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LARNING FROM DESIGN FAILURES – THE METHOD OF WEAK POINT ANALYSIS AND VIRTUAL DEVIATIONS

G. Höhne, T. Brix, H. Sperlich

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Abstract

The paper provides methodological guidelines on Weak Point Analysis in engineering design. The analysis is carried out at the abstraction levels of embodiment design, principle structure and function structure. The elements can then be assigned a "virtual deviation", a description of alterations to the parameters of the structure and the configuration which may be faulty. Detected design errors are classified according to their implications for product quality and according to the design changes necessary to remedy them. On this investigation based table of failures facilitates the evaluation of the design and gives orientation to eliminate or reduce errors. A parametric description of solution principles, can be used as a virtual prototype for simulating the factors influencing potential failures.

1 Introduction

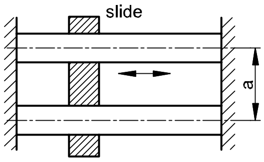
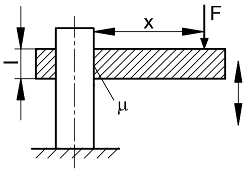
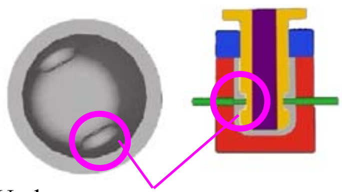
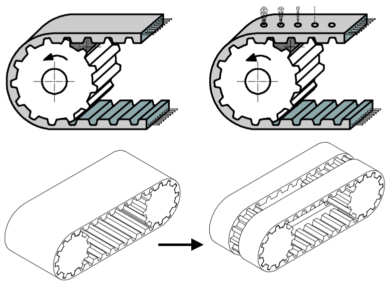
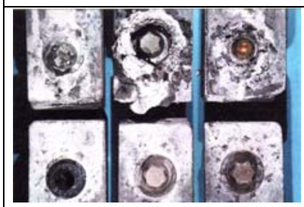
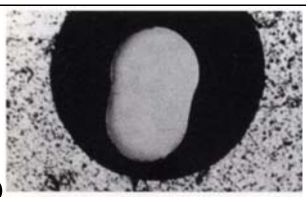
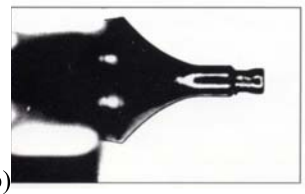
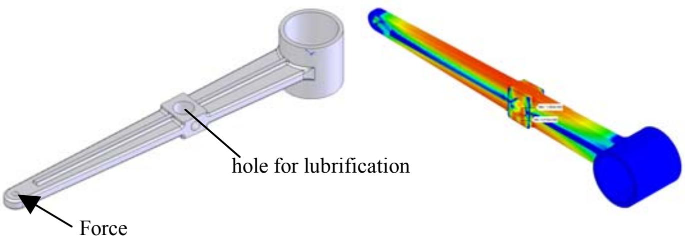
Design failures are errors in the design process that turn out in three possible ways – the product fails to fulfil its task, it is dangerous, or it is of reduced quality. 80% of all deficiencies in defective products are due to errors at the planning, design and development stages [1].

Design failures happen particularly in the case of innovative products. The reason for that is, because during the design process it is not possible to predict all product behaviours. The unsatisfactory compromises forced on the designer by often contradictory specifications are a similar source of difficulty. If the design errors could be recognised and analysed, the potential for improving the design process and method would be high, and more would be known of the product's eventual features. The paper deals with a method as a purposive tool to find design failures during and after design products.

2 Accruement and consequences of design failures

Every failure of a product follows from one of the life cycle processes. Table 1 illustrate some design failures, selected from reports on design work. Errors during designers work with subjective and objective reasons have consequences in all phases of the products lifecycle

Table 1. Examples of design failures

Example		Comment
 Double cylindrer guide		Over termination of the guide, correct function only if $a_{slide} = a_{cylindrers}$ and cylinders parallel to slide holes
 Sliding guide		Moment of tilt x·F causes locking of the slide. Condition for correct function: $l \leq 2\mu \cdot x$ F-force μ-friction coefficient
 Undercut at a cast part		Undercutting requires complicate castings form and expansive fabrication
 Tooth belt drive		Compressed air between belt and wheel provokes noise. Preventation by holes in the belts or double belts [4]
	Materials: a) steel/aluminium b) aluminium/aluminium	Corrosion at Bolted fastenings: a) high b) low [5]
a)  b)  Fine mechanical bearings		a) Galling of a brass bush (lubrification loss) b) damaged bearing pin (mal material [6]
 Lever		The hole for lubrification of sliding bearing reduces the critical cross section is the reason for ductill fracture

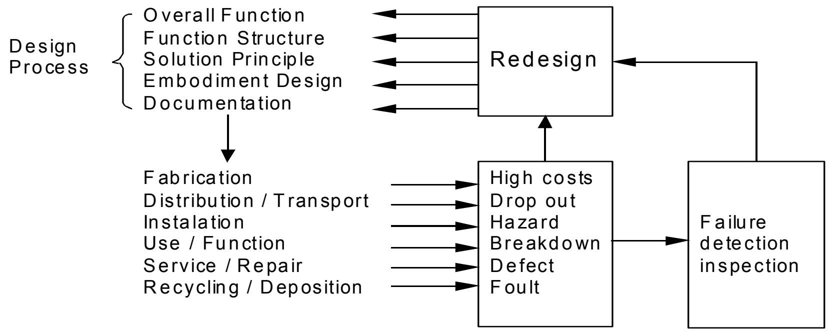


Figure 1. Situation of failure processing

They can arise in each step of the final design process starting with determination of the overall function up to the documentation phase. This failures provoke problems during fabrication, distribution, transport, installation, application, repair, recycling and other situations with different after-effects. A long cycle sometimes is necessary to eliminate errors by redesign.

Because design errors cause exponential growing costs during the development period (rule of ten) it is vital to recognise and eliminate faults as early as possible. What is needed is a predictive failure analysis method which will show the faults of the current design. FMEA (Failure Mode and Effect Analysis [2]) provide one systematic approach. To extend it, the paper offers the methods of Weak Point Analysis and Virtual Deviations with the following main purposes:

- Recognition and assessment of errors, and the attempt to remedy them, within the design process for an actual object.
- Acquisition of the data in respect of such errors, with generalisation to produce some means of remedy or minimisation as methodological gain making a material contribution to “Design for X”.
- Provision of a computerised tool to simulate the eventual behaviour of the product under the influence of disturbances.

3 The Method of Weak Point Analysis

Weak points of a product are all types of defects and unsatisfactory properties in relation to product requirements. To recognise and identify the weak points of a design the method is based on the following precepts:

- Each design has to be reviewed only in relation to the design task. Its requirements must be noted at the beginning of the analysis.
- Each design solution is a compromise between contradictory requirements. The necessity and balance of them should be checked.

- The most important criterion is the function of the product. Design failures affecting the function can be recognised on the abstraction level of solution principle and function structure.

  Therefore the weak point analysis starts with the analysis of the solution principle and if necessary the function structure. Then follows the investigation of the detailed design in relation to the verity of requirements in particular fabrication and economic demands.

- To avoid the investigation from any marginal detail analysis objective and focus of the weak point analysis should be fixed at the beginning.

With respect to the quality of a wanted product design failures should be ranked as follows:

1. Design failures affecting the product function,
2. Design failures affecting the fabrication,
3. Design failures affecting the economy.

The aim of the study has been pursued [3] by classifying the errors a) according to their implications for product quality and b) according to the design changes necessary to remedy them. This leads to a failure classification (Tab. 2).

Table 2. Failure classification of the Weak point Analysis

Types of failures	**failure class**
Failure requires modification of solution principle	A
Failure requires modification of embodiment design to fulfil function or to make possible fabrication	B
Failure requires modification of embodiment design to improve function or fabrication	C
Modification of embodiment design is appropriate but not necessary Failure requires correction of documentation	D

This methodology facilitates the determination of how the fault will ramify in the system, and thus what are the critical elements and dimensions and tolerances.

Figure 2 describes the main operations of the weak point analysis, which can start with different information given about the product to be inspected.

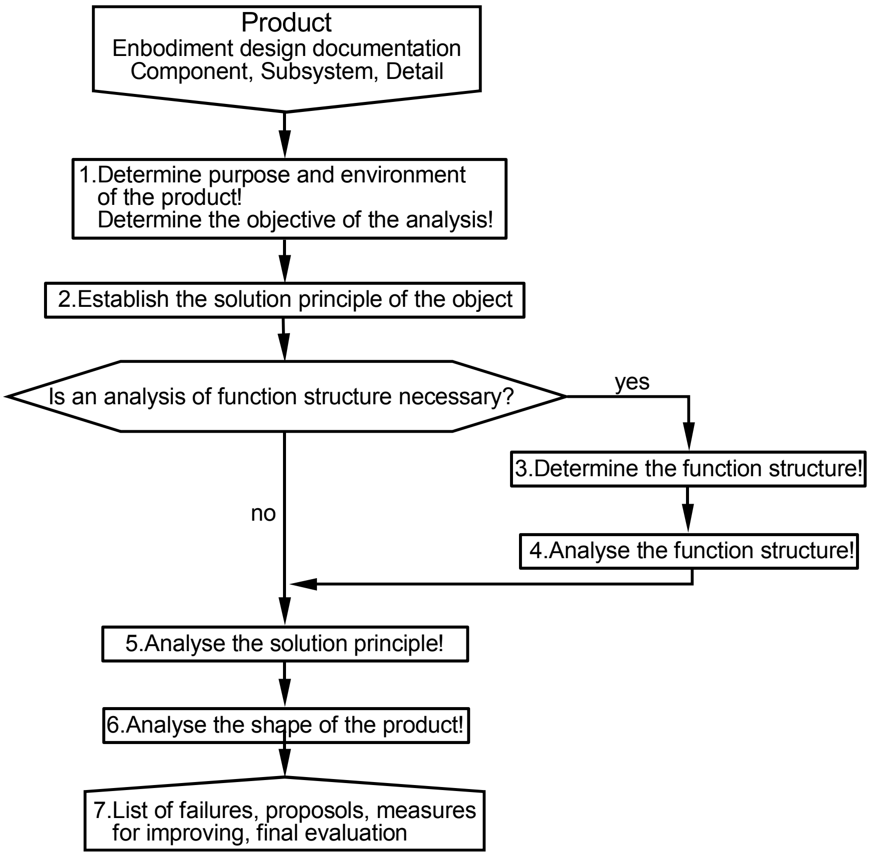


Figure 2. Procedure of the Weak Point Analysis

The use of the method of weak point analysis will be shown within an example in figure 3. The drawing represents the embodiment design of a friction wheel drive with transmission interruption. Input and output rotations of the friction wheel drive are in opposite directions and the input rotates continuously.

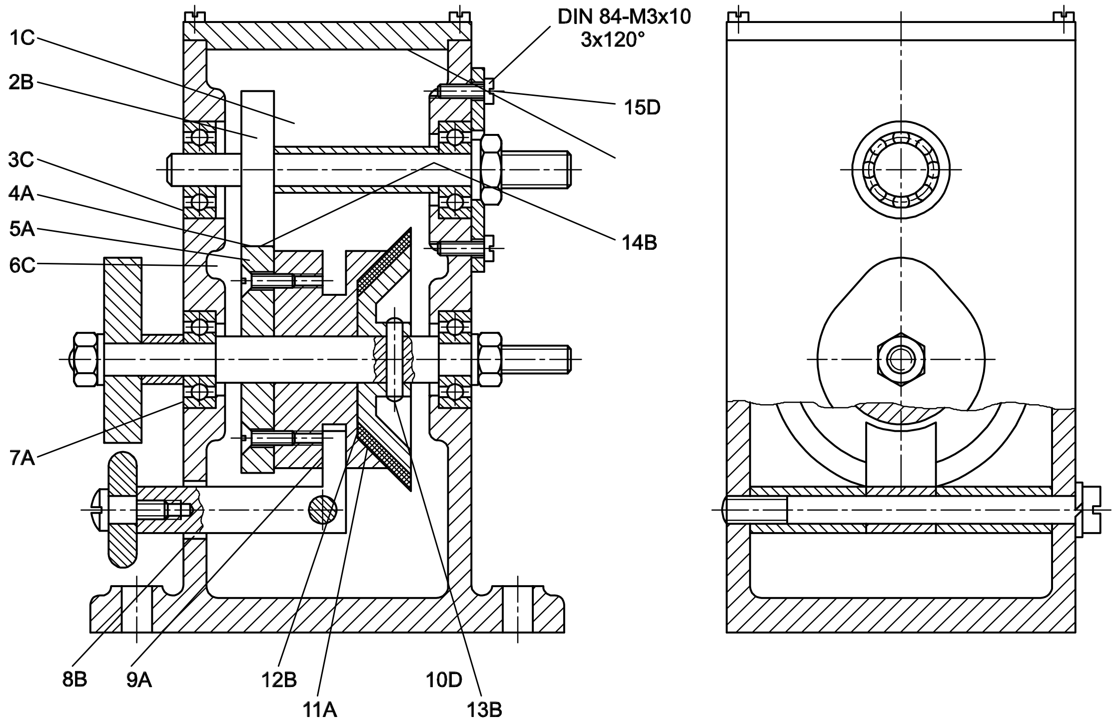


Figure 3. Design of a friction gear drive having design failures

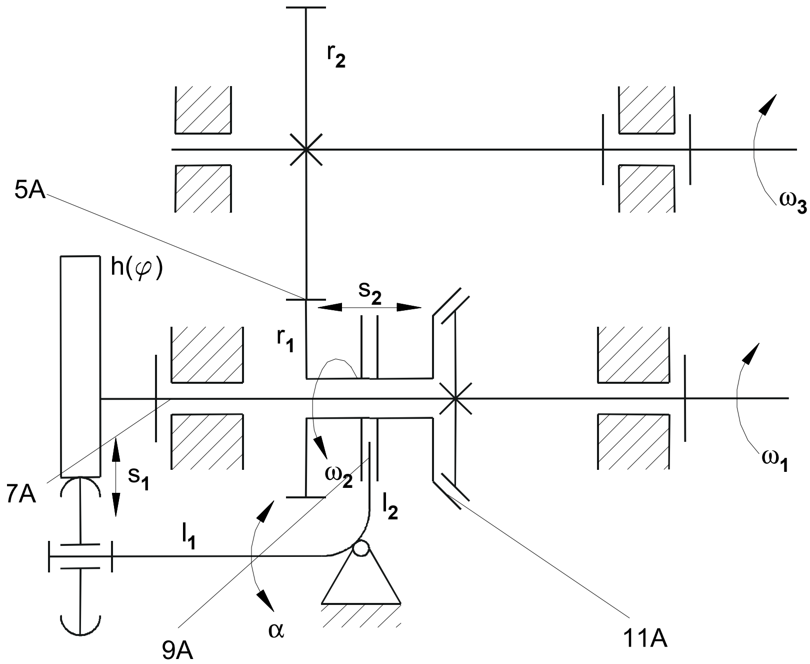


Figure 4. Principle structure of the friction gear drive

The first and most important question when interpreting a detailed technical drawing should be the operability of the solution principle. For this the solution principle will be investigated in a further step. This is demonstrated in the figure 4. For this example it is also convenient to draw and evaluate the functional structure. The functional structure of the friction wheel drive in figure 5 shows two function flows. It can be seen that in one of the flows the translation s2 at the output of the transmission gear affects the coupling as well as the friction wheel 1. Due to the fact that the coupling operates as a temporary engagement and disengagement of input and output, the axial movement of the friction wheel drive 1 can cause disturbed friction related transmission (see error 5 in table 3). Other errors are not found on this abstraction level in the functional structure.

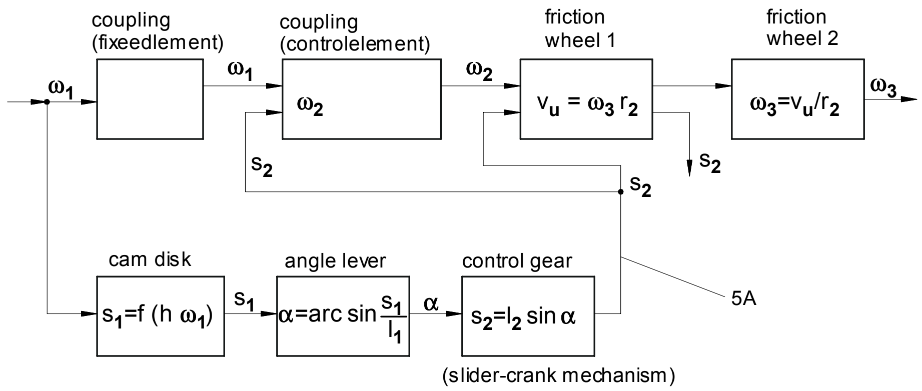


Figure 5. Function structure of the friction gear drive

Further errors (7, 9 and 11 in table 3) are identified through the solution principle of the friction wheel drive. This is a more concrete representation than the functional structure described above. Remained errors can be evaluated from the embodiment design (figure 3)

All errors will be inserted in table 3 and evaluated corresponding to the error groups towards table 2.

Table 3. Weak point list of the embodiment design (fig. 3)

Nr.	Error	Error group
1	material volume for drilling to big (separating wheel and shaft)	C
2	assembling impossible	B
3	floating bearing need axial fixing	C
4	normal force and necessary radial mobility are absence	A
5	lever moves the friction wheel 1 axially	A
6	undercutting of the cast housing	C
7	neither fix nor floating bearing	A
8	hole for movement of the lever too small	B
9	no sufficient clearance or other geometric pair	A
10	specifications of all fits are missing	D
11	no normal force	A
12	cone should not have contact on abutting face	B
13	assembling of the pin impossible	B
14	one wheel should be convex	B
15	incorrect representation (4x90° is shown)	D

Analysis of the errors in table 3 shows that error 4 and 5 cannot be eliminated easily. Therefore a redesign of the friction wheel drive is necessary in order to fulfil the functional requirements.

4 Method of virtual deviations

If a designer has decided upon a certain solution principle, then he will have laid down a series of dimensions and figures, i. e. a quantity of data, from which the planned technical structure must emerge. However, the real prototype constructed from the drawings – derivates from originally design. This inevitable deviations must be allowed for by the designer. He must take into account all those things which may differ from his original intension. Considering all important deviations he is able to make a precise statement about the errors in the overall function and other properties [7]. All system elements can than be assigned "virtual deviations", a description of alternations to the parameters of the structure and the configuration which may be faulty.

This visible modelling as shown in Fig.6 and 7 makes it easy to perceive possible failures of the system.

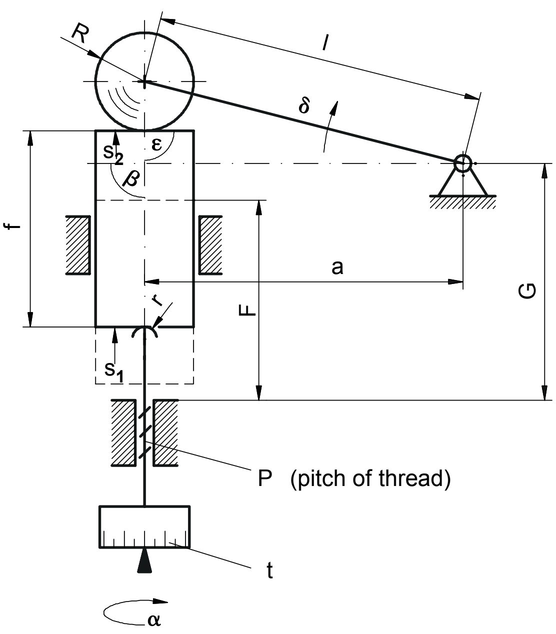


Figure 6. Principle solution of a sine mechanism

The output deviation of the angle $\Delta\delta$ of the sine mechanism is influenced by all denoted parameters of the solution principle. Analysing the functional chain from input α to the output the function relevant parameters of the elements, connections and spatial positions are assigned with virtual deviations. By means of a fault tree the error propagation can be discovered.

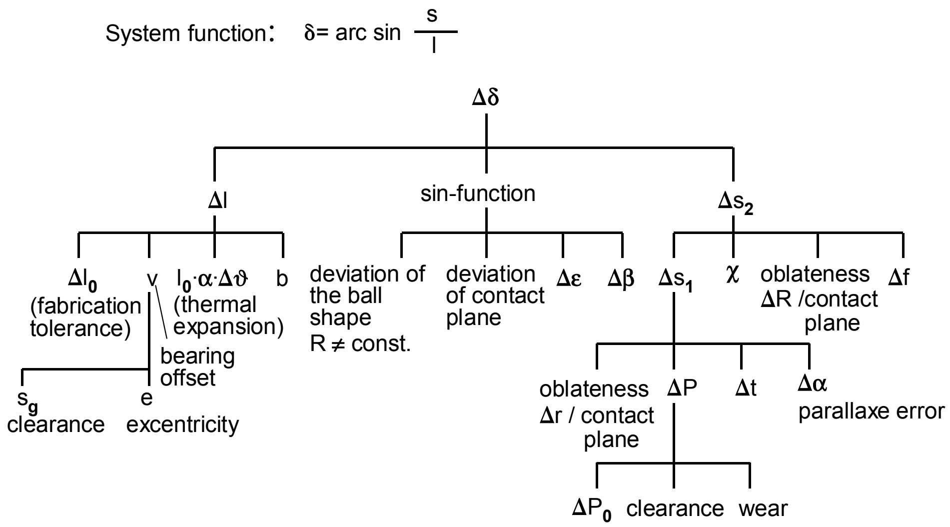


Figure 7. Fault tree of the sine mechanism

Calculating the influence of the parameters on the overall function the most critical design features and values can be identified and a sufficient distribution of tolerances may be find. In the presented case the length of the lever l and the thread pitch P are the most critical parameters . The idea and method of "virtual deviations" created by Hansen [7] is a purposive tool in the early phases of design. For elimination of design errors general design principles and rules already exist, thanks to many years of study in the field. Among them are the principles of low-error layout (innocence, invariance), tolerancing, adjustment, compensation, isolation – and so on [8]. These principles must be applied to those product features, in particular, which on Weak Point Analysis prove to be the most serious potential causes of failure.

At present the method becomes new importance for computer supported simulation of the product behaviour under influence of errors.

5 Simulation of product behaviour in failure situations

In the early stages of the design process essential functional and structural characteristics of complex design objects are determined. In this context the development and analysis of solution principles are very important. A parametric description of solution principles, can be used as a virtual prototype for the purpose of simulating the factors influencing potential failure.

In order to achieve this goal several software implementations exist on the market. One of those is the constraint-based design system called MASP (Modelling and Analysis of Solution Principles) that supports modelling and calculation of solution principles (figure 8).

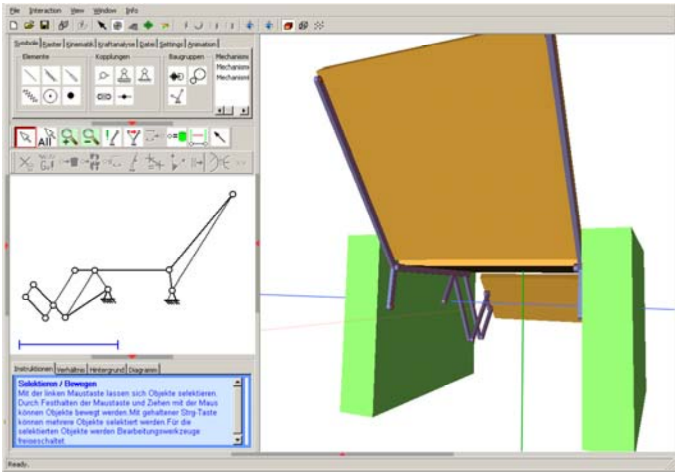


Figure 8. Screenshot of the design system MASP with a modeled armchair mechanism

The concept for an interactive modeling of solution principles utilizes a set of predefined symbols that allow an almost intuitive modeling. Besides an interactive (e.g. mouse controlled) or automatic motion simulation MASP also provides a support for the definition of function variables (forces, velocities etc.) that are necessary for further calculations (e.g. kinematics and static calculations, error analyses, tolerance optimization) [6].

Figure 9 shows an example in how MASP simulates tolerances in a linkage. The links “a” to “e” represent tolerated distances. Their effects on stretch “s” can be calculated by MASP without using explicit error function. The left side of figure 8 shows the sensivity of the links “a” to “e”, which is determined by one full rotation of the crank “a”. The right side of figure 9 illustrates the tolerance band of “s”.

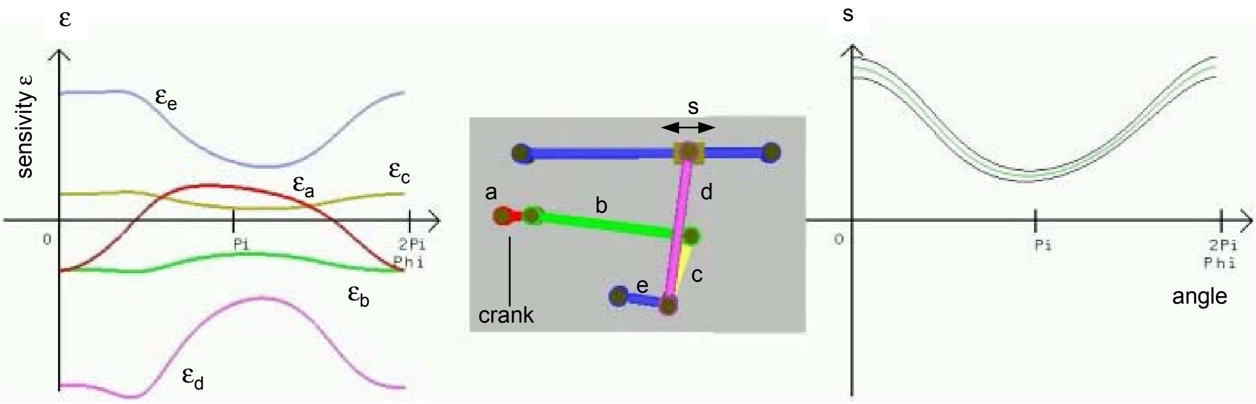


Figure 9. Tolerance analysis using MASP

6 Summary and Conclusion

The paper provides methodological guidelines on Weak Point Analysis in engineering design. They have already been applied with considerable success in industrial projects and education. The main stages are:

- analysis of the structure of the product on different levels of abstraction,
- creation of a list of weak points,

- classification of weak points in a manner geared to their remedy, and
- development of measures to eliminate the errors or minimise the faults.

Discovering, gathering and systematic analysis of design failures is an important source of knowledge to improve products, their development and the design process.

A combination of Weak Point Analysis, starting at the conceptual design phase, with the virtual deviation method and simulation of failure behaviour will enable to recognise design faults early enough, give a quantitative determination of their effects and support the elimination or minimisation of them. The method is also a proper mean to train the criticism faculty of engineering students.

The investigations contribute to the development of failure- reduced products. The assembly of a database on recurrent design errors, lists and trees of weak points, faults and failures, combined with MASP failure behaviour simulation constitutes a viable approach to a knowledge-based system of recognition and reduction in engineering design failure. This is subject of ongoing work.

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Prof. Dr.-Ing.habil. Günter Höhne
Technische Universität Ilmenau
Dep. Mechanical Engineering
D 98684 Ilmenau Pf 10 05 65
Germany
+49 3677 469021
+49 3677 469062
guenter.hoehne@tu-ilmenau.de