INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006
Dubrovnik - Croatia, May 15 - 18, 2006.

DESIGN 2006

THE DEVELOPMENT OF THE GUIDELINE VDI 2221 - THE CHANGE OF DIRECTION

J. Jänsch and H. Birkhofer

Keywords: design guidelines, design methods research, development of design guidelines

1. Introduction

Design guidelines have been developed over the past 50 years. Analyzing this development gives interesting insights into the changing character of the design guidelines. Special insights are obtained concerning the intention and direction of the guidelines. These insights give, on the one hand, explanations for the still reserved application and acceptance of design guidelines, and on the other hand, evidence of their improvement. This paper aims to give an overview of the development of the design guidelines in German-speaking lands, point out certain aspects of changes (aim, advice, instructions, terminology, and description) and provide ideas about the consequences and potentials of these changes.

2. Objectives: Guidelines for Inventiveness and Designing

This chapter will introduce the relevant guidelines that have contributed to and influenced the guideline VDI 2221. The guidelines and the persons who have created them can be seen as connected in one way or another because the majority of the persons mentioned have known each other and worked together in the VDI-Committee “Konstruktionsmethodik” ("design methodology"). Therefore, the four following guidelines can be thought of as a coherent development.

2.1 Guideline for invention according to Kesselring

The first guideline for inventions was developed by Fritz Kesselring [Kesselring, 1954] in 1954. In his book “Technische Kompositionslehre”, he describes a guideline named *Guideline for inventions (Wegleitung zur Erfindung)* based on his own practical experiences. His aim was to identify conditions and operations of a successful invention and externalize them in an *inventive science (Erfindungslehre)*.

In order to derive an *inventive science*, he analyzes his own inventions incipient with the invention of an oil circuit breaker to a disconnect switch. His analysis ends with a guideline presented in figure 1. The aim of the guideline from Kesselring is to propose aspects of inventions which are common to all invention processes. The content of this guideline is directed at the individual designer, his situation and gives advice concerning thinking and acting processes.

The considerations for this guideline are only based on the personal invention experiences of Kesselring. The guideline suggests to associate, to set up analogies and to have breaks. Furthermore, the guideline recommends freeing oneself of prejudice and existing solutions. It also gives instructions, such as to study the domain-specific literature and patents and to make notes and sketches

of all ideas that come up. Regarding the terminology in this guideline, only "household" words are used. The description of the guideline is text-based only (see figure 1).

1. Study of the technical literature, patent specifications and relevant propaganda material together with the legalities associated however lightly with the problem at hand.
2. Working out of the technical and economic shortcomings of previous solutions.
3. Liberation and disengagement from all existing prejudices.
4. Getting perpetually caught up in the conviction, bordering on an obsession, that one can find something better.
5. Weighing up all the physical legalities, technological experiences, and possibilities that intuitively come to mind for a solution, whereupon one should not initially shrink away from combinations that seem absurd.
6. Conscious utilization of the physical-mental-emotional state favorable to inventing. Typical of this is that floating, often dreamy state that is punctuated by moments of clarity but forsaking all logical, particularly mathematical, considerations.
7. The immediate capture of all ideas, aphorisms, associations, analogies, etc., however vague, in the form of key words and sketches.
8. Taking a break to get back into a creative frame of mind; blocking, even almost forgetting what one has previously worked out, and yet always being certain that the right idea will come to mind sooner or later.
9. Catching and when possible recording inventive ideas, which hit one most often like a sudden flash, together with the thought associations, realization possibilities, modifications, etc. that accompany such ideas in torrents.
10. Relaxation, review of visions, overcoming the ever-present disillusionment, examining the realization possibilities, or, in the event that the idea proves not to be sound enough, starting over from square one.

Figure 1. Guideline for inventions [Kesselring 1954]

2.2 Basis system with four development steps according to Hansen

The second guideline was proposed by Hansen [Hansen 1965] in 1965 in the book "Konstruktionssystematik".

The basis system is based on a system-oriented view (see figure 2). The experiences and ideas were gained at Carl Zeiss JENA together with his employees and researcher Bischoff and Bock. Hansen talks of a basis system that is founded on the relationships between the task and facts of successful solutions. According to Hansen, there are indispensable regularities and patterns in the development process [Hansen, 1965]. These regularities provide the foundation for instructions and logical sequences of thoughts and actions. The aim of the progressive plan was to make the flow of work more effective and efficient. In particular, he urges one to think logically and proceed systematically. The formulation of the guideline according to Hansen is directed at an individual designer as well as general engineering work on an technical level.

The guideline contains the step of failure criticism. This step offers advice about the possibility to improve existing solutions. Further, he stresses the necessity for iterations and for putting something down in writing. The thinking process is described in the book on a very result-oriented level; the thinking process during designing is analyzed as a creative act. But it is not addressed in the figure and the text of the guideline. The instructions of this guideline are on a technical level and basically oriented on a logical proceeding and the search for an efficient solution. The instructions in the figure and the text are quite short.

Accordingly, the terminology in this guideline is mainly technical. The termini *basic principle*, *working principles* and *concept* are used. They are defined and in advances, especially, the termini *designing, concepting, defining*, etc. But Hansen addressed and discussed the problem of terminology within the field of designing. He tried to define and separate them from household words. The description of this guideline is figure- and text-based (see figure 2). The text is very close to the figure and contains some supplementary information and explanations.

1. Determine the kernel of the task, because this all solutions in common (basic principle).
2. Combine all possible assembly elements efficiently, because all solutions consist of such combinations (working principles).
3. Determine all the defects of the solutions and strive to reduce their effects (improved working principle).
4. Establish the solution with the minor defects (optimum working principle).
5. Create documents, that provide the practical use.

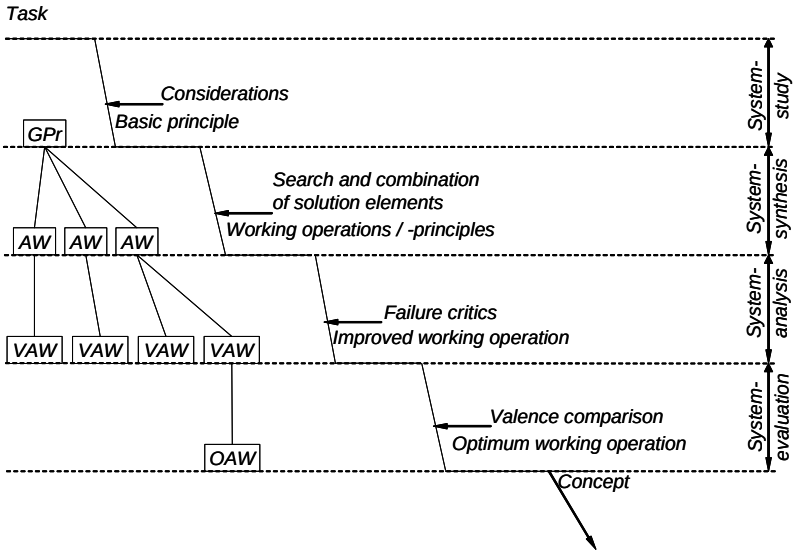

Figure 2. Stepped procedure [Hansen 1954]

2.3 The Guideline VDI 2222

In 1973 the guideline VDI 2222 *Design engineering methodics Conceptioning of industrial products* was set up on the proposals of Kesselring and Hansen by the VDI (Association of German engineers), the committee "design methodology" [Kesselring 1971]. Chairman of this group was Fritz Kesselring. So, the VDI 2221 was based on the practical experiences and scientific considerations of several professors. Among these were Beitz, Koller, Kollmann, Pahl, Rodenacker, and Roth. VDI 2222 was intended as a guideline to develop technical products in practice as well as a contribution for design education [VDI-Richtlinie 2222 1973]. The aim of this guideline is to provide a procedure for designing that is valid from precision mechanics to electrical engineering [VDI-Richtlinie 2222 1973]. The guideline is based on problem-solving processes and influenced by cybernetics. One desire for this guideline was to give designing a more scientific basis. Also, a central idea of the guideline was to assign design methods to the different design phases. The guideline encompasses the four main design phases: clarification of the task, conceptual design, embodiment design and detail design. Figure 3 shows this process with its steps. At every step, a decision has to be made as to whether the next step can be taken or whether previous steps have first to be repeated [Pahl, 1984].
The advice especially concerns the iterations and the adaptation of the requirements list during the complete design process given on the sides of the figure (see figure 3). Additional advice for the designers is given in the so-called 'Weißdruck' of the guideline, a 52-page text with detailed information about the guideline, examples of the application of the guidelines and relevant literature. The detailed information includes, for example, checking questions to establish the specifications. "What are the wishes and expectations of customers that are not mentioned? To what aim does the

solution strive? What properties of the solution are not allowed?" Also, the problem of freeing oneself from prejudice is addressed there. The 'Weißdruck' states: "To free oneself of fixation on solutions, it is advisable to start with the abstraction of the task" [VDI-Richtlinie 2222]. The instructions are action-based and procedure-oriented and are directed at finding a solution. The actions steps are divided in actions and decisions. The formulation of the instructions is abstract, such as *setting up a function structure* or *searching for solution principles*.

The terminology in this guideline is rather abstract and technical. New termini like *requirements list*, *function structure*, and *concept variants* were generated. The description is based on figures and text. The text (Weißdruck) that belongs to the VDI 2222 gives detailed descriptions of the procedure itself and the thinking process. Remarks are made about the thinking process, intuitive and descriptive thinking, goal-oriented thinking, and thinking failures. Also, one can find basic methods (also called heuristics), such as method of questioning, method of negation and new conception, method to move forward, method to move backwards, etc. [VDI-Richtlinie 2222, 1973]. Within these methods concrete advice is given on what one might specifically do while searching for solutions.

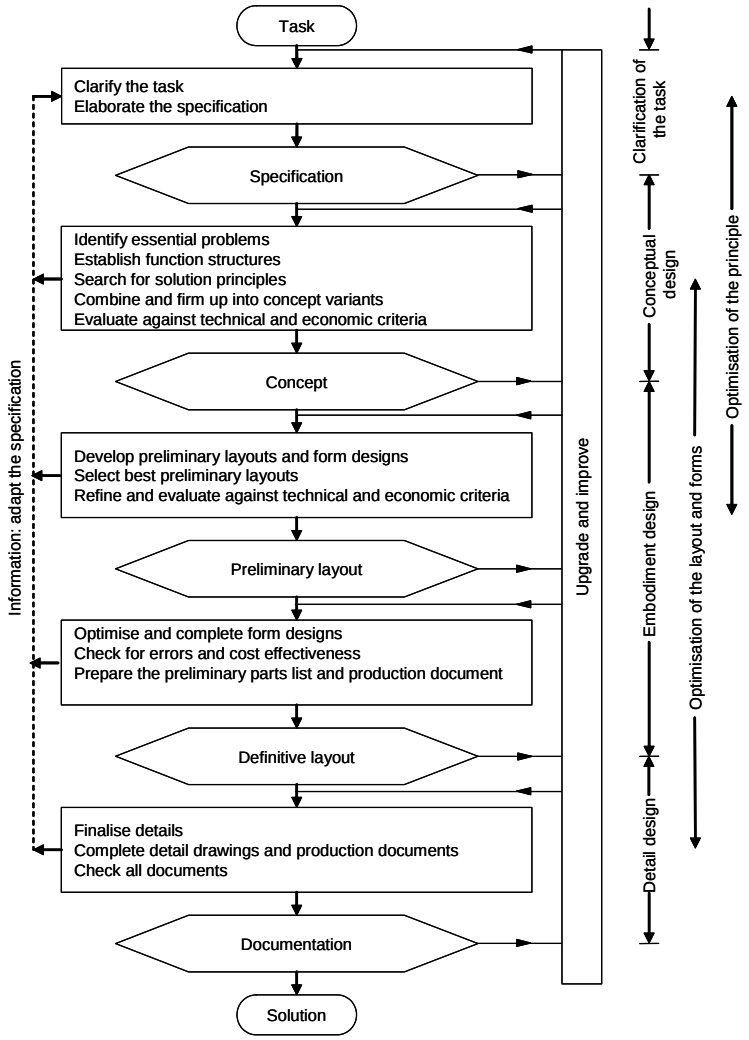

Figure 3. Guideline VDI 2222 [VDI-Richtlinie 2221 1993]

2.4 The Guideline VDI 2221

In 1993 the VDI 2222 guideline was replaced by the VDI 2221 guideline *Systematic approach to the development and design of technical systems and products* [VDI-Richtlinie 2221 1993]. The guideline is still based on VDI 2222. The goal of this guideline is to propose a general methodology for designing technical systems and products and to support a methodical and systematic designing, in order to produce a more efficient working style. The guideline is independent of the branch and addresses content and organizational aspects of designing. It stresses the broad application within mechanical engineering, precision mechanics, switches and software development and the planning of process engineering [Pahl, 2003]. The guideline is based on systems engineering and problem-solving.
One main aspect of it is the integral data processing and the application of CAD. This aspect takes up a third of the description in the Weißdruck.
The remaining advice addresses the iterations of the process and the adaptation of the requirements list during the whole process (see figure 4). The advice in the Weißdruck of the guideline contains more results of research than practical hints for thinking and acting. This means that the checking questions, for example, have changed into the requirements of a good problem-solver. So, the Weißdruck contains a paragraph with the research results of a successful designer [VDI-Richtlinie 2221, 1993]. The checking questions like those in VDI 2222 as well as the advice concerning the thinking process are omitted. The instructions of VDI 2221 compared to VDI 2222 are reduced to "establish the function and their structures, search for solution principles and their structures and structure in modules" (see figure 4). The terminology is more abstract then in VDI 2221. Especially the termini *modules and module structure* are introduced. The description is demonstrated pictorially with the flow chart and the Weißdruck text. The Weißdruck encompasses 42 pages. In the figure it is only differentiated between instruction and working results. The steps of decisions have been omitted.

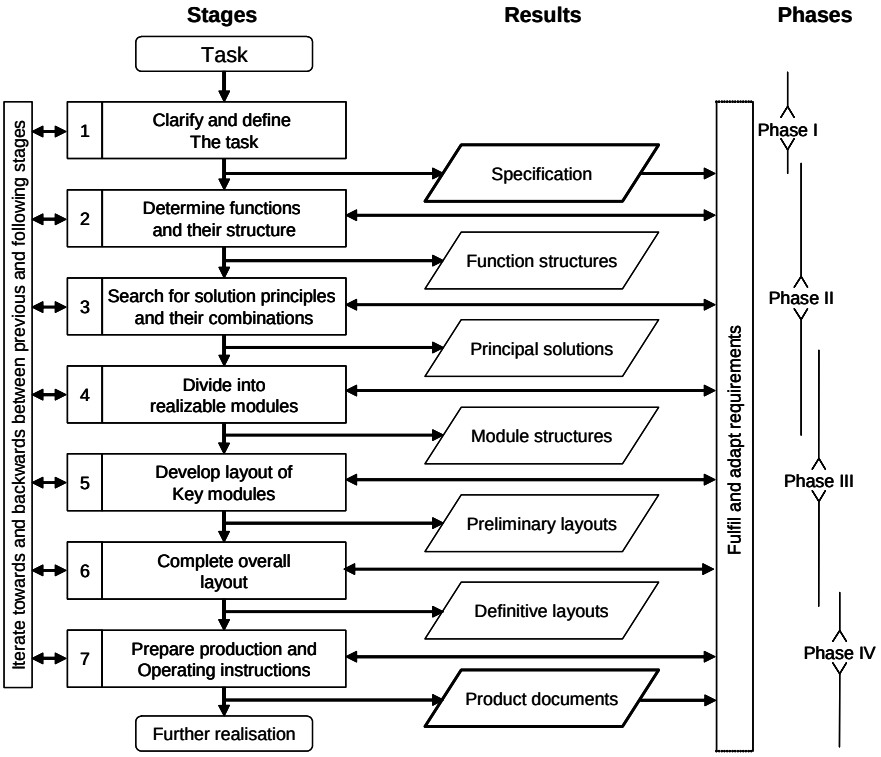

Figure 4. Guideline VDI 2221

3. Changes and Alternations of the Guidelines

The analysis of the four guidelines point out the change and alternation of the aim, the basis, the direction, the advice, the instructions, the terminology and the method of description. Comparing these aspects during the development from the procedure for inventions according to Kesselring to the VDI 2221, some remarkable changes and alternations have come to pass. These changes and their consequences for the effect of the guidelines on individual designers will be considered in the next four sections.

3.1 Changes of basis, aims and direction

The basis of the guideline started with Kesselring with personal experiences and the search for constant facts during the act of invention. Hansen has already gathered his experiences with two other persons (Bischoff and Bock in Carl Zeiss Jena). The VDI guidelines are the product of more then ten persons' scientific and practical experiences. Kesselring created the guideline by transforming the porcedure and the incidences of his inventions. Hansen established his guideline already more on the system idea and methodological thought, like the title and foreword of his book illustrate (design systematic). The VDI guidelines focus more and more on system engineering, problem-solving, and cybernetics, partly dependent on the desire to give designing a stronger scientific foundation. The aim of the guideline to support a more efficient and foreseeable invention process has changed and broadened towards a support of the complete design process in a company where many types of people, not only designers, are involved. The generality inherent in all guidelines has been greatly increased and currently implemented. The direction of the guidelines has changed from a personal support for individuals (Kesselring) towards a general procedure for a company addressing organization and content (VDI 2221).

3.2 Change of advice

The advice in Kesselring's guideline addresses the individual designer in his/her thinking, acting, and actual situation. Already the guideline from Hansen and his employees have become much more technically oriented. They certainly give advice for iteration and failure criticism, but there is already much information based on research results. VDI 2222 has besides the iterations and the continuous adaptation of the specification no advice in the flow chart, but gives comprehensive and firsthand advice in the Weißdruck that are immediately practicable. VDI 2221 retains the advice in the flow chart but has reduced the firsthand advice in the Weißdruck decisively in favor of the research results and computer support in design. The advice within the guidelines have changed from addressing concrete thinking processes to general problem solving advice. Kesselring suggests associating and setting up analogies as well as searching in failures, etc. VDI 2221 suggests making iterations and adapting the requirement list continuously.

3.3 Change of instructions

The instructions have changed from statements that can be immediately put into action or thought to instruction on an abstract level, which need to be adapted to the current situation of the designer. For example, Kesselring instructs designers to study domain-specific literature and patent and write ideas down. VDI 2221 instructs the designer on establishing a function structure or structure modules.

3.4 Change of termini

The termini within the guidelines have changed from household words into newly created abstract technical termini. Kesselring was working with household words. Hansen already switched to technical termini, which he established and defined (*basic principle*, *working principles* and *concept*). He mentioned the problems in finding the suitable terms in the domain of designing. In order to provide generality, new termini were needed. The VDIs introduce new termini, guided by their new insights and methods (e.g. function structure) and the pursuit of generality. Furthermore, it is difficult to agree on a certain term within such a large working group like the VDI working group, and this also

leads to more abstract and general termini. This development of termini already shows that there is a central need in design to find, use and create suitable termini, which are understandable and not misleading. Nowadays, there is a mixture of daily terms (*function*, *modules*) and newly generated technical terms (*concept*, *specification*). An additional problem in this field arises on account of the fact that one term has different meanings in different knowledge domains in which the guidelines can be applied (mechanical engineering, system engineering, etc.). The problem increases when translating new technical termini into other languages.

3.5 Changes of descriptions

The appearance of the descriptions of the guidelines have altered from a pure one-page text-based description to comprehensive descriptions with figures, in particular flow charts and in-depth texts. The content of the descriptions has been enhanced with figures, examples and a quantity of text. An important role is taken on by the figures, especially by the flow charts of VDI 2222 and VDI 2221. In books, presentations, seminars and lectures one usually finds the flowchart of the VDI's, but seldom the complete text of the Weißdruck. So, the flow charts have become the dominant and focused part of the guideline, also because human cognition responds more to figures and perceives and remembers figures better. Due to this fact, a loss of important information takes place. The analysis of the content in the Weißdruck has shown that there is much information in particular for the human thinking process, which is missing in the figures and is only mentioned in the Weißdruck.
The insights of designing and the design process have increased considerably over the last 50 years. These insights of generality, requirements, computer-based support, suitable structures, etc. have been integrated in the descriptions, but the figures are company- and process-oriented and so the directly applicable information for individual designers are placed in the background.

4. Result: The development from an individual towards a company directed design guideline

The analysis of the guidelines has shown that a development from individual thinking and acting to a holistic, general and company-oriented direction has taken place (see figure 5). The idea and the wish to put designing on a scientific level has to a large extent been realized. The striving for generality of the guideline in different branches has been realized in the guideline by the abstract terminology and the formulations of the (technical) logical processes. The research results in designing are implemented in the guideline with the intention of implementing them in practice. Therefore, the individual designers have taken a back seat regarding the guidelines and their descriptions.
Especially within the figures of the guidelines the individual designers have taken second place to company-directed aspects. The advice concerning thinking and action has dwindled and become more abstract and been placed in the textual description. The same has happened to the instructions; they have become more abstract and abridged. The terminology has changed from household words understandable by everybody to new abstract and technical termini that require considerable background knowledge for a correct interpretation.

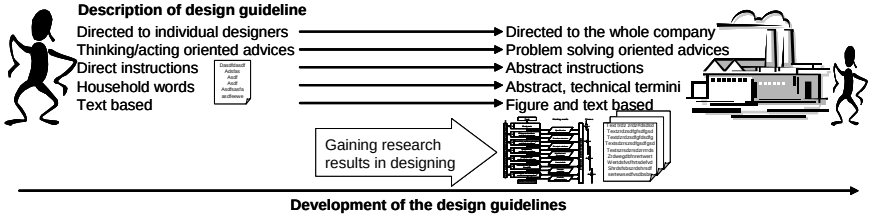

Figure 5. The development of changes in the guidelines

According to this development, the demands on designers who should work with the guidelines have been increased. The designers have to have a holistic and comprehensive view of the design process to have an adequate understanding of the guideline and to adopt and apply it appropriately. Furthermore,

they must be familiar with the complete guideline: figure, text and terminology. When applying the guideline, they have to adopt the abstract instructions and advice into their thinking and acting processes and the current situation. The first guidelines certainly contain less information and research results, but they seem easier to understand and to apply to the individual designer. So, most of the identified changes might cause acceptance and application problems of design methods in industry. From this point of view, it seems to be considerable to let science, industry and teaching come closer together and seek for useful chances for all the parties.

5. Conclusion and Outlook: Consequences of this development for the understandability and acceptance of design methods

The consequences that could be concluded from these considerations is that science, industry und teaching have to work closer together in order to bridge the gap between the offered design methods by science and the demanded methods from industry. This means, that science has to transform the scientific results into concrete instructions for action in the guideline. Further, science has to focus more on the actual problems in industry. To gain experience, science has to go into industry and adopt their methods and collect impressions what are the demand of methods in industry [Birkhofer et. al. 2005]. For VDI 2221 this would mean generating an additional description of the guideline that is directed and adopted to the individual designer and to the identified problems. This description should include a figure that points out the most important facts for the work (thinking and acting) of the designer, which are already mentioned in the Weißdruck of both VDI guidelines. The teaching of design methods has to be taught more method-suitable in order to train the abstraction of design methods and their adaptation. These contemplations do not criticize the development of the guidelines and the guidelines itself. Rather, they should serve more as a reminder that there are many important and valuable research results for the individual designer in all of the guidelines contained, but not effectively used.

References

Birkhofer, H., Jänsch, J. und Kloberdanz, H. An extensive and detailed view of the application of design methods and methodology in industry. In: Samuel, A. and Lewis, W. (Hg.). ICED 2005 Proceedings. Australia, Melbourne, 2005.

Kesselring, F., "Technische Kompositionslehre", Springer, Berlin, 1954.

Hansen, F., "Konstruktionssystematik", VEB Verlag, Berlin, 1966.

Kesselring, F., Winterthur, A. "Methodisches Planen, entwickeln und Gestalten technischer Produkte", Konstruktion 22, 1971, pp.121-128.

Beitz, W. „Möglichkeiten methodischer Lösungsfindung in der Konstruktion", Konstruktion 23, 1971, pp. 161-167.

Pahl, G., Beitz, W., "Engineering Design", Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 1984.

VDI-Richtlinie 2222, „Konzipieren technischer Produkte" VDI-Verlag, Düsseldorf, 1973.

VDI-Richtlinie 2221, „Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte", VDI-Verlag, Düsseldorf, 1993.

Pahl, G., Beitz, W., „Konstruktionslehre, Grundlagen erfolgreicher Produktentwicklung, Methoden und Anwendung", Springer, Berlin, Heidelberg, 2003.

Dipl.-Wirtsch.-Ing. Judith Jänsch
Research Assistent
Darmstadt, University of Technology, product development and maschine elements (pmd)
Magdalenenstr. 4, 64283 Darmstadt, Germany
Tel.: + 49 (0) 6151 16 3055
Fax.: + 49 (0) 6151 16 3355
Email: jaensch@pmd.tu-darmstadt.de
URL: http://www.pmd.tu-darmstadt.de