THE PAIR CHARACTER OF WORKING SURFACES – SIGNIFICENT ELEMENTS OF THE CONTACT & CHANNEL MODEL C&CM

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Abstract: The elementary design model "Contact & Channel Model" (C&CM) is a new access to the treatment of technical systems. It connects the abstract level of the function of a technical system with the detailed level of the system's real shape. This connection is generated by the description of the areas relevant to the function of the system: The Working Surface Pairs and the Channel and Support Structures linking them. Basic hypotheses concerning C&CM are described in [Mat 02]. They define the connections between a pair of working surfaces and their linking channel and support structure. Two important hypotheses are that functions can only be generated in Working Surface Pairs and that the fulfilment of any technical function at least needs two Working Surface Pairs and a connecting Channel and Support Structure. In this paper these two basic hypotheses are validated and explained by means of technical examples.

Key words: design theory, element model, analysis, synthesis, thinking process

1. INTRODUCTION

The design of technical systems includes many subconscious processes which are difficult to be determined and which require a designer with a great deal of experience and expertise.

Although the design process cannot be automated it is still possible to support the designer in his thinking process. In order to be helpful to the designer in his everyday work the support is to precisely describe all technical processes. However, it is to be easily applicable and the designer should be aware in every single stage of the design process which consequences his changes may have concerning the entire system.

At the Institute of Product Development at the University of Karlsruhe (TH) the elementary thinking model "Contact and Channel Model – C&CM" has been used successfully in research and Product Development for several years. One advantage of C&CM is the abstraction of a technical system which is very clear and easily applicable to the properties relevant to its function.

The central message „functions are always fulfilled by means of the Working Surface Pairs of the technical system and their connecting Channel and Support Structures" will be further explained and verified in this paper. Objective of this paper is to demonstrate the pair character of Working Surface Pairs as a condition to fulfil a predefined function. It is referenced on the basic theories of C&CM [AlbMat 02, Mat 02]

2. ELEMENTARY MODEL C&CM

The elementary design model C&CM – Contact & Channel Model – is developed at the Institute of Product Development of the University of Karlsruhe (TH) since 1997 [AlbMat 02, Mat 02]. The successful application of this model to several design problems in research and also increasingly in engineering practice shows that this model is a great help for the designer.

C&CM describes the correlation between the design and the function of technical systems. This correlation exists in form of the Working Surface Pairs of the system and the Channel and Support Structures linking them. They are also geometrical characteristics of the system as they are the areas where the functions are fulfilled.

One reason for the success of this model is that it does not reduce the system to formulas and matrices like e.g. Roth [Rot 94] and Hubka [Hub 73]. C&CM is a method that supports the designer in his "normal" thinking process. It makes it easier to switch between the abstraction levels of function and of design.

There are several basic definitions and propositions that help the designer to keep the whole technical system in mind even when he is working at a very special detail of the system.

3. IMPORTANCE OF THE PAIR CHARACTER IN C&CM

The aim of this paper is to show the relevance of the hypothesis that functions cannot be fulfilled in unique working surfaces and that Working Surface Pairs are always necessary to realise a function in a technical system. Moreover, the message that at least two Working Surface Pairs and one Channel and Support Structure linking them are required for fulfilling a technical function is validated.

3.1 Basic definitions of C&CM

The basic hypothesis I in [AlbMat 02] and [Mat 02] reads as follows:

“Every basic element of a technical system fulfils its function by interacting with at least one other basic element.

The actual function – and thus the desired effect – is only possible by means of the contact of one surface with another surface. These surfaces are working surfaces and form together a Working Surface Pair.“

This basic hypothesis clearly states that one single working surface cannot fulfil a function. It is also not possible to draw conclusions concerning the function of a technical system from the properties of a single working surface when the properties of the other working surface, which forms a Working Surface Pair with the first one, is unknown.

Furthermore, the theory of basic hypothesis II says: “The function of a technical system or a technical subsystem is basically realised by at least two Working Surface Pairs and one Channel and Support Structure connecting them.

In this context only the properties and the interactions of the two Working Surface Pairs and the Channel and Support Structure connecting them determine the function. ” [AlbMat 02].

This means that a technical system can only fulfil a function when it provides at least two Working Surface Pairs as well as one Channel and Support Structure linking them.

All system quantities – material, energy and information – are conducted via Working Surface Pairs into the technical system and out of it. Inside the technical system the conducting is realised via Working Surface Pairs and Channel and Support Structures. Apart from that also the system quantities are stored in the Channel and Support Structures, if necessary.

Therefore evidently it can be concluded that a single surface can never have a function.

The function can only be fulfilled if there are two working surfaces that form a Working Surface Pair. And this Working Surface Pair can only fulfil a function if there is a further Working Surface Pair connected to it by a Channel and Support Structure.

If one of these elements is missing the technical system considered cannot fulfil a function – neither a desired nor an undesired one.

3.2 Example 1: Tolerances and Fittings

The function of fittings and tolerances cannot be explained with the aid of single surfaces. Fittings and positional tolerances cannot even be defined by means of a single working surface. In connection with the fact that fittings and tolerances are always to ensure the fulfilling of a technical function this also confirms the theory explained above and defined in [Mat 02] by the theory of the basic hypotheses I and II that individual working surfaces cannot fulfil functions.

In the following, this message is explained by means of dimensional, form and positional tolerances as well as fittings.

Tolerances generally describe the admissible deviations of a component from the theoretically exact nominal value. The indication of tolerances for manufacturing is necessary as the components cannot be manufactured with only theoretical measures. The dimension of tolerances is to be selected in such a way that the technical function of the component or the component system can still be easily fulfilled while the manufacturing is as economical as possible. From this, one basic rule can be directly derived: The tolerances are to be selected as big as possible and as small as necessary.

The designer can only usefully carry out this definition when he knows the function of the component the tolerances of which he determines. The function of a component is fulfilled in its Working Surface Pairs. Therefore, only the Working Surface Pairs are to be tolerated. A tolerating of the boundary surfaces is generally determined with the aid of general tolerances. Boundary surfaces are only especially tolerated in exceptional circumstances. This is to generally prevent that the tolerated boundary surface collides with another surface of the machine system due to an imprecision, which is geometrically to big, and thus fulfils an undesired function by becoming a working surface.

3.2.1 Dimensional tolerances

Dimensional tolerances describe the admissible deviations of individual dimensions of a component from the theoretically exact nominal value. This means that not the property of a Working Surface Pair but only the property of a single working surface will be determined. Since according to [Mat02]a single working surface does not fulfil a function it cannot be determined by means of a single dimensional tolerance whether and how the technical function of a component is fulfilled in its system connection.

If like in figure 1 e.g. the diameter of a shaft end is described with

$$Ø\ 50\ h6 \tag{1}$$

this means that the shaft has a diameter of at least 49,84 mm and 50,00 mm at the most. [DIN ISO 286]

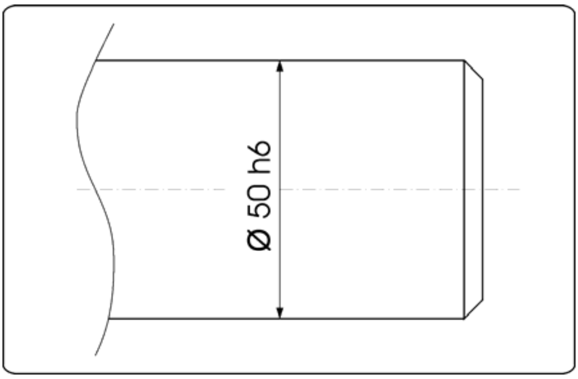

Figure 1 Dimensional tolerance of a working surface

From this information the function of this shaft cannot yet be derived. This is only possible with the aid of the tolerance of the counter working surface as described in chapter 3.2.2 Fittings. The measurement Ø 50 h6 alone does not determine if the shaft can e.g transmit a torque.

The function of the surface considered can thus not be derived from the tolerance of the individual working surface but only from the tolerance of the Working Surface Pair.

3.2.2 Fittings

Fittings result from the tolerances of two paired components. As explained in chapter 3.2.1 Dimensional tolerances it is not possible to draw any conclusions concerning the function of a single working surface from its dimensional tolerance as it does not describe a Working Surface Pair and functions always require Working Surface Pairs.

The fitting of a Working Surface Pair defines its function in the system connection. The shaft presented in figure 1 can form a clearance fit with a hub with a diameter of Ø 50 H7 or an interference fit with a hub with a diameter of Ø 50 R7.

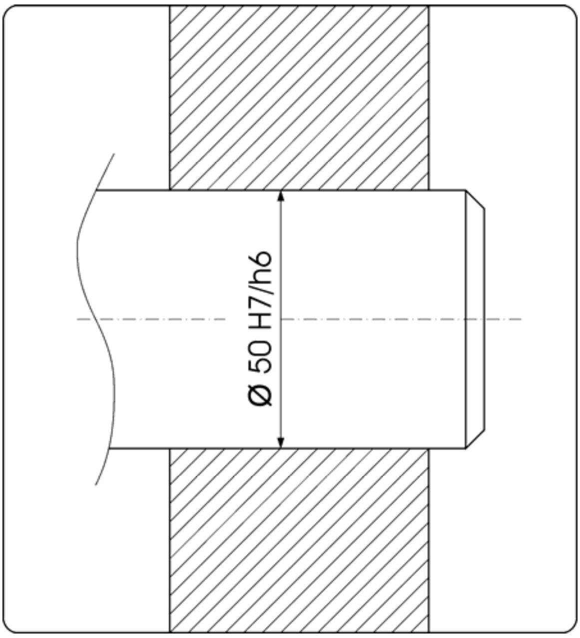

Figure 2 Fitting of a Working Surface Pair

Figure 2 shows a combination of the shaft with a hub which's inner working surface is tolerated with the dimensional tolerance of Ø 50 H7. The combination of the two working surfaces forms a Working Surface Pair with the fitting Ø 50 H7/h6. This is a clearance fit which means that by this fitting no normal forces F_N perpendicular to the working surface pair that means in radial direction are generated and thus according to the Coulomb law

$$F_R = \mu \cdot F_N \tag{2}$$

no friction forces F_R in tangential direction can be transmitted.
As the transmitted torque that can be transmitted by this joint can be calculated as the product of the frictional tangential force F_R and the radius of the Working Surface Pair r_{WSP}

$$T = r_{WSP} \cdot F_R \tag{3}$$

it is evident that the regardes working surface pair can not transmit a torque due to its properties.

Therefore, its function is limited to the transmission of radial forces.

A Working Surface Pair that forms a fitting of e.g. Ø 50 R7/h6 can additionally transmit tangential forces and hence a torque as the elastic deformation of the channel and support structures due to the fitting generates a normal force in the working surface pair. According to equations (2) and (3) the transmittable torque can be calculated.

As a result of this consideration and basic hypothesis II (see chapter 3.1), the function „transmit torque“ cannot be fulfilled by the considered Working Surface Pair alone. Even the third Newton’s axiom says actio equals reactio [New et al 14]. In order to fulfil the function “transmit torque” the shaft thus needs at least one further Working Surface Pair in which the torque can be passed on into a further component. The same applies to the hub, which may be e.g. a gearwheel. In this case, the second Working Surface Pair is located at the tooth flank which is engaged with the counter gear.

3.2.3 Form tolerances

Similar to dimensional tolerances form tolerances determine the maximum admissible deviations of the form of a component with which it can reliably fulfil its function. Figure 3 shows a typical form tolerance- the cylindricity measurement.

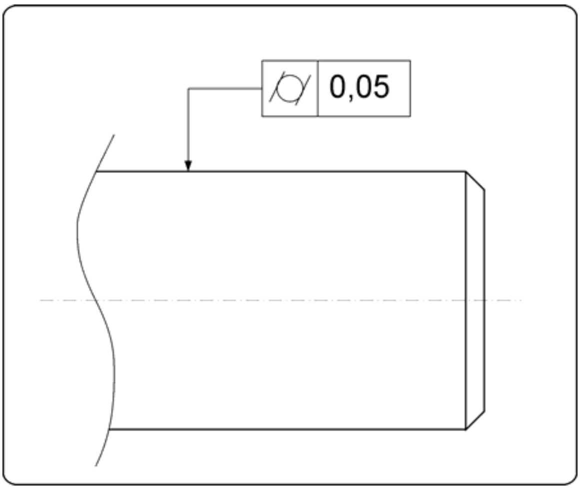

Figure 3 Form tolerance of a working surface

Without knowing anything about the properties of the respective counter working surface, this form tolerance of the working surface again provides no information about the technical function which can be fulfilled in the thus formed Working Surface Pair. It does not make any sense to tolerate only one of the two working surfaces on concentricity.

Only the additional tolerating of the counter working surface determines the property of the Working Surface Pair and therefore ensures the fulfilling of the function. So we must think in Working Surface Pairs in order to determine a function-oriented form-tolerance.

3.2.4 Positional tolerances

All messages concerning the pair character of form tolerances contained in chapter 3.2.3 also apply to positional tolerances. Regarding positional tolerances, it is even easier to realise that technical functions like those explained in basic hypothesis 2 [Mat 02] require at least two Working Surface Pairs in order to be fulfilled:

A positional tolerance defines the property of a working surface with regard to another working surface of the component. Thus, as shown e.g. in Figure 4, the rectangularity of the axial working surface to the cylindrical Working Surface of the shaft can be tolerated in order to guarantee e.g. an accurate axial force transmission from a roller bearing to the shaft. A functional-oriented tolerancing is only possible regarding both the radial and the cylindrical working surface pairs of the subsystem and their functional and geometrical interrelations. The connection between these can be easily regarded on the abstract level of C&CM.

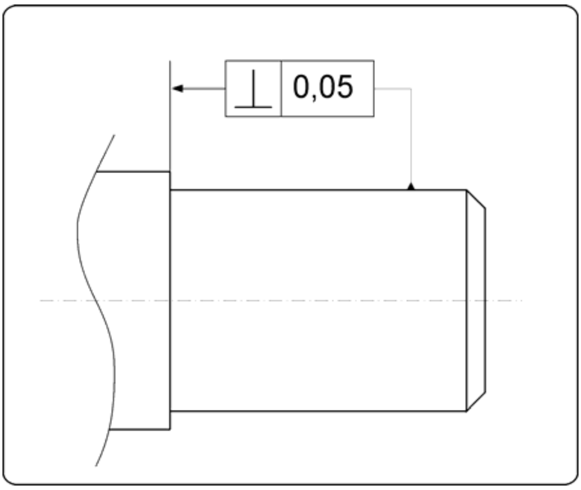

Figure 4 Positional tolerance of a working surface

3.2.5 Experiences

In a current exchange of experience with a business partner it became evident that the abstract thinking of the elementary model is very important for the designer in order to correctly implement these actually obvious conclusions into the individual design. In the case described above an inexperienced designer determined form tolerances for a surface which was always a boundary surface and never a working surface during the operation of the component. This caused high costs.

If the designer in question had used the thinking model C&CM for his considerations this error would have never occurred as he had looked for the fitting with the counter working surface of the entire system, as described in chapter 3.2.1. Here, he would have noticed the error at the latest.

3.3 Example 2: Abrasive wear

Abrasive wear is a – mostly undesired – function which occurs in virtually all technical systems. In connection with the basic hypothesis II “Only the properties and the interactions of the two Working Surface Pairs and the Channel and Support Structure connecting them determine the functions“ [Mat02] it can be directly concluded that this function occurs in a Working Surface Pair.

The message that not only the properties of one of the two working surfaces but also those of the Working Surface Pair are decisive is of considerable importance.

The wear behaviour of a Working Surface Pair is substantially influenced by the geometrical micro and macro structure of the two working surfaces as well as by their material properties such as e.g. hardness.

If one of the two working surfaces is much harder than the other the softer one will generally wear out more than the harder one. If the properties of the two working surfaces are similar wear can be normally observed at both of them. Especially with metallic materials the wear can be very high when the two working surfaces have almost identical properties. In this case intermolecular forces are developed at many places as two similar structures encounter each other. In order to prevent that in special cases, in which one can expect that the lubricating film between two surfaces sliding on each other can tear up, metals with completely differing structure properties are often employed deliberately. A classical example for this are slide bushes made of brass or bronze which contain a steel shaft.

Consequently, it is not possible to draw any conclusions concerning the wear behaviour only due to the knowledge of one single working surface of the Working Surface Pair. It is always necessary to have information about both partners forming the Working Surface Pair and thus fulfilling the function in the system connection. A brass slide bush may show excellent wear properties in connection with a steel shaft. If a shaft made of the same brass as the slide bush is installed into the machine system, both working surfaces may wear out faster than with the original material pairing.

3.4 Example 3: Conduction of electric energy

The conduction of energy in a technical system is a further example which illustrates very clearly the advantage of the pair consideration in the elementary model C&CM.

If a form of energy is to be conducted through a system this energy generally needs to be conducted via several Working Surface Pairs and through several Channel and Support Structures.

Conducting energy in a Working Surface Pair can again only be explained and understood by considering the complete Working Surface Pair.

The example of electric current being conducted by means of a switch plug demonstrates why it is not possible to draw a conclusion concerning the change of the energy conducted in a Working Surface Pair from changing the property of one of the two working surfaces contained in a Working Surface Pair.

If due to such a switch plug the current cannot be completely transmitted, this problem cannot be solved by considering and improving only one of the working surfaces contained in the Working Surface Pair. It is necessary to consider the entire place where the function is fulfilled, i.e. the entire Working Surface Pair.

Gilding the switch plugs - a very expensive process which is carried out frequently – only makes sense when the good conductivity of a gold film on one working surface also shows a better end result in combination with the other working surface. If there is a problem due to corrosion of the counter working surface, it will not be possible to considerably improve the electrical conductivity by gilding the other working surface. Mechanical problems such as a missing contact pressure in the Working Surface Pair cannot be enhanced this way either.

The basic message of this knowledge can be directly applied to further types of energy conduction such as thermal conduction.

By means of the example of conducting electric current the message of the basic hypothesis 2 (see chapter 3.1) [Mat02] can also be clearly understood:

The electric current is always conducted in a Working Surface Pair into a part, passes through its Channel and Support Structure and is conducted in the next Working Surface Pair into the next body. If one of the two Working Surface Pairs is changed or even removed this will affect the entire technical system.

4. CONCLUSIONS

The examples described above illustrate the importance of the pair character for working surfaces and Working Surface Pairs in the elementary model C&CM as well as the power and the diversity of this instrument.

As the basis for numerous successful research and business projects the elementary model C&CM is proved to be a precise multi-purpose thinking model with the aid of which even the most complex problems from the conception to the validating and manufacturing of technical systems can be reliably solved. The connection of function and shape is a valuable support for the designer whose primary task is to fulfil the required function by defining the embodiment design of a technical system.

Current research projects at the mkl institute deal with creating rules which are to support the designer in being able to constantly apply the theory of the elementary model C&CM in everyday work and thus to quickly generate solutions.

Apart from that in the last few years the elementary model C&CM has also been the basis of the lecture “Mechanical Design” at the University of Karlsruhe (TH). In this lecture all elements and types of behaviour of a technical system are based on this thinking model. It was proven that this way of thinking makes it much easier for students to understand the complex principle of technical systems [Alb et al 03a, Alb et al 03b].

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