APPROACHES FOR THE SYNTHESIS OF TECHNICAL SYSTEMS WITHIN THE CONTACT AND CHANNEL MODEL C&CM

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1 Introduction

The Elementary Design Model C&CM (Contact and Channel Model) describes the correlation between function and shape of technical systems. This correlation exists in the form of the smallest, functional – relevant areas of technical systems: the Working Surface Pairs (WSP) and the structures linking them, the Channel and Support Structures (CSS). The model is being developed at the Institute of Product Development (IPEK) of the University of Karlsruhe (TH) since 1999.

Apart from C&CM, design principles, guidelines and rules are supporting the designer in fulfilling the requirements of a technical system. They exist on various levels of abstraction. Some of them are formulated in the abstraction level of functions – e.g. the principle of task sharing - and some of them are formulated in the level of shape – e.g. the principles of force transmission. So the strategy of applying them to a special design problem is not self-evident.

This paper describes how design principles and guidelines were found and applied in the abstract level of C&CM. The correlation between shape and function of C&CM helps to find the optimal principles for a problem and to apply the chosen principles in an efficient way without losing the view for the consequences for the whole technical system.

Section 2 gives a brief overview over the basics of C&CM and about its application during the synthesis of technical systems. Section 3 gives an example for this application on a real problem and section 4 will summarize the benefits for the designer and the needs for future research.

2 C&CM

The thinking model C&CM is a way of regarding technical systems with a view simultaneous on the function as well as on the shape of the system. The definition of the *Working Surface Pairs* and the *Channel and Support structures* as the geometrical entity where technical functions are fulfilled and additional basic definitions of their correlations are an important further step that helps the designer to understand the function of existing technical systems and to create new ones.

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The basics of C&CM are described in section 2.1. The development of heuristics on the abstraction level is described in section 2.2 and section 2.3 shows an approach for the visualization of the properties of the basic elements of C&CM.

2.1 C&CM basics

Conventionally engineering products are modeled by components with defined geometry, which are grouped into sub-system and systems. The C&CM approach takes a different cut on the geometry, by using Working Surface Pairs, which carry out functions and Channel and Support Structures that sit between the working surface pairs and link them. This idea was originally purposed by [3]. It bases on earlier considerations of important design scientists like e.g. Releaux [10], Rodenacker [11], Roth [12], Koller [7], Hubka [6] and others and enlarges these by some important definitions concerning the relations between the basic elements of different technical systems. The experiences of the authors with the description of many technical systems indicate that the concepts defined in the following are sufficient to describe any system with any functionality:

- **Working Surface Pairs (WSP)** are all pair-wise interfaces between components and a component and its environment. This can be solid surfaces of bodies or boundaries with surfaces of liquids, gases or fields which are in permanent or occasional contact with the Working Surface. They take part in the exchange of energy, material and information within the technical system.

- **Channel and Support Structures (CSS)** are physical components or volumes of liquids, gases or spaces containing fields, which connect only two Working Surface Pairs. They do not only transfer the system variables energy, material and information from one Working Surface Pair to the other but they can also store them (e.g. the mass inertia).

- **Limiting Surfaces (LS)** are surfaces that are not involved in fulfilling the regarded function of a system. But they are potential working surfaces. E.g. the side of the crane pillar in Figure 1 only needs to be regarded as a Working Surface, when wind is considered or when it fulfils any other function that the designer has to think about.

- **Remaining Structures (RS)** are those volumes of material that do not fulfil any function but are nevertheless part of the system. Examples for Remaining Structures are production-caused parts of a molded housing. Removing them would not change the function of the system but would cause additional costs.
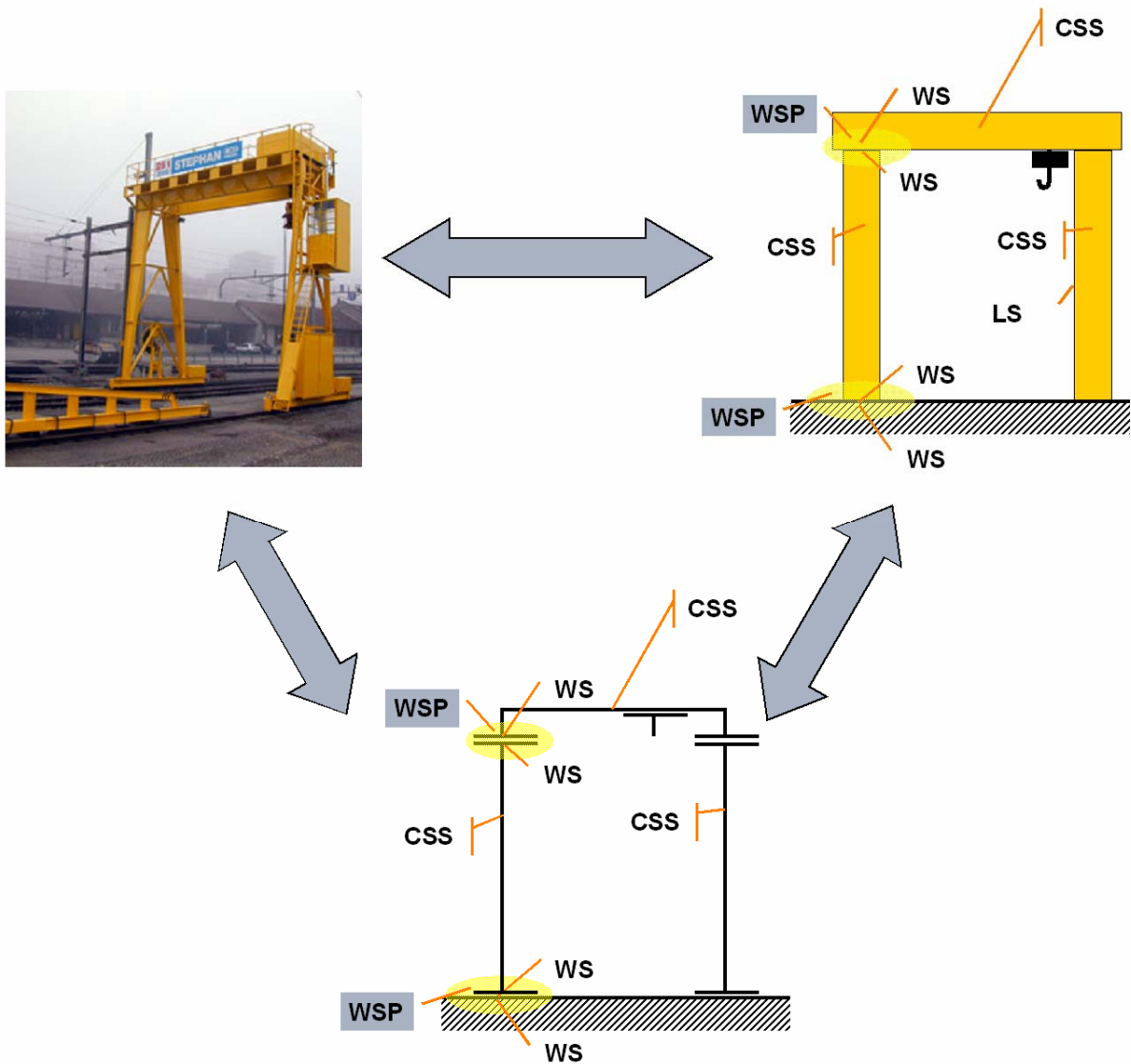
Figure 1. The abstract description of a product in C&CM

The function of a technical system is exclusively determined by the properties of the Working Surface Pairs and the Channel and Support Structures of this system. [1]. These properties include all information about the basic elements: the material, the area / volume, the relation with other basic elements, all physical and chemical properties and many more.

Due to the strict definition of these terms the C&CM cannot be applied only to solid systems but also to any technical system occurring in Mechanical Engineering – for example the oil film of a journal bearing or the magnetic field of an electric motor.

In addition to basic hypotheses and definitions the Element Model also contains tools and methods to make its application easier so that it can be regarded as a considerable aid during the design process.

2.2 C&CM Heuristics

Principles, guidelines and rules from literature [9], [13], [12] and others were analysed and made available on the abstract level of the Element Model C&CM. The correlation between function and shape of technical systems is very helpful in this case as some of the principles are formulated in the level of shape and some in the level of functions as described in section 1.

In a further step these principles, guidelines and rules are compared and classified. Some of them are combined to new, comprehensive principles and many new ones are found. So a set of consistent heuristics is created in the abstraction level of C&CM. They all can be applied in the functional abstraction level as well as on the abstraction level of the shape of the technical system. These heuristics are classified by patterns of application for a better overview about the possibilities to change the properties of a technical system. One example for these heuristics is shown in Table 1:

Table 1.   Example for a solution heuristic

Problem	Create a Detachable Connection	
Solutions	Frictional Working Surface Pair is to be added to the technical system	"elasticity" of a Channel and Support Structure must be increased so that that form closure within the technical system can be deleted
Example	clamping or screwed connections	snap-on caps

Additional to the classical principles, guidelines and rules new ones have been established based on for instance new experiences or technologies. One current example is the micro technology, where new experience is gained in some Centres of Excellence in Research and is consistently transformed into new design principles, guidelines and design rules. The design guideline „micro-oriented" is one example, which considers the special impacts of the manufacturing processes of micro technology with all its restrictions [2].

The newly established heuristics are made available for the designer in a way that safeguards an efficient way of application. Coherences between the original principles from literature and the newly found heuristics are documented. So the designer can easily switch between the different abstraction levels or even switch between the original principles and the new heuristics.

For an easier application during the synthesis of a new technical system the heuristics were classified by patterns of application. All of them can be categorisized depending on what is changed in the technical system: the number of Working Surface Pairs and Channel and Support Structures or their Properties. So there are four patterns of application including all of the developed heuristics:

1. Adding WSP and CSS

2. Removing WSP and CSS

3. Changing the properties of WSP

4. Changing the properties of CSS

In addition to these patterns of application there are some further possibilities of classifying the concrete rules: E.g. heuristics with the same intention and heuristics that demand the same or similar actions.

2.3 C&CM Drawings

For a defined and effective documentation of the properties of Working Surface Pairs and Channel and Support Structures a set of graphical symbols is being developed. The structure of this way of indicating WSP and CSS is similar to DIN ISO 1101 [5]: Each property is placed in a square. The left of the squares indicates the kind of property which is defined. To the right there is more and more detailed information about the property.

For an easy optical differentiation from the symbols of DIN ISO 1101 the edges of the squares are rounded.

A simple example can be seen in Figure 2: The working surface pair between the piston of a hydraulic cylinder and the fluid medium in the piston chamber is marked. In this first step there is little information about the Working Surface Pair documented in the drawing: The left of the squares indicates that a Working Surface Pair is described (in contrast to a Channel and Support Structure). The right of the squares indicates the state of aggregation of the two Working Surfaces: The left one is solid and the right one is liquid.
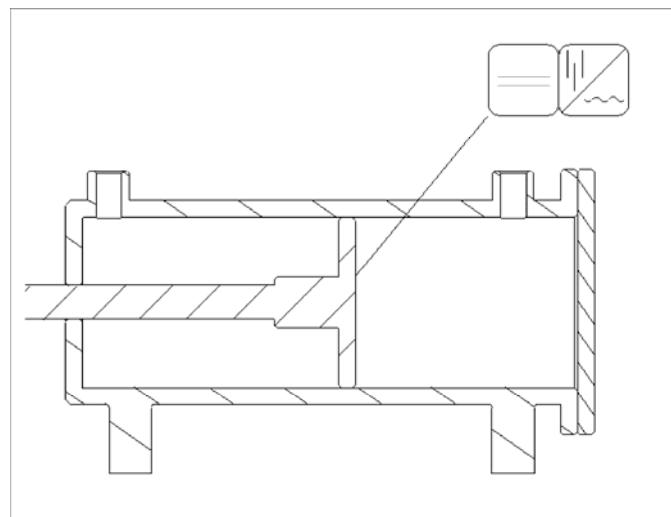

Figure 2. Designation of a Working Surface Pair

This description of the Working Surface Pair can be specified arbitrarily. Any information about the Working Surface Pair can be added in form of a pre-defined or self-defined symbol or in form of a short additional information.

Figure 3 shows the same Working Surface Pair with a lot more of information:

The first line of symbols did not change. The second line stands for the system variable that is mainly transmitted in this Working Surface Pair: It is energy. (There is also a transmission of information and maybe of material in this Working Surface Pair, but they are in this case subordinate.) The kind of energy is even explained more particular with the symbols that are arranged to the right of this line: It is mechanical energy in form of a force that is transmitted and this force is oriented orthogonal with the Working Surface Pair (It is a kind of form closure).

The symbol of the third line explains that there is no or at least no significant relative movement of the both Working Surfaces. The Working Surface Pairs at the sidewall of the cylinder would have another symbol as here the fluid will move relatively to the wall.

The symbol at the bottom means that the Working Surface Pair is permanently in contact. Other Working Surface Pairs – for example those of the valves of the hydraulic system would have a symbol for a contact at some discreet times.

Depending on the case of application more symbols for special properties or functions of this Working Surface Pair can be added.
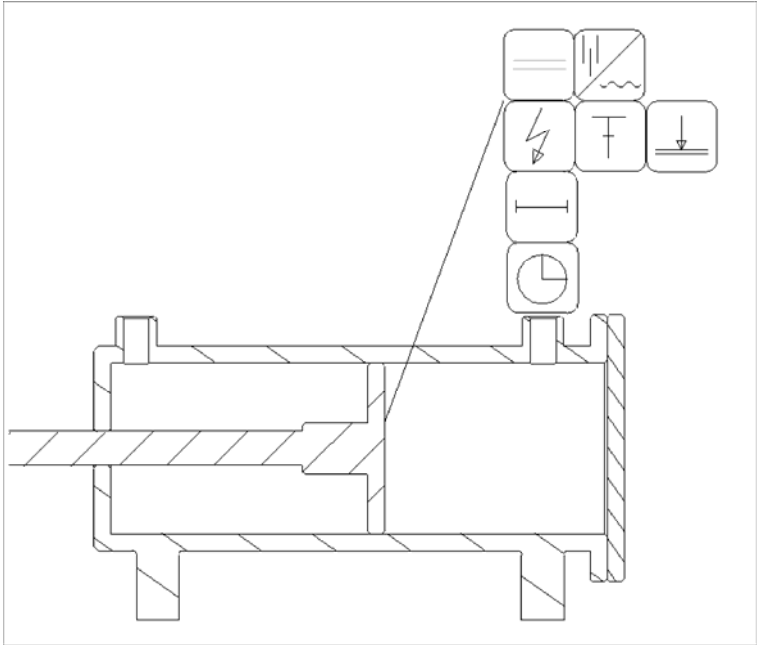

Figure 3. More information about the Working Surface Pair

3 Example of application

The Element Model C&CM supports the thinking process both during analysis as well as during synthesis of technical systems. The solution of the simple problem of moving a rotating shaft of a mechanical stirrer up and down (shaft 2 in Figure 4 – "creative part") will show the advantages and facilitation of thinking with C&CM during the design process of technical systems.
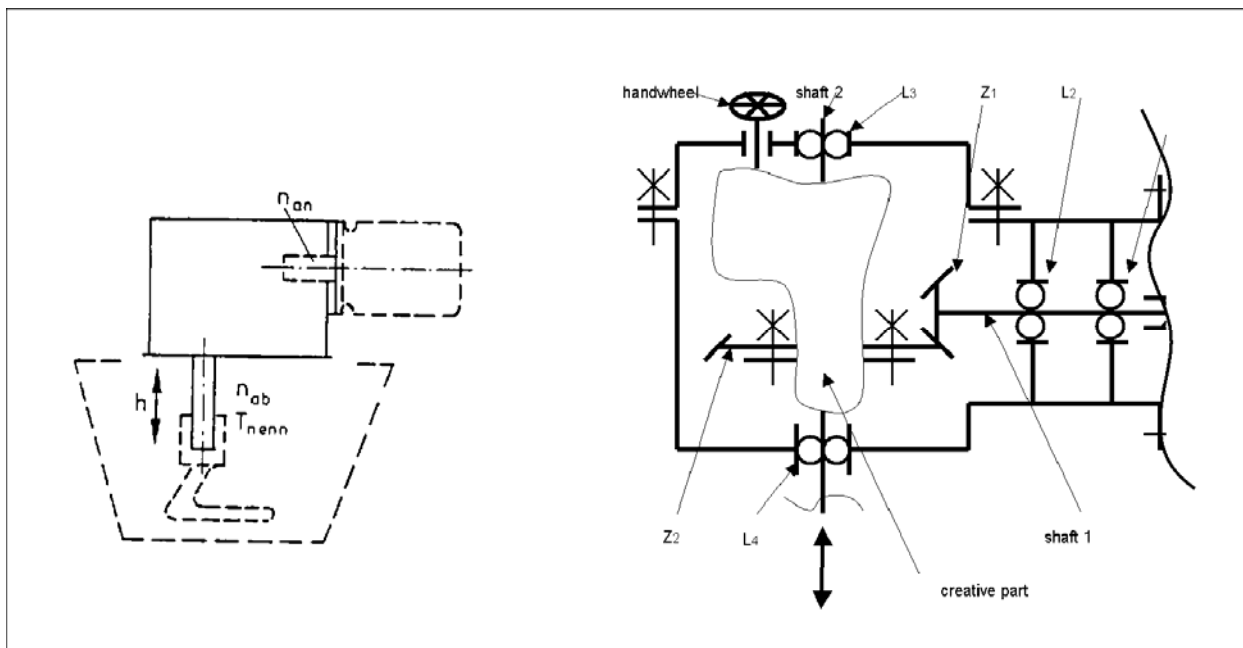

Figure 4. Principle of the design task

The designer is given a principle solution for the task "transmit torque and rotations from shaft 1 to shaft 2" in the right part of Figure 4. The additional function "Move the stirrer up and down during operation" is not yet fulfilled. One of the C&CM-heuristics that are described in section 2.2 is shown in Table 2:

Table 2.   Solution heuristic for fulfilling an additional function

Problem	Add an additional function to an existing system	
Solutions	Insert (at least) one additional Working Surface Pair that fulfills the additional function	Change the properties of an existing Working Surface Pair so that this Working Surface Pair can fulfil the additional function.

Deciding the first possibility (inserting an additional Working Surface Pair), the properties of this Working Surface Pair have to be defined (Figure 5a). As the C&CM-Model connects the function and the shape of the system, the function of the Working Surface pair has to be defined first. This is: "Move the rotating shaft in vertical direction and fix it on definite positions".

So the Working Surface Pair has to transmit forces and the information of the axial position of the shaft (Figure 5b). Also there will be a relative movement of the both Working Surfaces (Figure 5c).
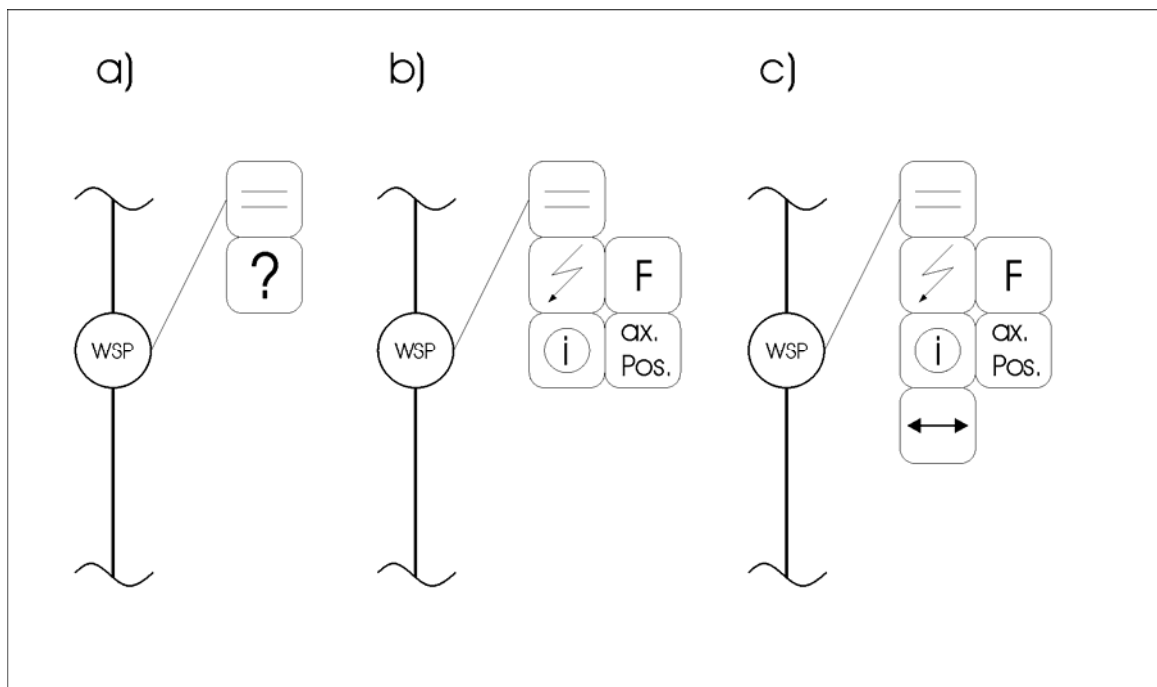

Figure 5. Development of a WSP with its properties

The next decision will e.g. be that both of the Working Surfaces are solid and that the force is to be transmitted by form closure, i.e. orthogonal with the Working Surface Pair. With these information the geometrical orientation of the Working Surface Pair can be defined as shown in Figure 6d.

Keeping in mind that a sliding contact between two surfaces can not transmit tractive forces but only pushing forces, the developed Working Surface Pair will not be able to fulfil all of its requirements. It can only transmit forces upwards the shaft. The force transmission downwards must be fulfilled by a unique Working Surface Pair that can have the same properties but has to be oriented in the other direction (Figure 6e).
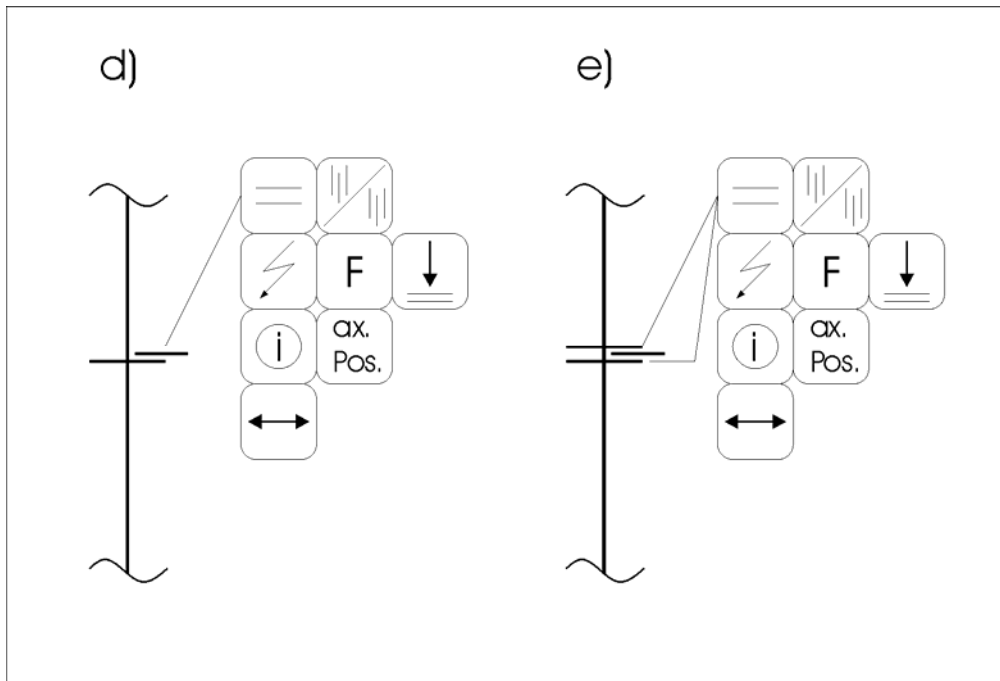
Figure 6. Further development of the WSP

With this step a kind of plain bearing is developed. This solution is e.g. used as selector forks of manual shift transmissions in automobiles.

Of course many more Working Surface Pairs have to be defined before the desired function can be fulfilled. The way of defining their properties can be defined intuitively if it is a standard problem or the same way like the regarded Working Surface Pair if the solution seems to be not self-evident.

To implement further functions or to enhance the quality of this solution further Working Surface Pairs must be added or the properties of existing Working Surface Pairs must be modified or augmented. This way e.g. lubrication can be improved, the best way of using rolling bearings in this situation can be explored or functions like the measurement of positions or forces can be added.

A big advantage of this proceeding is that every idea of solving a problem or a task is directly and clearly documented and that the functional specifications always have a geometrical pendant.

4 Conclusions and Future Research

The new set of principles and the new way of inserting symbols into drawings is tested at IPEK since the first steps of its development. The newly created set of principles, guidelines and rules has yet been successfully applied to several standard design problems as well as to very complex problems of design science.

In several centres of excellence the new set of heuristics on the abstract level of C&CM was used. E.g. the heuristic "Add a new Working Surface Pair" was one of the most important supports in finding a way for the successful application of ceramics in a CVT gear in a current center of excellence in research.

The described success achieved by the application of the newly established principles and symbols makes obvious that they are of great value for design research and that it will be necessary to upgrade and structure them rapidly further for making them available in research and technical application.

The IPEK-Institute is researching further heuristics and symbols and the way of their application with great effort. The next step will be the development of a reliable strategy supporting the designer in finding the correct heuristic for solving a concrete problem.

Creating drawing symbols for analysis and synthesis of technical systems is a further field of research at the IPEK-Institute. Not only basic correlations but also complex physical effects and functions for that several Working Surface pairs are necessary (e.g. the spline effect) are analysed and documented.

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