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PRINCIPLES FOR DESIGN ON THE ABSTRACT LEVEL OF THE CONTACT & CHANNEL MODEL

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ABSTRACT

By means of the elementary design model "Contact & Channel Model C&CM" developed at the Institute of Machine Design and Automotive Engineering of the University of Karlsruhe (TH) (mkl) it is possible to connect the shape-oriented level of describing technical systems with the corresponding function-oriented level. Design principles as well as design rules have been examined and made consistently applicable on the level of the C&CM. This level enables the designer to evaluate principles, which in their unmodified form concern to different abstract-tion levels, and to recognise a superior structure due to which new, superior principles and rules can be derived. By transforming the original form of the rules to their new form on the consistently abstract level of the C&CM a vast improvement of the applicability as well as the advantages of application for the designer can be achieved. At the mkl these rules have been successfully applied in various Centres of Excellence in Research in order to substantially enhance technical systems. One example for this is the contact between pin and disc of a CVT transmission. Here the newly generated rule "adding a further Working Surface Pair" helped finding an innovative new technical solution.

KEYWORDS

Element model "contact and channel model C&CM", working surface pairs & channel and support structures, rules, principles, guidelines

1. INTRODUCTION

The design process of a technical system is a complex process which involves many parameter so that it is not possible to realise its complete and reliable automation even in standard design problems. As a result, the human mind is still indispensable for carrying out this process.

Saving and transferring the gained experience of a professional working designer is an important component for guaranteeing a company and a market economy permanent success.

An approved method to support this process is creating guidelines, principles and rules which enable the designer to document his experience with a technical system. Although literature already provides a large number of these rules, new ones are constantly developed.

Another effective method is the documentation of the own thinking process and thereby applied or developed methodology, which is to support the inexperienced designer to usefully organise his thinking process. One example for this methodology is the elementary design model "Contact & Channel Model" C&CM. [Albers, A et al., 2002].

In this paper the both methods, the guidelines, principles or rules and the Element Model C&CM are combined in order to provide a more effective support for the design process.

2. OBJECTIVES

2.1. C&CM - Basics

The Institute of Machine Design and Automotive Engineering of the University of Karlsruhe (TH) (mkl) started developing the Element Model “Contact & Channel Model C&CM“ in 1999 [Albers, A and Matthiesen, S, 2002 and Matthiesen, S, 2002].It connects the abstract level of functions with the concrete level of the shape of technical machine elements and systems.

Working Surface Pairs (WSP) and Channel and Support Structures (CSS) are basic elements of this design model and they define the interface between these two abstraction levels.

Working Surface Pairs are the surfaces of a technical system via which system parameter such as material, energy and information are transmitted. Channel and Support Structures always connect two Working Surface Pairs and can therefore be regarded as a linkage. Channel and Support Structures conduct system parameter such as material, energy and information from one Working Surface Pair to the next. Apart from that they can also save these system parameter for giving them to one of the two Working Surface Pairs some time later.

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. [Albers, A. and Matthiesen, S, 2002].

Due to the strict definition of these terms the C&CM cannot only be applied 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 electro 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. Design principles and guidelines

Apart from the Element Model C&CM literature [Beitz, W. and Grote, K.-H., 1997 and Pahl, G. and Beitz, W., 1997] provides a large number of classical principles, guidelines and rules on different concrete levels, which are supposed to help fulfilling the requirements of technical systems.

Design principles and guidelines are valuable aids for the designer to effectively use previously gained experience in a current design and also making this experience available for other designers.

The main objective is now to find innovative solutions and to make it easier for the designer to develop and improve technical systems to safeguard a further competitive advantage.

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. [Albers, A. et al.., 2003]

These principles and guidelines are formulated in different abstraction levels. Most of them are located on the shape level, e.g. the principles of force transmission. In order to achieve an improvement it is not necessary to change one of the functions or partial functions of a technical system but to alter the shape of a system while keeping the given function. Some of the guidelines and principles have also been formulated on the abstraction level of the functions, e.g. the principle of task sharing or self-help. A change in this area is only possible by altering the function or partial function of one or more machine parts.

The objective of this thesis is to establish a set of rules and principles, consistent with the abstract level of the Element Model C&CM, which may be a help to the designer during the product development phases "conceptual and embodiment design" as well as for problem solving. The designer should be enabled to consistently apply the existing guidelines on this clearly defined abstraction level of the Element Model C&CM. Since the C&CM-method is shape-oriented as well as function- oriented, the simultaneous consideration of this both levels of abstraction during the design-process is possible.

Thus, the applicability of the existing guidelines and principles are to be made easier on all abstraction levels by making them consistently available on a very abstract level. At the same time a method is needed by means of which it is possible to move from this abstract level very quickly to a real shape level.

Moreover, it needs to be checked whether these guidelines can be newly classified and summarised on the abstract level of the C&CM or whether it is possible to formulate further principles on this new level.

Furthermore, a strategy is to be pointed out by means of which these rules can be applied on the abstract level of the Element Model and implemented into the real level of shape.

3. METHODS AND MEANS

In order to make principles and instructions available to the designer of a technical system on the abstract level of the Element Model C&CM, previously established design principles and guidelines have been examined concerning their meaning on the higher level of the Element Model C&CM.

By means of the linking of C&CM with the real level of shape as well as with the abstract level of function it is possible to illustrate the complete guidelines and rules on the level of the C&CM- regardless whether they concern the shape or the function or partial function of technical (partial) systems.

Examples for this are the principle of the direct force transmission, which is applicable on the shape level, and the principle of task sharing, which is applicable on the level of functions as follows:

The principle of direct force transmission demands to "transmit forces only the shortest and most direct transmission path in order to ensure a minimum use of materials and a minimum of deformation" [Pahl, G. and Beitz, W., 1997]. Transferred to the abstract level of the C&CM this means that the forces are to be conducted via Channel and Support Structures, which are as short as possible, and as few Working Surface Pairs as possible inside the technical system.

The principle of division of tasks (with the same function) implies that when having reached the limit of performance of a technical system a further increase of performance can be achieved by assigning the partial functions to further function carriers. Firstly, the performance is branched and then combined. On the abstract level of the Element Model C&CM this means that several Working Surface Pairs and therefore also several Channel and Support Structures are to take over identical functions. Furthermore, Working Surface Pairs are to exist which have a partial function for branching and collecting the performance.

It becomes evident that the principles mentioned above can be described by a consistent mode of expression on the level of C&CM despite their differences in the classical formulation.

In a further step these newly established principles and guidelines have been tested and structured regarding their common aspects. For this purpose, groups were formed, which require the same measures on the abstract level, e.g. introducing additional Working Surface Pairs and Channel and Support Structures or adjusting properties of two Working Surfaces.

A second possibility for structuring was found by sorting the newly established principles and guidelines according to the position at which they are used on the abstract level of the Element Model C&CM. There are e.g. principles which are exclusively relevant to Working Surface Pairs, e.g. everything concerning corrosion. Other principles are only applicable for Channel and Support Structures such as the principle of direct force transmission.

Comparing these two possibilities it becomes evident that with both ways similar groups can be obtained. On this basis new instructions were searched for systematically on the abstract level of the Element Model C&CM. One result was that for each principle requiring a certain property there is also a principle which demands exactly the opposite property.

In addition to the principle of adjusting properties of two Working Surfaces of a Working Surface Pair, which can e.g. prevent corrosion, it might be just as useful to deliberately select different properties for these two Working Surfaces in order to e.g. control the wear.

To place principles and guidelines suitable for specific situations at the designer's disposal, firstly a matrix was developed which connects the newly established principles and guidelines depending on the respective case of application with the previous design principles and guidelines, which are familiar to the designer to a great extent.

By using this support the designer is able to find and compare possible solutions for special problems on the rather concrete level of the previous design principles and guidelines as well as on the abstract level of the Element Model C&CM. Thus, he can further develop or improve the system or solve problems on every abstraction level between the Element Model C&CM and the real level of shape.

This method also supports the designer having a holistic view with its main and partial functions in mind.

4. RESULTS AND DELIVERABLES

In the course of this research project at the mkl a collection of different new rules has been developed on the levels of classical design principles, design guidelines and design rules which can be distinguished according to their degree of abstractness. In order to ensure a general applicability they have all been transferred to the uniform abstraction level of the Element Model C&CM.

Examples for this are the principles of direct force transmission and division of tasks with the same function, which have already been mentioned above.

A further example is the design guideline corrosion-oriented design implying that machine systems are to be designed so that corrosion can be prevented. If this is not possible due to technical or economic reasons the design of the technical system is to control corrosion as much as possible and enable the system to fulfil its function despite corrosion. This may be realised by means of "corrosion-oriented design".[Pahl, G. and Beitz, W., 1997] If this guideline is presented on the abstract level of the C&CM, the following can be stated concerning the realisation of this guideline: Corrosion is a harmful function always occurring at Working Surface Pairs. In order to avoid or reduce corrosion the following measures can be taken:

- *Removing one of the Working Surface Pairs* causing the corrosion: either the Working Surface Pair through which e.g. oxygen atoms diffuse into the iron lattice of the material and thus iron atoms oxidise or the Working Surface Pair, through which the resulting reflux of electrons can flow from the reactive to the non-reactive reactant. Applied to the example of an iron girder exposed to all kinds of weather this means either protecting the iron girder from the weather or sever the possible conducting connection to a more noble metal.
- *Adding a further Working Surface Pair:* e.g. by varnishing an iron girder two new Working Surface Pairs are added, the first of which is located on the surface of the iron girder. Here the varnish layer adheres to the iron and forms a Working Surface Pair. The second new Working Surface Pair is developed at the surface of the varnish layer between environment and varnish. Only if both new Working Surface Pairs show suitable properties corrosion may be averted. The Working Surface Pair located between iron girder and varnish layer is to have a high adhesion and must not serve as a catalyst for the rusting of the iron girder. The Working Surface Pair varnish - environment is to be weatherproof and must not let oxygen diffuse through the Channel and Support Structure varnish layer. A completely different possibility would be – analogue to the first example – to add a Working Surface Pair at another part of the iron girder enabling the electron flow in the direction of the iron girder when connected with a more reactive metal than iron. This may also serve to effectively decrease the corrosion of the iron girder. This principle is often applied in ships in the form of sacrificial anodes.
- *Changing the properties of a Working Surface Pair:* By selecting an iron girder with different material properties such as stainless steel corrosion may be reduced or even prevented. This may also be realised by changing the properties of the other working surface of the Working Surface Pair iron / environment: Corrosion can also be avoided by selecting a less corrosive environment.

For the question which method is the most advisable there is no general answer, since this strongly depends on the respective environmental conditions of the technical system. Therefore, it is not possible to change the surrounding medium of a pylon as the latter rusts. Neither can an iron girder in a steelworks, which is exposed to very high temperatures, be easily coated with a varnish layer. Already with this simple example for averting the corrosion of an iron girder a pattern becomes evident which occurs in all the principles and guidelines examined:

These principles and guidelines can be divided into different groups, depending on which changes are made and how they are carried out in order to improve the result:

One step is to form a group which only concerns the Working Surface Pairs of a technical system. This includes among others the principle of assembly-oriented design, wear-oriented design and corrosion-oriented design.

A further group only influences the Channel & Support Structures of a technical system. It contains creeping and relaxation-oriented design, deformation-oriented design as well as some of the principles concerning energy and force transmission.

Apart from that there is a group which concerns the complete Working Structure of the technical system, i.e. the Working Surface Pairs essential for the function as well as the Channel and Support Structures. This group is relatively big and contains e.g. the principles of nearly flawless design, the principles of safety engineering, the principle of self-help and the risk-oriented design.

A further important organising criterion overlapping with this is the way the changes concerning the application of the principle or the guideline in the technical system are realised. This has been illustrated by means of the example for corrosion-oriented design mentioned above. In general, there are four possibilities for changing a technical system:

- Adding Working Surface Pairs or Channel and Support Structures
- Removing Working Surface Pairs or Channel and Support Structures
- Changing the properties of Working Surface Pairs, including their relation to other Working Surface Pairs or Channel and Support Structures and
- Changing the properties of Channel and Support Structures.

From these rules all changes of any technical system can be derived. However, as the rules are so general a designer with some experience is required to guarantee a safe application in the design process and derive the correct measure from these very generally put rules. The example of the iron girder shows that a Working Surface Pair can be added at very different places (at its surface or at a place to a metal with an anodic effect) in order to fulfil the originally desired function "Avoiding or at least decreasing corrosion".

Therefore, to provide effective support for the designer in his everyday work it is necessary to put an aid at his disposal by means of which he can decide which design principle to choose for solving different kinds of problems. Moreover, a method is to be developed which helps the designer to understand how the generally formulated measure - e.g. „Adding a further Working Surface Pair" can be realised in detail.

In a first step a matrix has been developed at the mkl which helps the newly formulated principles and rules, which are presented on the abstract level of the Element Model C&CM, to convert into their previous form and vice versa. The line parameter of the matrix are the principles and guidelines in the until then existing form. The column parameter, however, are the new rules introduced in this paper. Connections between guidelines, principles and rules on the two abstraction levels are highlighted in this matrix. This enables also the less experienced designer to change between the previous, relatively unstructured point of view and the new point of view based on the Element Model C&CM. Thus, he is also able to implement guidelines and principles in a much more effective way.

In the course of several product development projects in cooperation with companies and various Centres of Excellence in Research of the University of Karlsruhe (TH) the described rules have been successfully applied and implemented.

Hence, the Center of Excellence in Research 483 „High performance sliding and friction systems based on advanced ceramics" was enabled to use a Working Surface Pair with high loading capacity consisting of two ceramic Working Surfaces at a heavily strained spot of a CVT by means of introducing additional Working Surface Pairs:

A CVT is based on the principle of a chain that runs between two conic discs with variable distance. The torque is transmitted by force closure between one pair of discs to another (Figure 1). Changing the distance between the discs the transmission can be varied. The contact between conic disc and pin is realised by pins that are linked by the mounting links of the chain. Here, especially the WSP between one pin and one of the conic discs is to be considered.

At current CVT's both pin and discs made of a metallic material are state of the art. The Centre of Excellence in Research 483 "High performance sliding and friction systems based on advanced ceramics" considers possibilities and risks of the use of advanced ceramics.

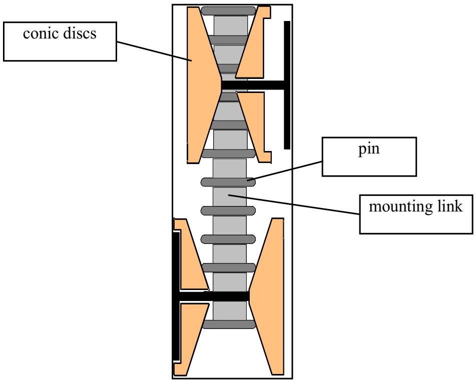

Figure 1 principle of a CVT-drive

Advanced ceramics allow a higher contact stress and higher friction coefficients so that power density can be higher. Therefore, the use of advanced ceramics should be possible in order to improve the properties of a CVT. A first solution included discs of ceramic material and pins of metal. This hybrid solution indicated positive operating characteristics. The wear resistance of the metallic pin, however, was not satisfying.

Due to the improvement of wear resistance in a WSP ceramic / ceramic between pin and disc the possibility of manufacturing the pin from a ceramic material instead of metal is a new research project.

But regarding the complete subsystem pin with all its WSP that are necessary to fulfil its function it becomes obvious that a main stress for the pin is bending as the forces transmitted into the pin in the WSP between pin and disc are transmitted through the CSS „pin“ to the mounting links of the chain.

Due to the fact that even advanced ceramics have a limited load capacity at bending load, the pin had better be made of metal. Regarding the requirements for the pin a contradiction can be realised:

To fulfil the function in the WSP between pin and disc the pin should ideally be made of a ceramic material. On the other hand, the CSS of the pin should be made of metal to be able to resist the stress that is transmitted into the CSS in the different WSP.

This conflict can be solved by a rule that has already been used in a different form in the example described above This rule is formulated on the higher abstract level of the Element Model:

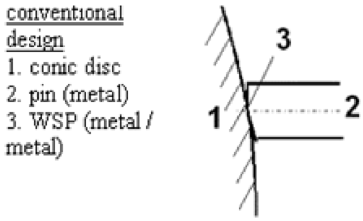

Figure 2 contact between pin and disc

For solving a conflict that is due to different requirements in the used material, an additional WSP can be introduced.

By the introduction of a new WSP the functions of the pin can be divided: This new WSP is introduced between the outer (turned towards the disc) region of the pin that realises the force transmission between pin and disc and the inner region of the pin that is stressed by bend. The pin is divided: the outer region is made of a ceramic material, the inner region is made of a metal. Between these both regions the newly introduced WSP is formed.

The function of these new WSP is to „link the two regions of the pin considering the stress safely“. These requirements are hints for the embodiment design of this newly introduced WSP.

Among others the following prerequisites are to be proven: Is the force to be transmitted parallel to the WSP, i.e. by force closure or orthogonal to the WSP, i.e. by form closure? Is the connection to be loosened or not?

Using a connection which cannot be loosened it is possible to realise the transmission of the force with an adhesive binding. In this example this possibility is to be regarded in more detail.

By pasting the two regions of the pin not only one, but two new WSP are formed, as can be seen in figure 4: WSP2 between the ceramic part of the pin and the adhesive and WSP3 between the adhesive and the metallic part of the pin. Dimensioning this connection it needs to be proven that both WSP and the additional CSS can sustain the stress. In the considered case for the main part this is shear strain.

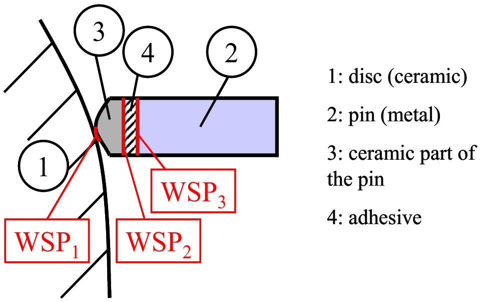

Figure 3 metallic pin with ceramic part

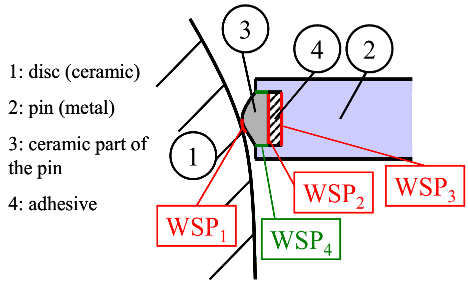

Figure 4 optimisation of the principle

Selecting the adhesive both new WSP are important as both of them define the adhesion.

As an adhesive linking cannot stand the shear strain in the considered case safely, the rule used above can be applied once again to realise a further function, namely building a form-closure-connection in the direction of the main stress. This is also shown in figure 4: Inlays made of a ceramic material are put into a hollow at the end of the metallic part of the pin. The newly created WSP4 parallel to the axis of the pin transmits the radial force by form closure, i.e. orthogonal to the new WSP. The original WSP orthogonal to the axis of the pin prevents the ceramic part of the pin from falling out of the metallic part by the adhesive link. However, it is no more stressed by the shearing strain.

This example illustrated that solving this complex technical problem was almost solely possible by the simple rule of adding new Working Surface Pairs at the right places.

5. CONCLUSIONS AND FUTURE RESEARCH

The previous success achieved by the application of the newly established principles for developing element models makes obvious that it will be sensible to upgrade them. In the course of future research work at the mkl institute these rules are to be further structured and complemented.

A substantial part of these research projects will be to find a way to safely implement these generally formulated strategies into detailed instructions for the designer while considering the respective requirements and boundary conditions.

For doing so, first of all it will be necessary to develop a reliable strategy supporting the designer in finding the correct rule for solving a particular problem.

Furthermore, it is vital to determine which steps to carry out in detail in order to usefully and effectively implement the abstract rule in the respective case. In this context, the fact that according to its definition the Element Model C&CM is very close to the abstract function level as well as to the real shape level is a considerable advantage.

The four above-named newly developed rules that are

- Adding Working Surface Pairs or Channel and Support Structures
- Removing Working Surface Pairs or Channel and Support Structures
- Changing the properties of Working Surface Pairs, including their relation to other Working Surface Pairs or Channel and Support Structures and
- Changing the properties of Channel and Support Structures

are not yet structured so far that the designer can be unerringly sure to find the right rule for solving a problem.

So in a next step a structured collection of helps for the application of these four rules on a special problem will be developed at mkl.

The presented example of the CVT transmission points out that the rules can be effectively implemented already today as it is rather easy for a professional designer to realise the decisions he needs to make after finding the correct rule. Nevertheless, as mentioned above further research projects are to support this step.

One of these helps could look like:

"**If** a notched part of a machine system breaks during use

then try to change the properties of the Working Surface Pairs

so that the notched region of the part is not element of the highly charged Channel and Support Structures that link them."

That means that the notch will be displaced into the Remaining Structure of the machine part.

But this is not the only way to solve the problem. Another help could look like:

"**If** a notched part of a machine system breaks during use

then try to change the properties of the Channel and Support Structure

so that the notch effect will be lower than before."

Many other solutions can be found solving the same problem. Finding the right help for a special problem will be subject of the further research.

The mkl institute successfully uses the Element Model C&CM in basic and advanced lectures for explaining general aspects. In accordance with the didactic principle of Humboldt the presented deriving of rules on the abstract level of the Element Model C&CM is to be immediately included into the lectures offered for the subject of Development Methodology for the next semesters. As a consequence, the current research results will be directly available. A checking of the new method, which is currently carried out, clearly shows that with the aid of the tool C&CM the students develop a far better understanding of machine systems than the previous students, who had been taught by the common machine part teaching model. [Albers, A., Matthiesen, S. and Ohmer, M., 2003].

This success encourages further research projects in this field. Especially the application of the developed rules appears to constitute a substantial progress towards a further systematic researching and teaching of the system of a design process.

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