Knowledge-based Support of Decision Making at the Example of Microtechnology

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Abstract:

Designing products is a sequence of decisions. Especially early decisions have great impact on later product life cycle stages. The more complex products become the more information is required in order to support design when making decisions. The present contribution shows for the example of the skill-intensive technology of microsystems, what tools can be applied. First, design processes in microtechnology are presented, which depict the necessity of bringing knowledge from later product life cycle stages to the early ones. For this front loading process design rules as a methodological means of support are proposed. Further on that paper presents two tools that are based on design rules, which support the designer. The first one, wikis, open content management systems represent knowledge from later stages for design engineers. The same design rules on a formal level can be implemented into the second proposed tool, a knowledge-based engineering system.

Keywords: *design process, microsystem technology, design rules, knowledge-based engineering, wiki*

1. Introduction

Today's products usually consist of a multitude of different subsystems and components, which derive from different domains, e.g. microelectronics, microsystem technology, precision engineering or classic macroscopic mechanical engineering. Also the integration of nanotechnology as another domain is expected. These systems are multi-scaled, i.e. they merge systems of different levels of magnitudes and of different production technologies. Designers have to be aware of specific manufacturing details, often decisive knowledge, which usually is reserved to specialists. Thus, designers have to be supported by methodological means that lead them to products being in accordance to given requirements. Early decisions in product development strongly influence subsequent stages of a product's life cycle. Hence, transfer and representation of knowledge to the design stage from subsequent stages, e.g. production or system integration, has to be enabled by integrating means of knowledge management. Further on, this decision support enables decision tracking later on, if appropriate tools of knowledge management are applied.

The present contribution discusses the reference model of a micro-specific design process in contrast to other processes and points out the application of design rules as a means of support. Wiki systems for early design stages and a computer-aided knowledge-based engineering system tools are proposed.

2. Design in Microsystem Technology

Within single branches, e.g. microtechnology, specific process models were developed due to the reason that universal development processes were too general and thus insufficient for depicting special aspects – which have to be considered for reducing cost and development time while increasing product quality. Hence, some specific design process models are presented in order to give the reader an idea of the special aspects that have to be considered.

The potential functionality and the development process of microsystems are heavily dependent on production technology. As a matter of principle, two areas can be distinguished. There are lithographic microtechnologies, e.g. silicon micromachining or LIGA (German acronym for lithography, electroforming, moulding), which both are called mask-based processes, since substantial structuring steps are performed by exposure to radiation through a patterned mask. Silicon-based microsystems often are referred to as MEMS, microelectromechanical systems. And there is tool-based microtechnology employing mechanical micromachining, i.e. miniaturized tools known from macroscopic technology, e.g. milling of moulds and subsequent moulding by thermoplastic injection moulding or powder injection moulding of ceramic or metallic feedstocks.

The following sections briefly describe how design processes for microtechnology are modelled.

3. Mask-based Microsystem Technology

For mask-based microsystem technology there are different models describing the design flow, which strongly depends on production technology. For silicon-based microsystems the technology was derived from microelectronics. Manufacturing of silicon chips is based on structuring by lithography and subsequent deposing or etching of layers. By combining layers with different electric properties (physical design), structural components are established, that enable electronic functions within a microchip, e.g. microprocessors, amplifiers, etc. While handling and treatment of silicon wafers, on which the chips are developed, several processing steps are required. Some of these steps are not compatible, e.g. one production step would require higher temperature, than a before deposited layer could withstand.

In 1984 Gajski and Kuhn [9] published a model, which is based on a tripartite representation of designs (Y-chart). Design refinement can be done on each of the three axes, which represent functional, structural and physical design. The functional representation describes what the chip does - without comprising anything about geometrical or structural details. The structural representation describes the circuit itself, i.e. components and connections, while the physical representation deals with cells, layout planning and mask geometries. This model was enhanced by Walker and Thomas [16]. Their model also consists of three perspectives (behavioural, structural and physical perspectives arranged in y-shape with a common vertex). The design flow itself is characterized by changes of the perspective while keeping the level of abstraction and changes of the level of abstraction while keeping the same perspective (refinement).

For mechanical microsystem being made of silicon, Hahn [10] adapted the Y-model, whereas the evidently occurring difference can be found in the levels of abstraction, which are system, component and structural level. But when designing micromechanical systems not only the object of design itself has to be created, also production, i.e. the technological processing sequence, has to be developed in parallel, especially due to the fact that not only design but also the manufacturing process is application-specific and heavily influences the resulting shape. Improving the Y-model, Brück and Schumer [7] employ a highly iterative such-called "circle-model", which is adapted to the requirements of designing microstructures. The model consists of four steps of layout design, process development, verification and process modification being arranged in a circle and especially considers the parallelism of developing mask layout and production process. Wagener's and Hahn's "pretzel model" [15] clearly shows the parallelism of developing behavioural design and processing sequence. On the one hand, based on a behavioural model and supported by a component library, a verifiable 3D model is synthesized. This 3D model comprises relevant information on design and structure of the single layers and the materials these are consisting of. Based on the known materials of the layers, process sequences and according process parameters are defined. On the other hand, when developing a new process sequence, analysis of this processing leads to mask properties and hence to a 3D model. In 2006 Watty [17] proposed another model for development of microelectromechanical devices being derived from VDI 2206 V-model for mechatronic design [14].

4. Tool-based Microsystem Technology

Considering tool-based microtechnology, there are technological conditions and restrictions, e.g. achievable flow lengths, minimum milling cutter diameter or minimum wall thickness. This results in a strong orientation in what is producible and therefore in a technology-driven design flow – in contrast to macroscopic product design, which is driven by market requirements. In order to achieve a design compatible to production, specific knowledge from process preparation (e.g. mould manufacture) and production (e.g. injection moulding) is required. The special aspects of designing tool-based microsystems are visualized by a model introduced by Marz [12], which is called "sickle-model" (cp. Figure 1) due to its sickle-shape transition from the design stage to the detail stage. The model represents the design stages conceptual, basic and detail design on system, component and structural level, i.e. on different levels of abstraction. The levels of abstraction are represented by three concentric rings, whereas the outermost ring is most abstract. The design flow itself runs counter clockwise from conceptual to detail design becoming more concrete. For system design, during the first quarter, conceptual design is performed, then in the second quarter the system is basically designed and finally detailed. The design activity is a superposition of a bottom-up design approach from structural level to system level and of a top-down design approach from conceptual design to detail design. When deciding on system level for concepts, on structural level, structures already have to be detailed due to the strong influence of technology. Visualization of this activity results in a sickle-shaped curve. For the transition from functional description to embodiment, the junction of design and detailing has to be considered. Therefore, a "methodological stage of transition" is introduced. The designer approaches this transition stage with the results of conceptual design on system level. Main functions and subfunctions are extracted. Employing methodological means of support, e.g. effect catalogues, the designer finds effects, i.e. working principles that fulfil the subfunctions. Conceptual design derives from the combination of these partial solutions and consists of functional items and basic shapes without any quantified dimensions or specified materials. The system itself is subdivided into components. On structural level, details for the functional items are designed with respect to technological conditions and restrictions. The latter are provided externally by a knowledge representation, for which design rules are used. These design rules represent knowledge from subsequent life cycle stages, e.g. process preparation in terms of realizable structural details, e.g. the minimum edge radius. Thus, while synthesizing, the transition stage is required to adhere to invariant structural details.

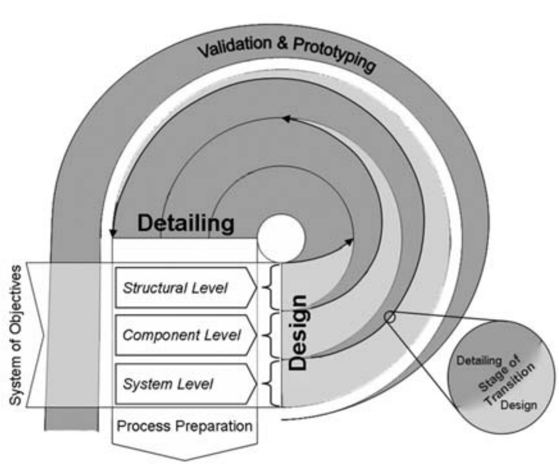

Figure 1. Design flow for tool-based microtechnology (sickle model [12]).

As an example, design of a micro gear is discussed: When beginning to concept the micro gear on system level, structural details like the tooth shape have to be considered. Assuming a powder injection moulding process, for production a mould insert is required. The cavity has to be scaled up by a certain percentage (shrinkage) and has to be milled. Employing one of the smallest off-shelf end mill cutters (100µm diameter), the minimum edge radius within the mould is 50μm. This strongly affects the tooth shape and results in a shorter involute and therefore in a reduced contact length. At the same time the tooth width is restricted by the cutting depth of 200μm, which influences the transmittable torque and hence the conceptual design of the gear system. [1] [4] [5] [12]

5. Tools and Methods for Knowledge-base Design

Designing technical systems, regardless of size, is a complex process, which is influenced by many parameters. Especially strongly technology-driven design, like that of microsystems, requires the transmission of knowledge and experience, which are gained within other stages, e.g. process preparation or production, in order to be able to design a functioning product. Generally approved means of supporting design decisions are design principles, guidelines and rules. Another method for supporting an inexperienced designer is the methodological documentation and knowledge representation, for which the authors propose a wiki system.

Knowledge-based Design in Microsystem Technology

Usage of design rules is a widely applied method for providing knowledge for designers. The terms design rule, design guideline, design advice or embodiment rule often are used in a synonym way, while the design rule term also is used for rules of varying levels of abstraction. Therefore, herein design rules are defined as instructions deriving from technological conditions and restrictions that have to be regarded stringently in order to achieve a realizable design. These technological conditions and restrictions derive from all methods and processes of process preparation, production and material science. They include all influences and effects being adjacent or subsequent to the design stage.

Due to the technology-driven design process and the hence higher importance of knowing about details from stages subsequent to design (production preparation, production) when designing microsystems, knowledge-based design of those systems is described.

Design of microsystems is a technology-driven process. Shape and material strongly are dependent on production. Especially within microelectronics, design rules are an established method for supporting designers in order to achieve products that are producible. The design methodology according to Mead and Conway [13] separates functional and physical design. This separation is enabled by design rules, which describe minimum geometrical values for certain widths, thicknesses, distances or superpositions on and in-between processes layers. Due to this separation, enterprises with costly fabrication lines (foundries) can provide their production facilities to several designers, like universities, small companies, etc. Often foundries and designer communicate by design rule kits. These kits include a set of design rules, which are relevant for the producer's fabrication line. Computer-aided design tools for microelectronics support design rules and enable online design rule checks for direct feedback during design.

Since microelectronic circuits are characterized by simple and repeatedly occurring two-dimensional patterns, design rule checking can be implemented. For mask-based microsystem design this approach cannot be applied due to the enabled third dimension, a greater shape variety and more applicable materials. Design rules within knowledge-based design are an established means of support within design in microelectronics and micromechanics. There are several references having investigated such design rule systems, e.g. Hahn [10], Leßmöllmann [11], Buchberger [8], Albers [3] and Marz [12].

Application of design rules is a powerful instrument for supporting decision making in design. After derivation of manufacturing-specific knowledge, design decisions can be founded on a stable grounding. Implementation of these rules in computer-aided engineering environments (such called knowledge-based engineering systems, KBE) can support designers during modelling, while less formal derivatives of design rules may already influence design decisions during earlier stages.

Derivation of Design Rules

During conceptual and embodiment design engineers have to decided on shape, material, manufacturing possibilities and many more aspects. Design rules as very concret and precise representative of the domain of design principles, guidelines and rules help to decide by providing information from subsequent product life cycle stages concerning manufacturing technology for example. The derivation of design rules is exemplarily described by those for tool-based microtechnology. First of all, the potential influence of existing domains needs to be detected. In a following step, all relevant machine and process parameters are extracted from process preparation, production or quality assurance. Regarding process preparation, exemplary conditions and restrictions are type and size of milling cutters, tool tolerances, machine tolerances or the realizable surface roughness. In a third step, these parameters have to be interpreted in a way relevant for design, i.e. external knowledge is transformed into a methodological knowledge that can be used by designers. Then rules are formulated, classified for the ease of access and filed in a database. Finally, they have to be provided by an information portal (cp. wiki in Figure 2) or can be integrated into a knowledge-based engineering system.

Wiki Support

Wikis are software tools for computer supported cooperative work [18]. They are content management systems enabling users to integrated informational aspects and files. Not only for supporting groups in communication, coordination and cooperation, a wiki especially can be used for documenting design information knowledge. Applying this tool for documentation, decisions cannot only be facilitated, but also the entire design process and design decisions can be reconstructed from a later point of view. Late design stages are characterised by a relative high level of structure, many participants, defined means of support and defined workflows. These late stages usually are supported by highly integrated software, e.g. product data management (PDM) or enterprise resource planning (ERP) tools. On the other side, early design stages, e.g. conceptual design, have a relative low structure, is characterised by individuality and small design teams and is not supported by specified means of software. Especially for those wikis have the necessary flexibility when integrating new content.

(UG/Knowledge Fusion) as well as a programmable user interface. In a rule database design rules are filed, based on which an online design rule check can be performed. The data comprises explanatory text, which is displayed in

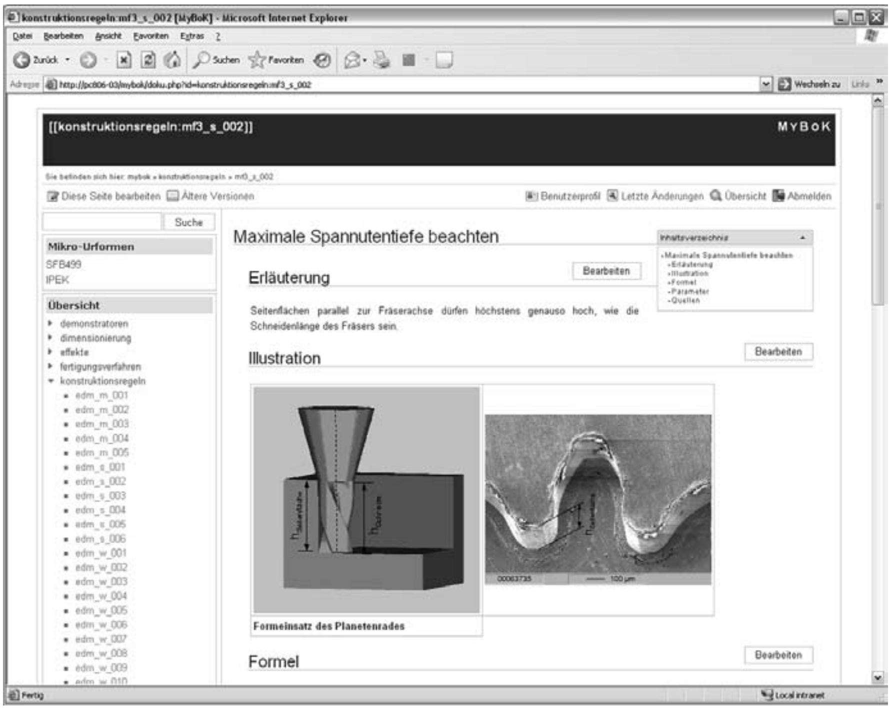

Figure 2. Design rule representation in a wiki system.

Wikis allow easy and instant collaboration over the internet, an instant "online-documentation" that is web-accessible *via* browser while no client application is required. Other advantages are versioning an page locking mechanisms, always up-to-date-versions, online discussion and improvement. It is very easy to revert unwanted changes. Pages easily are created and edited. Text formatting is simple and does not require HTML skills. Editing designers can focus on content instead of formatting due to easy syntax. Some wikis come with an (optional) What-You-See-Is-What-You-Get (WYSIWYG) editing functionality. Edited work is immediately visible. Finally low install and maintenance costs are a big advantage.

In product development, wikis can be used for all documentation processes. This makes them being very interesting for design. Based on a good documentation, the entire design process including all decisions can be reviewed and reconstructed. Further on, the same platform enables production engineers to share their knowledge regarding relevant features and properties of production technology. This knowledge representation can be realized in an unstructured way or by using design rules. All information can be accesses by using implemented search funtions. Figure 2 shows an exemplary design rule depicted in a wiki system for supporting design of tool-based microsystems. [6]

Knowledge-based Engineering

Realization of a knowledge-based design environment for primary-shaped microparts was shown by Albers [2]. Unigraphics (UG) was used as a compuer-aided design (CAD) system, which offers all possibilities of parametric design and includes a knowledge-based module

case of rule infringement, and the rule itself being formulated in IF-THEN-ELSE conditions. The IF-part is formally described as a mathematical equation. If the IF-condition is fulfilled, the THEN-part is carried out, otherwise the ELSE-part offers alternative actions, e.g. an automatic correction. [2][12]

Figure 3. Micro planetary gear on a Cent coin.

Figure 3 shows a micro planetary gear. As the feature being relevant for function, the module, is within micron range (m=169µm), the gear itself is classified as a microsystem, whereas its outer dimensions are within millimetre range (approx. 7mm). Design followed – obviously successfully – the presented design flow for tool-based microtechnology (sickle model) in combination the knowledge-based design as a methodological means of support.

6. Summary and Conclusion

The paper summarized models of development processes for the specific application of microtechnology to motivate the necessity of knowledge-based support tools for decision making in design. Increasingly becoming more complex, products can only be designed by (globally distributed) engineering teams, when supporting design decisions as early as possible and on a sustained basis that can be reconstructed from a later point of view. The paper points out wikis for decision documentation and knowledge representation by design rules. These rules then support decisions on geometry or material by just providing information or even by being integrated into CAD-systems.

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