol.

5 Conclusion

The complexity of a real manufacturing process like the fabrication of LIGA structures needs the integrated design support and a knowledge based product environment. There exists only a chance to handle and to understand the complete process with a computer based formal engineering support. A knowledge based component, responsible for the design support, correlates the information, given in different partial knowledge models and guarantees a efficient manufacturing process. The different constraint dependant areas are realized by different knowledge base complexes. The architecture of the described expert system guarantees a modular extension of the manufacturing in the application level, based on information coming from partial models in the deeper level.

References

1. K.P. Scherer, I. Brauch, H. Eggert, P. Stiller, „Object Oriented Modelling of Different Know-ledge Domains inside the LIGA Process", IEEE International Conference on Systems, Man and Cybernetics, Le Touquet, France, 1993.
2. B. Bürg, H. Guth, A. Hellmann, „Parametric Optical Measurements of Micromechanical Structures with Arbitrary Plane Surface Geometries: The COSMOS-2D System", Reichl (ed.), Miccro System Technologies 91, [2nd International Conference on Micro Electro, Opto, Mechanic Systems and Components, Berlin 1991], VDE Verlag Berlin, Offenbach, 1991.
3. P. Bley, Göttert, Harmening, Himmelhaus, W. Menz, Mohr, Müller, U. Wallrabe, „The LIGA Process for the Fabrication of Micromechanical and Microoptical Components", Reichl (ed), Micro System Technologies 91, [2nd International Conference on Micro Electro, Opto, Mechanic Systems and Components, Berlin 1991], VDE Verlag Berlin, Offenbach, 1991.
4. C. Leßmöllmann, „Fertigungsgerechte Gestaltung von Mikrostrukturen für die LIGA-Technik", Dissertation, Uni Karlsruhe, Dec. 1992
5. Reiner Anderl, „CAD Schnittstellen: Methoden und Werkzeuge zur CA-Integration", Carl Hanser Verlag München, Wien, 1993
6. Reed (ed), „Initial Graphic Exchange Specification (IGES)", Version 5.1, National Institute of Standards and Technology, Gaithersburg MD 1991.