Product Optimization by Analysis of Gentelligent Life Cycle Information

R. Lachmayer, B. Sauthoff* and P. Gottwald

Leibniz Universität Hannover, Institut für Produktentwicklung und Gerätebau, Welfengarten 1A, 30167 Hannover, Germany
*E-Mail: sauthoff@ipeg.uni-hannover.de

Summary: Application of components gathering information about its environmental conditions called gentelligent components are suitable for feedback of life cycle data to the development process. By analysis life cycle data it is possible to get essential conclusions about the product itself. Thus gentelligent information feature a high potential for the development of optimized products of the following generation. Using optimization strategies to vary geometrical shape of a component an adaption to environmental boundaries is possible. Therefor a specific feedback strategy presented in this paper exemplary implemented for a car hub enables a technical evolution orientated product development.

Keywords: Design, Optimization, Computer Aided Design.

1. Motivation

By developing new product generations engineers only have available quantitative experience based information about application conditions of a product encountered during its life cycle. Detailed information about the individual condition of components are solely ascertainable because of a special occurrence like an accident or maintenance. Thereby life cycle information are only fragmentary existent and limited serviceably applicable.

In the framework of Collaborative Research Centre 653 „Gentelligent Components in their Lifecycle“ scientists develop intelligent components with integrated sensor effects and memorising equipment. Engineering components collecting data about itself is the vision of this Research Centre. This approach affords new opportunities for production technology as well as for product development. In this context the application of life cycle data for the developing process is challenging just as well the question of developing products itself in a way to get the right response to a technical problem formulated by engineers.

By analysing gentelligent data allocated by such intelligent components it is possible to get reliable information about the application conditions of each individual product. This information are not only expedient for improving of monitoring and self-optimizing systems but also suitable for optimization of fundamental product properties like geometrical design or dynamical performance of variants actually in development [1,2].

Thus the development of feedback strategies integrating a process of inheritance of gentelligent information in the product generation process as well as analysis and specification of optimization strategies in reference to product design are focused in this paper.

2. Concept

For extending the existing approach of product development methodology by feedback of gentelligent information a process model is necessary. Linking the classical product generation process and gentelligent products in application is the main approach of this model presented in fig.1. A process of inheritance is established to transform the gentelligent data of a multitude of component individuals into condensed information applicable for product development. This element comprises strategies of filtering measurement data inside

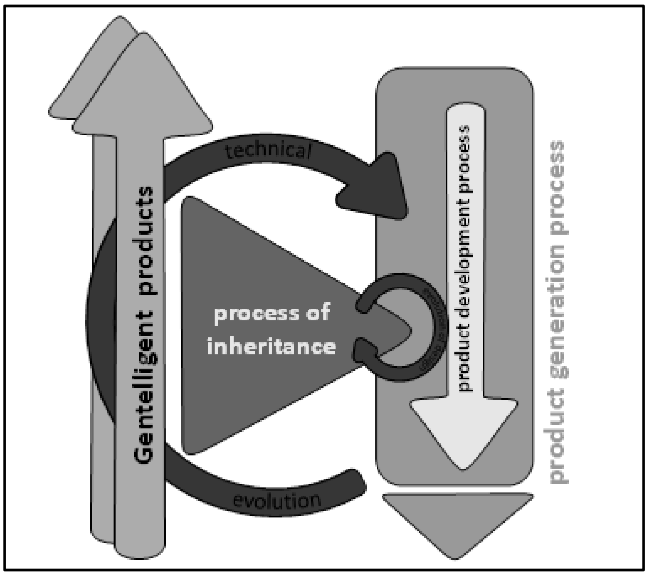

Figure 1. Feedback of life cycle information.

the gentelligent component as well as evaluation and clustering the information of different component individuals. In addition to the life cycle information itself it is necessary to correlate the information with the function of the components, the problems submitted to the gentelligent components during its development and the expected characteristics [3]. Thus the process of inheritance doesn't only extend the current methodology, it has to be integrated in the approach of product development. In this way the technical evolution itself becomes a product development process.

For integration of gentelligent information in the ongoing product development process mathematical optimization strategies are proposed. Using optimization strategies for the improvement of component construction is an established approach in the development process. A multitude of various methods focusing different levels of optimization e.g. parameter, shape or topology has been approved for many years. In addition strategies for integrated optimization considering most steps of the development process are defined e.g. the Autogenetic Design Theory. Focusing the integration of gentelligent life cycle information the question of selecting the most applicable optimization strategy considering the constitution of information is a challenge as well as linking established developments tools e.g. CAD and FEM to an optimization strategy. Thus the categorization of gentelligent information using knowledge based systems is an important topic, too [4,5].

Due to complexity of function interconnection of technical products optimization is only practicable by iteration. In this context especially the variation of design including geometrical and conceptional aspects is a challenge. The different kinds of geometrical computational representation, e.g. parametric CAD or mesh discretization, are reasons for this.

In conclusion the approach of gentelligent information feedback facilitates the chance to impact the process of technical evolution purposefully.

3. Application

One of the key aspects of the Collaborative Research Centre 653 is the validation of theoretical principals in practical examples clarifying the potentials of gentelligent technologies. Thus a demonstrator application consisting of a wheel suspension is in development. Applying the presented process model to this wheel suspension the process of inheritance can be contained to mechanical life cycle data focused on applied loads.

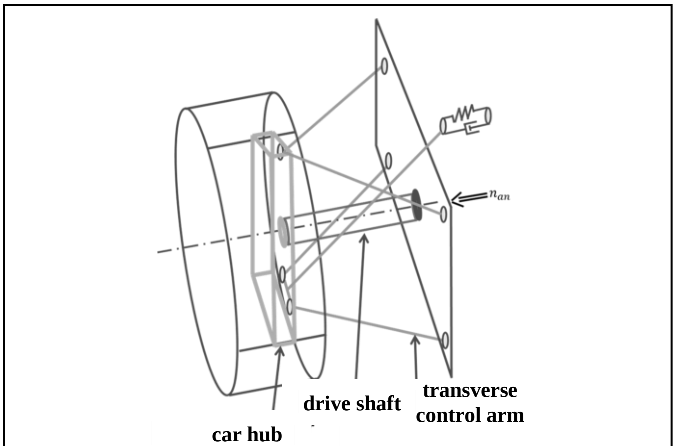

Figure 2. Demonstrator application wheel suspension.

For development of practical feedback strategies three components of the wheel suspension shown in figure 2, the car hub, the drive shaft and one of the transverse control arms, are primary analysed. The gentelligent technology is integrated in these components by research groups of the Collaborative Research Centre 653. Validated by DMS sensors load measurement by the gentelligent components based on magnetic magnesium is possible. In the following the feedback strategy is presented for one hard point of the car hub.

3.1. Process of inheritance for a car hub

The applied load measured by a gentelligent car hub is analyzed continually to get representative information about its load conditions. Considering a limited date rate transmitting information to a receiver out of the gentelligent component an extraction of relevant information inside the component is necessary. The force data of x,y and z direction on hard point including dynamical effects are not suitable for predication about critical load cases in focus to the whole product life. Statistical analysis is necessary to extract the critical cases of fatigue. In addition theses critical cases are not only related to loads but also to the geometry of the component. For analyzing the time dependent force data a transformation in a three dimensional load space diagram containing the forces in x,y,z direction as axis is suitable. For reduction of force data volume a period cluster analysis is utilized and a weighted statistical analysis with acceptably computational effort is possible. Updating the load space diagram and the clusters by fixed time steps new data is regarded.

In conclusion the life cycle data of applied load are concentrated on significant information by means of statistics and reliability theory.

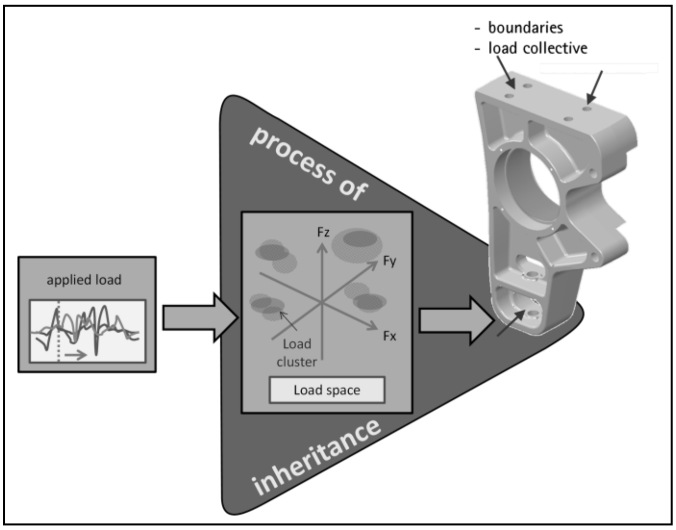

Figure 3. Process of inheritance for the car hub.

3.2. Design optimization

Using the determined load cases ascertained by load clusters for an improvement of a car hub variant which is still in development, linking the load information to the mechanical simulation is necessary. For each load case a critical values of stress and the regions of damage of the car hub is identified by a static finite element simulation.

For an optimization strategy minimizing the weight of the car hub it is necessary to consider each FEM-result based on the critical load cases as restrictions. Thus a direct linking of loads based on application conditions to the optimization problem is possible.

The weight of the car hub depends on geometrical parameters of the car hub construction. Reducing the complexity of the geometric al variation opportunities in this study, only a few geometric parameters of the car hub are chosen as design parameters for optimization. In this example the wall thickness as well as the radians of roundings are used as design parameters.

The Lagrangian objective function for the optimization strategy for the car hub is shown in equation 1:

$$L(\vec{x},\lambda) = f(\vec{x}) + \sum_i^n \lambda_i \left(R_i(\vec{x}) + \eta_i^2 \right) \qquad (1)$$

$$\underset{min}{\Longrightarrow} L(\vec{x},\lambda)$$

$f(\vec{x})$ = objective function including the car hub weight
$\vec{x}$=vector of design parameters
λ_i= Lagrange factor
$R_i(\vec{x})$= restriction functions for different load cases
η_i^2 = slack variable
n = number of load cases

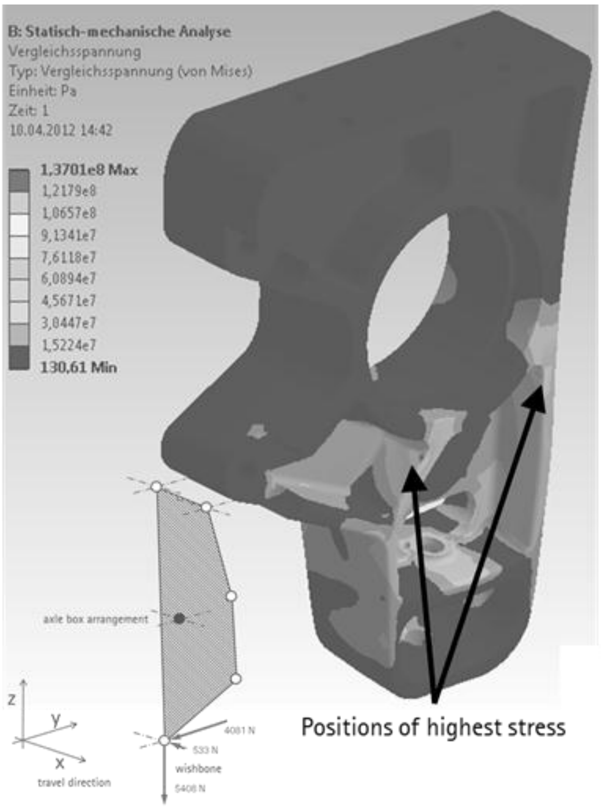

Figure 4. Result of FEM analysis for a special load case.

For minimizing the objective function an evolution strategy algorithm is used. Variation of the design parameter is accomplished by a parametric finite element input file including the geometrical representation of the car hub. The APDL of the finite element software ANSYS is used for this case. Calling ANSYS with the load case related input file by the evolutional algorithm design variation of the actual step is evaluated by the objective function [6].

Nevertheless linking gentelligent information e.g. load populations and optimization strategies form the basis for an individual adaption of the car hub in respect to environmental applied loads.

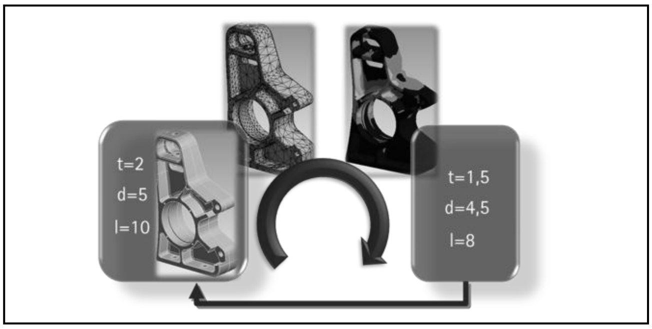

Figure 5. Parameter optimization process.

4. Results

The feedback of gentelligent life cycle data to the product development process enables a specific integration of environmental conditions. In reference to advanced development tools like nonlinear FEM simulation the impact of gentelligent information is significant to get authentic information about boundaries. Without environmental information even the most detailed simulation model will fail. In the same way consigning of problems formulated during the development process to gentelligent components enhances the validation of simulation models. On the other hand an optimization strategy implies a well-known correlation of virtual product models and reality. Thus linking gentelligent information, development tools and optimization strategies exemplary demonstrated by the car hub enables a technical evolution orientated product development incorporating adaption to environmental conditions.

5. Conclusions

The potential of gentelligent information feedback as well as the challenge of linking are demonstrated by the car hub exemplarily analyzed. An extension of linking and optimization methods in focus to more complex problems like consideration of dynamics, advanced design parameters and system optimization of the wheel suspension are imaginable as well as integration of manufacturing machinery independently recommending a suggestion regarding process optimized design changes. In addition the development of data mining strategies which can be utilized to condense information of multiple product individuals are necessary. For this purpose the development and implementation of software tools is a challenge.

Acknowledgements

The results presented in this paper were obtained within the Collaborative Research Centre 653 „Gentelligent Components in their Lifecycle“ preliminary inspection project N4. The authors would like to thank the German Research Foundation (DFG) and the CRC 653 for its financial and organizational support.

References

[1] Denkena, B., Litwinski, K. M, 2007, Gentelligente Maschinenkonzepte für Werkzeugmaschinen, 1. Kolloquium Genetik und Intelligenz – Neue Wege in der Produktionstechnik, Hannover Messe.
[2] Denkena, B, 2009, Gentelligente Bauteile im Lebenszyklus, Nutzung vererbbarer, bauteilinhärenter Informationen in der

Produktionstechnik, Sonderforschungsbereich 653, Leibniz Universität Hannover.
[3] Bacher, Johann, 2010, Clusteranalyse: Anwendungs-orientierte Einführung in Klassifikationsverfahren, Oldenbourg Wissenschaftsverlag GmbH.
[4] Geen, Z. W. (Ed.) et al., 2009, Harmony Search Algorithms for Structural Design Optimization, Springer-Verlag Berlin Heidelberg.
[5] Clement, S., 2008, Autogenetische Konstruktionstheorie – Produktentwicklung mit Hilfe der Evolution, Fachzeitschrift Konstruktion.
[6] Kost, Bernd, 2003, Optimierung mit Evolutionsstrategien, Verlag Harri Deutsch.