INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

SYNTHESIS AND ANALYSIS STEPS ACCORDING PRODUCT PRECISION IN EARLY AND LATER DEVELOPMENT STAGES

M. Koch, R. Hochmuth and H. Meerkamm

Keywords: Product Development, Product Accuracy, Tolerances, Engineering Workbench, Computer Support

1. Introduction

Engineering Design is considered as a main important step towards a fully constrained product fulfilling all demands of the requirements-list as well as several DfX-criteria. Till now, however, the designer is not sufficiently supported by a CAD-System or an Engineering Workbench in placing suitable accuracy requirements in the early – non-geometrical – design stages nor in defining tolerances with their adequate references in a later stage. In order to solve this problem, both the administration of vague accuracy statements (emerging in the early stages) and of exact tolerance specifications (worked out in the a later stage of the design process) into the Engineering Workbench *mfk* (KS*mfk*) will be introduced. A useful simulation method will be presented first of all, which can evaluate the behaviour of a technical system with non-ideal joints.

2. Approach for Evaluating the Precision of Technical Systems

2.1 Motivation for the Approach

The precision of technical systems has developed to an important criterion in association with quality and market-acceptance of products. Generally it can be divided into the following three main aspects:

- Precision of functional characteristics (by accuracy),
- Precision of geometrical properties (by tolerances) and
- Precision of material characteristics.

This paper will focus on the analysis of functional aspects (accuracy) with respect to stated accuracy requirements in the early design stages and on toleranced geometrical characteristics in the later design stages (Fig. 1).

The precision requirement is to be allocated onto each main function carrier of the early conceptual scheme (deductive top-down approach). During the synthesis task (finding a geometrical representation for each main function carrier) the complete tolerance representation, including dimensional, form and positional tolerances with all of their individual references, has to be determined. This first preliminary layout of functional important joints shall be simulated towards the fulfilment of any functional relevant value of the system (inductive bottom-up approach). This may lead to the change of the tolerancing scheme, of tolerance-types or simply of the tolerance values.

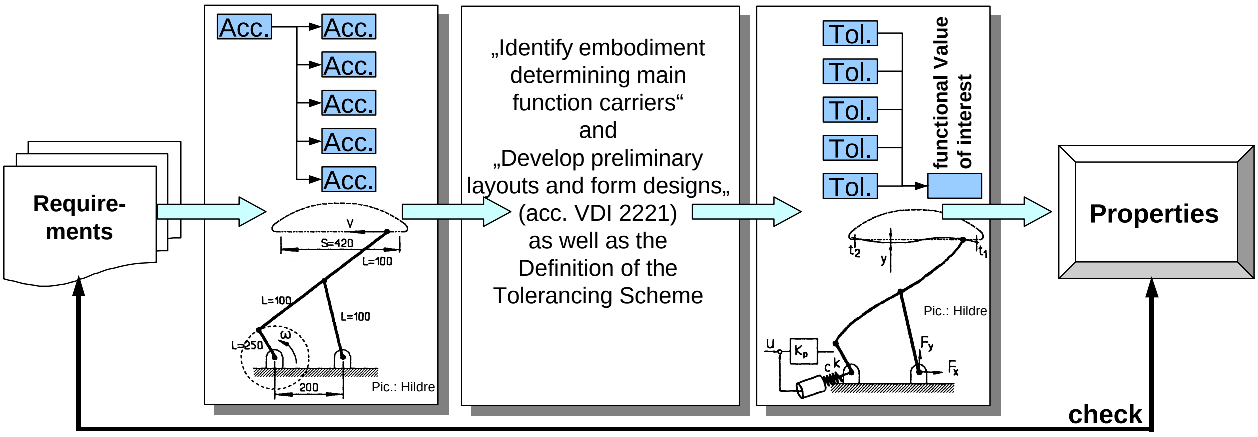

Figure 1. Accuracy and tolerances in the development process

2.2 Idea and Concept of the Approach

Standard tolerance analysis, by making use of commercial systems as CE/TOL 6σ™ or VisVSA™, can be performed for one or more kinematic conditions. These kinematic conditions result from the dynamic simulation method. Both aspects, tolerance analysis on small geometric variations as well as large kinematic motions, will have to be coupled in order to reach a full description of the system's behaviour.

The system of multi-bodies is widely used for the analysis of dynamic systems behaviour with large motions. Arbitrary ideal joints connect the rigid bodies. The approach pursued in this paper has to be seen as: The dynamic simulation of the kinematic-kinetic behaviour of systems under the influence of "real-world"-joints with deviations.

One state-of-the-art approach [Hörsken 1999] uses a multi-body system and varies the former CAD-parameter by the MonteCarloMethod. Form and position tolerances as well as a real-world behaviour are not integrated in this special approach. Most commercial systems, as mentioned before, simply calculate the closure tolerance of a mechanism with form and positional tolerances, considering only discrete kinematic situation without taking in account dynamic aspects.

In our work we pursued the coupling of the correct and complete tolerance scheme according to standards as ISO 1101 and ISO 5459 as well as the inclusion of real-world system behaviour. Our approach can be described as follows: The former ideal joint without deviations is replaced by a more proper genuine joint, which can perform small displacements in fixed directions (Fig. 2).

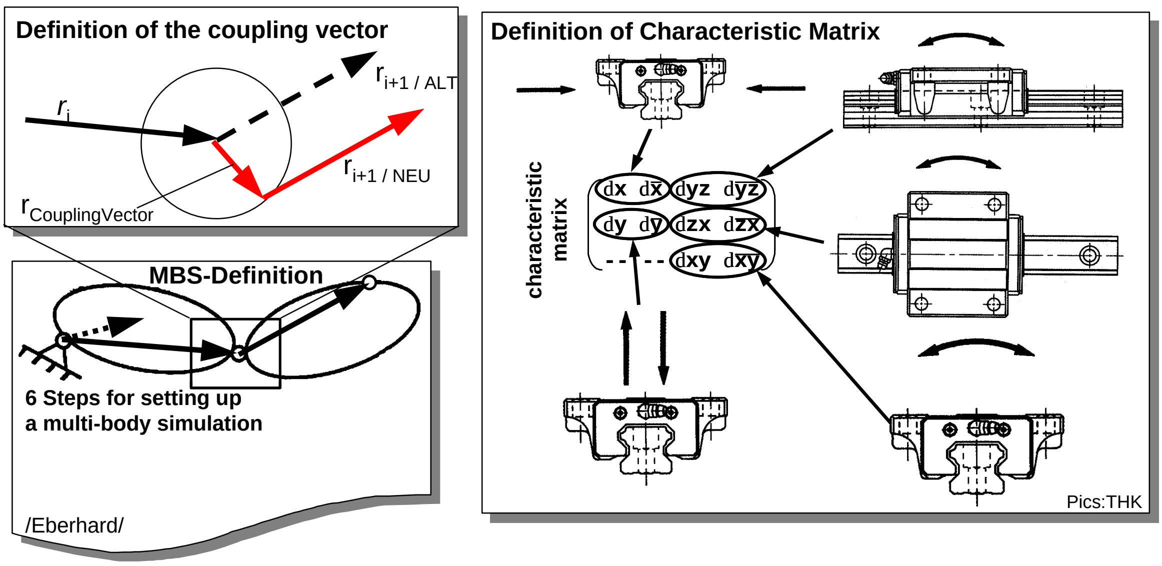

Figure 2. Integration of tolerances, resp. accuracy, into the multi-body simulation

E.g. a former completely fixed joint gets now three translational movements and three rotational movements (pitch, yaw, roll), each in two directions. These 12 movements are represented in a matrix-notation. In [Eberhard 1998] the method of multi-body-systems, restricted to holonomic systems without kinematic loops for simplicity, is described very comprehensible. To this notation a tolerance vector is added to the vector chain in the multi-body-system-description. This leads to a determined system, which can be solved state-of-the-art by numerical methods for one small time step. According to calculated reaction force vectors, the position of each relative part position is adapted by the direction of mentioned vector and the size of the tolerance zone; the numerical calculation starts again [Hochmuth 2001, Hochmuth 2002, Koch 2001].

2.3 Interpretation of Results and Example

As a result the designer gets a hint to the influence of toleranced joints to kinematic behaviour of the system, and the influence to kinetic results. All these values are calculated in each relevant kinematic status and can be presented as distributions of all calculated values of interest over the calculated results of nominal value. Actually we calculated a simple mechanism. The requirement was given with a position-accuracy for repeated movements of +-0.7 mm (x-direction) in the relevant end point. The accuracy was in a first step developed as shown in Fig. 3 by the characteristic matrix, which represents the allowed area of translational and rotational movement in each positive and negative x-, y- and z-direction.

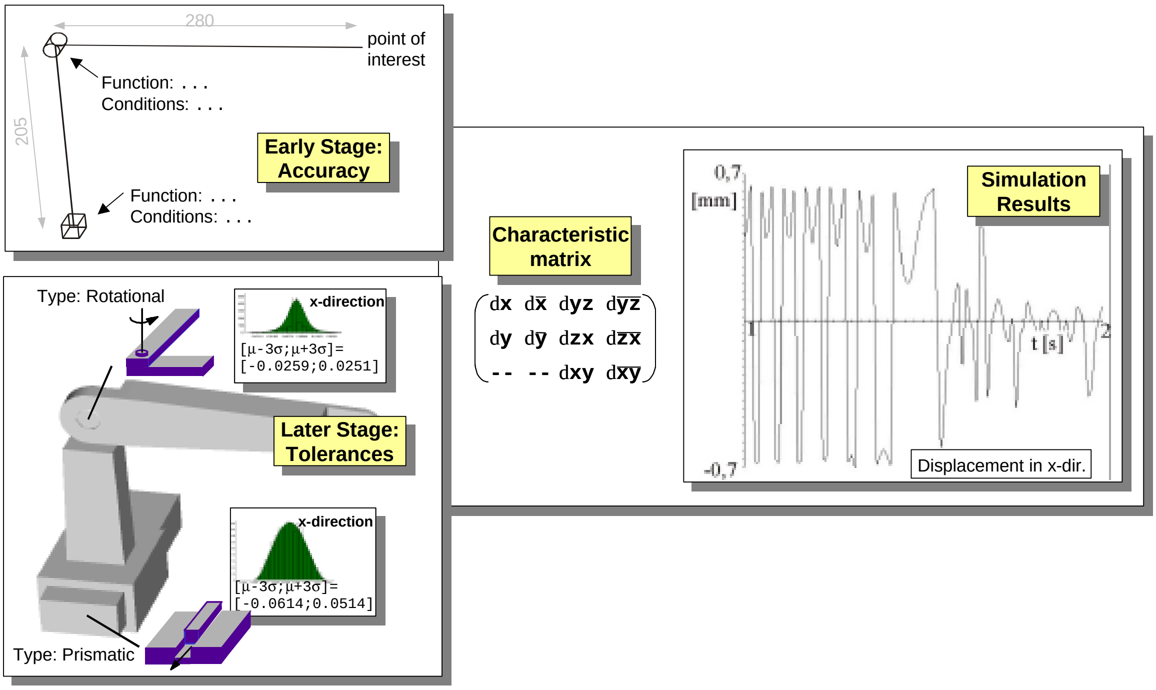

Figure 3. Example and Simulation Results (Displacements)

The simulation results state, that the accuracy values were selected in a correct way in addition to the system behaviour. The next step in progress could be the optimisation of the characteristic matrix according the measured displacements.

The embodiment solution for each joint with the corresponding realisation by tolerances shall represent the required accuracy, as mentioned above. To check out, whether these tolerance representations are adequate to former accuracy definitions, the mentioned simulation method can be applicated to this later development step as well. The tolerance representation will have to be reduced to the characteristic matrix by the use of the vectorial tolerance analysis or a commercial tolerance simulation package as VisVSA™.

Perspective would be the coupling with a virtual-reality-environment to allow the designer to "shake" his system and to control directly the waggling "answer".

3. The Engineering Workbench *mfk* and its Product Model to support this Method

An Engineering Workbench is a system, which contains all product relevant data in its product model and allows the designer to generate and modify these data in an easy way. And, of course one important point, is, that the designer could use analysis and information modules in order to check out, whether his design meets several criteria.

The Design System *mfk* is one concept to engage the idea of an Engineering Workbench. Several aspects have been developed during past ten years [Meerkamm 1998]. The Engineering Workbench is set up by a Synthesis and an Analysis part, which are connected by the product model. Predefined constructive elements can be synthesized in an easy way. These elements contain besides geometrical information also technological, functional and organisational information, which is very important for following analysis tasks. The designer can define new design elements by using the pattern editor (Fig. 4).

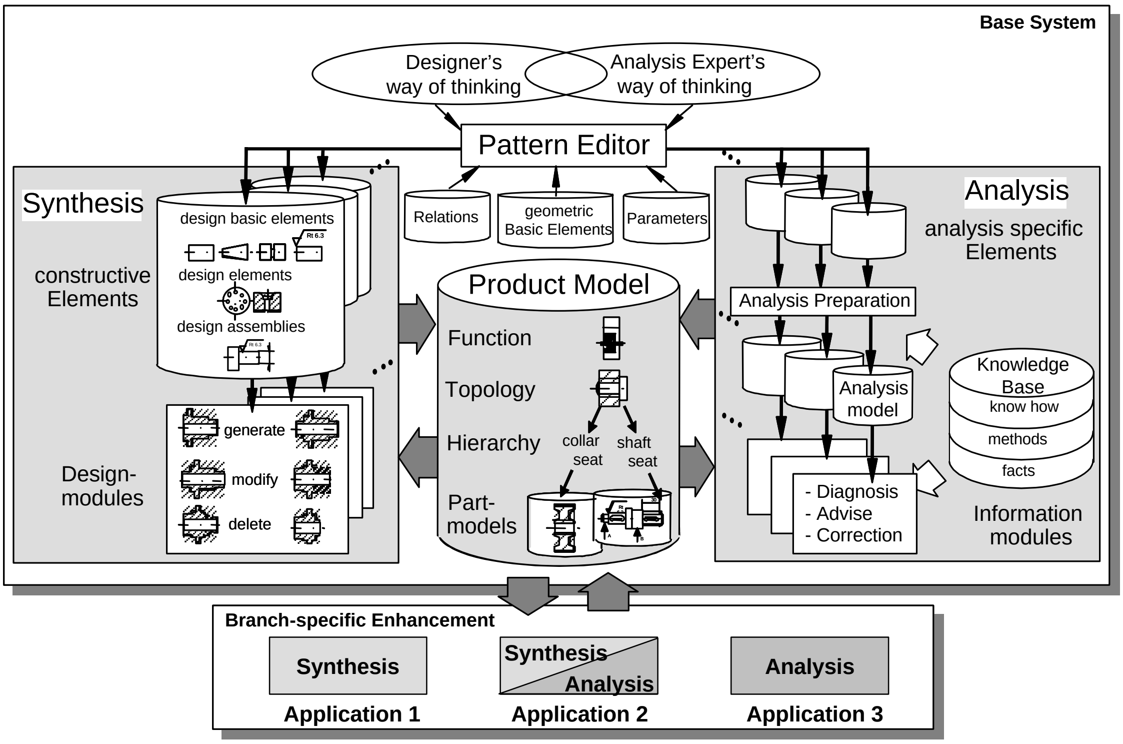

Figure 4. Design System *mfk*

The actual approach is the hybrid product model [Koch 2001], which can contain CAD-geometry as well as constructive elements (Fig. 5). By this approach it becomes possible to describe the shape of free-form-surfaces for instance and use the constructive elements with their functional, technological and organisational characteristics.

Based on our good experiences handling tolerance information especially in later embodiment and elaboration stages our Engineering Workbench is supposed to be expanded to remove the obvious breach between the support of the accuracy in the early stages and the tolerances of the later stages of the design process. Both sides can be managed in the product model of the engineering workbench *mfk*: On the one hand the accuracy, the designer uses for important points in the early stages of the design process, and an the other hand the tolerances, being assigned to certain active surfaces in the late design stages to limit fabrication deviations. The designer can define accuracies at explicit points of his concept in the early stages. But it does not become obvious, which quantitative demands are placed on the accuracy of the joints between several parts of the treated assembly.

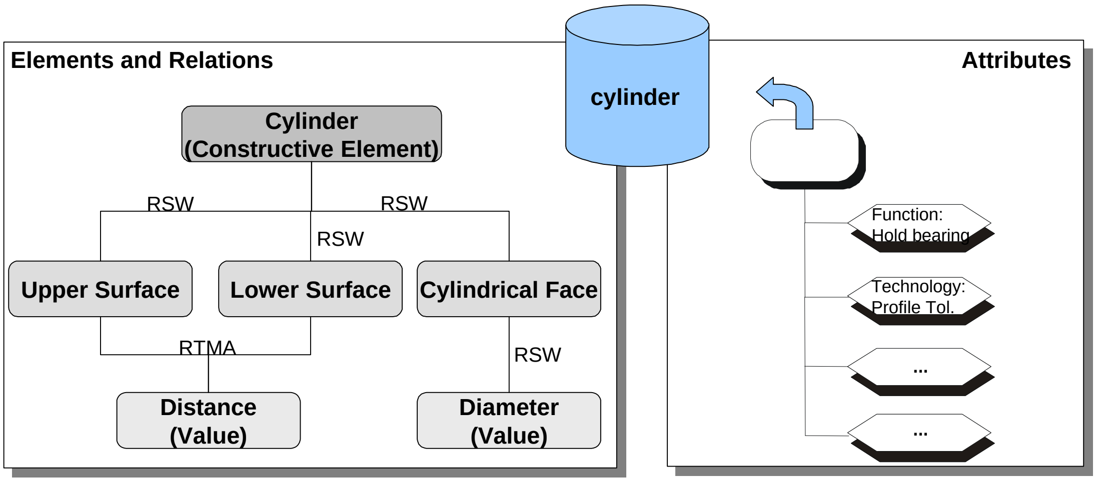

Figure 5. Hybrid Product Model: Storing Elements and Relations as well as Attributes

4. Approach for the step from an early to a later Stage

A simulation method for technical systems with non-ideal joints has been presented as well the integration of the method into the design system *mfk*. Due to the fundamentally different data tribe, which is necessary for the administration of accuracies on the one and for the administration of tolerances on the other hand, a breach in the continuity of the design process emerges. Here the designer has to transform the futile accuracy information into adequate tolerances "by hand".

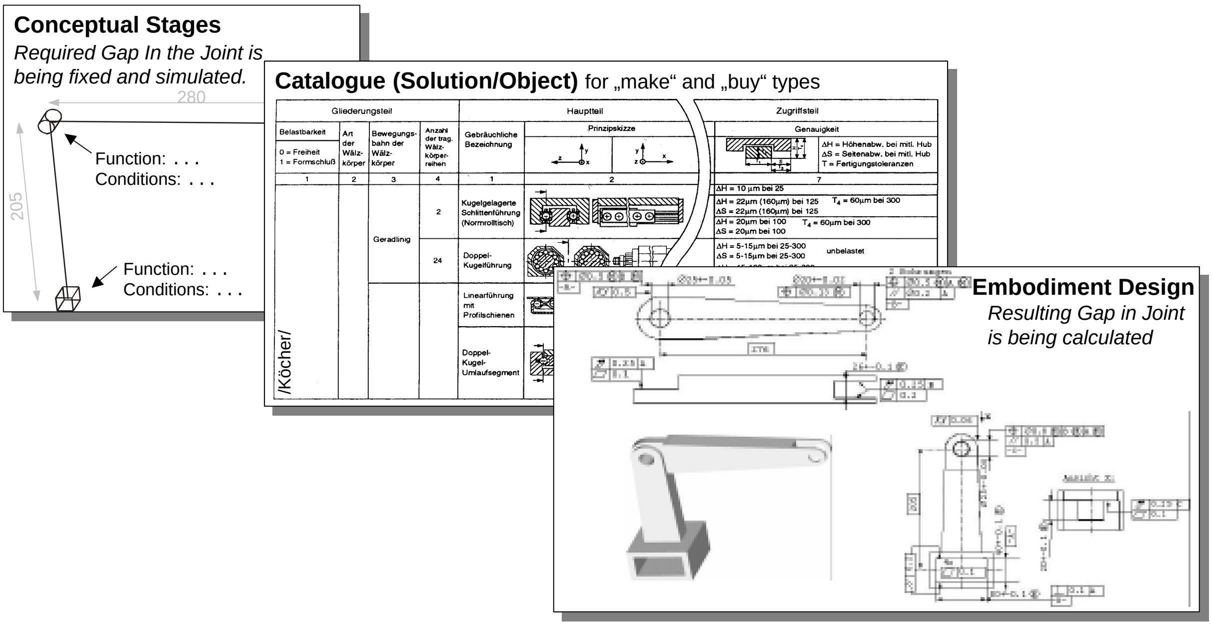

Figure 6. Transforming accuracy into tolerance specifications

We propagate a Catalogue System (Fig. 6) for the tolerance scheme with default tolerance values for the Wirkflächen of interconnected system components to solve the required technical accuracy, which has been proven in the early stage already. The consequently next step would be the iterative synthesis task for tolerance values and the analysis of resulting motion and dynamic aspects. By an iterative loop in connection with a variance analysis step the influence of each tolerance value to the resulting value can be extracted.

5. Summary and Conclusions

The designer's task of solving an engineering problem is to fulfil all requirements. Especially the accuracy of technical systems is a very important and basic requirement. This paper presented a method for the simulation of the precision in the dynamic movement of technical systems under the influence of non-ideal joints. This method can be applied in the early design stages, where the accuracy of movements is one of the main aspects the designer has to deal with. The exertion is feasible as well in the later design stages, where toleranced joint geometries are in the focus. Any new method will only be accepted by an engineer, whether the method is presented in an acceptable manner, e.g. through inclusion in an engineering workbench. In order to achieve a high acceptability the integration of the developed method into the engineering workbench *mfk* was performed.

By the use of the hybrid product model, which contains functional, geometrical, technological and organisational information as well as CAD-geometry, and that provides the option of attachment of additional information, the support of the analysis-method is possible.

References

Hochmuth, R., Meerkamm, H., "Approach to Evaluate the Precision of Technical Systems", Proceedings of the 13th International Conference on Engineering Design, Glasgow, 2001, 75-82.

Koch, M., Hochmuth R., "Mehrkörpersimulation unter Berücksichtigung nicht-idealer Gelenke und Integration dieser in das Konstruktionssystem mfk*", Symposium DfX 2001 (Ed. H. Meerkamm), Neukirchen, 2001, 67-74.*

Hörsken, C., Hiller, M., "Statistical methods for tolerance analysis in multibody systems and computer aided design", Advances in Computational Multibody Dynamics (Ed. Ambrósio, J.A.C.; Schiehlen, W.O.), Lissabon, 1999, 749-767.

Eberhard, P., Schiehlen, W., „Hierarchical Modeling in Multibody Dynamics", Applied Mechanics, 68, 1998, 237-246.

Hochmuth, R., "Methoden und Werkzeuge als Teil eines Assistenzsystems zur rechnergestützten Analyse und Optimierung fehlertoleranter, robuster Produkte", Dissertation (in preparation), Institute for Engineering Design, 2002.

Meerkamm, H., Hochmuth, R., "Integrated Product Development based on the Design System mfk", Proceedings of the 5th International Design Conference, Dubrovnik, 1998, 31-38.

Dipl.-Ing. Michael Koch
Institute for Engineering Design
University Erlangen-Nuremberg
Martensstr. 9, 91058 Erlangen, Germany
+49 (0)9131-85-27986, +49 (0)9131-85-27988,
Email: mlkoch@mfk.uni-erlangen.de