INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19 - 22, 2008.

DESIGN 2008

# A WEB-BASED SOLUTION REPOSITORY IN MECHANISM THEORY TO SUPPORT THE DESIGN PROCESS

T. Brix, U. Döring and M. Reeßing

*Keywords: motion systems, digital library, information retrieval, knowledge base*

## 1. Introduction

In the middle of the 19th century the systematic research on mechanisms and gears began specially in Europe as a result of the rapidly growing mechanical engineering industry. One pioneer in this field was the german engineer F. Reuleaux [Reuleaux 1875] with his important theoretical reflections and practical works. He described more than one thousand mechanisms systematically.
Today mechanism and gear technology is still essential for industry and it will become even more important due to the introduction of new technologies like nanotechnology and respective new fields of application. The existing knowledge about mechanisms in theory and practice is worldwide scattered in hand- and textbooks, photographs, solid functional models, engineering drawings, etc. These are very limited, only fragmentarily accessible. This does not comply with today's requirements concerning a rapid information retrieval [Borgman et al. 2002]. However, industrial companies and research institutes demand an efficient access to the whole mechanism and gear theory. Existing activities to provide such access are promising (like kmoddl.library.cornell.edu), but by far insufficient. The preservation of knowledge and didactic experiences in mechanism theory is also important, because e.g. education material often gets lost when lecturers retire (Fig. 1a). Old and unique literature and models with only a few of them left are quite difficult to be accessed (Fig. 1b and c). They have to be digitized and posted online, being accessible for the public again. A solution for this will be the collection and presentation of all relevant information resources for mechanism and gear science in a centralized worldwide accessible platform [Brix et al. 2005], [Döring et al. 2006]. A comprehensive library of knowledge will certainly benefit research and education in several engineering disciplines.
In 2004 the development of the worldwide accessible "Digital Mechanism and Gear Library" (DMG-Lib) was started as an interdisciplinary project involving different departments of the Technical Universities of Ilmenau, Dresden and the RWTH Aachen. The aim of this project is the collection, integration, preservation, systematization and adequate presentation of the worldwide knowledge about mechanisms and gears. The gained results and experiences of this project will hopefully help future digital libraries in different application domains as well. The digital library is designed to satisfy the requirements of different user groups like engineers, scientists, teachers, students, librarians, historians and others. To offer users a wide variety of opportunities for retrieval and use, the digitized resources are extensively post-processed and enriched with various information like animations, metadata, references and constraint based models. The focus is not only on textual documents, images and animations, but also on digitalized functional models, which exists in thousands of unique models with no or only very limited access for the public. This huge amount of available heterogeneous

information resources in the DMG-Lib implies a key challenge of this project: the implementation of an efficient, uniform and user-satisfying information retrieval [Döring et al. 2006], [Pepper 2000].


**Figure 1. Forms of stored knowledge in mechanism theory: a) education material b) „Einleitung zu der Architectura Hydraulica“ of L. Voch from 1769 (libri rari) c) Schubert model from 1850 (Schubert collection , TU Dresden)**

In the following sections the concept and implementation of the DMG-Lib are presented. Thereby the digitalization and enrichment of the information resources and the DMG-Lib online portal are discussed. Furthermore a semantic information retrieval environment for innovative ways of presentation and retrieval in the knowledge space and developed multimedia applications are described. Finally the paper discusses possibilities how to support designers work today and in the future.

## 2. Concept of the DMG-Lib

The DMG-Lib contains very heterogeneous information resources (see Fig. 2) like books, publications, functional models, gear catalogues, videos, images, technical reports, etc. The original sources are procured, digitized and converted to suitable data formats. The information resources can be accessed worldwide on the DMG-Lib internet portal. This simplifies the access and distribution of these information resources, but does not directly enhance a goal-oriented usage and retrieval for solutions of technical tasks in research and industry. Furthermore the common storage method for knowledge, mainly in static texts and images, does not comply with requirements concerning an efficient and quick information retrieval. The advantages of functional models for a better understanding of complex construction and function principles are well known. Today the necessary techniques are available to provide an easy access to such helpful demonstration models for a broad public. Computer-based methods enable the generation of multimedia documents, which describe the function and other relevant attributes of mechanisms and gears. These can easily be distributed and enriched with extensive additional information [Kammer der Technik 1978].
In contrast to other digital libraries projects, which often provide only access to the digital raw data, the DMG-Lib contains digitized resources which are extensively post-processed and enriched with further information like animations, constraint-based models or various verbal descriptions. Simulations and analyses are also possible, because constraint-based models can be used in external analysis, synthesis and optimization systems (see section 4). Such approaches are necessary to make a transition from a static to a dynamic problem oriented supply of knowledge for a wide range of application domains and user requirements. An overview of the complex production workflow for the

identification, digitalization, enrichment, storage and presentation of information resources in the DMG-Lib is displayed in the following figure (Fig. 3).

**Figure 2. Sources of the DMG-Lib**

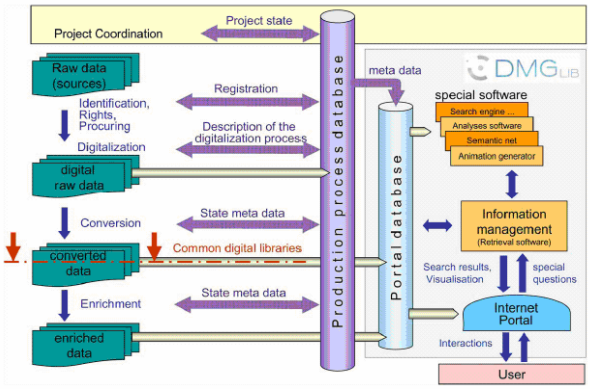


**Figure 3. Production workflow in the DMG-Lib**

Based on the available heterogeneous information resources in the library and the extensive enrichment, the DMG-Lib is able to provide an efficient retrieval as well as various utilization options for users. Following these considerations several additional aims of the DMG-Lib project can be derived:

- Constraint-based modelling of mechanisms and gears as base for generation of further description forms [Döring et al. 2006]
- Supply of descriptions of mechanism and gear knowledge in various forms to ensure a flexible, adaptive and long term usability (verbal, images, constraint-based descriptions, animations)
- Cross-platform presentation in the internet for different user groups and different use cases like research, product development or self-study
- Development of information retrieval systems, which allow a structural selection and type syntheses of mechanisms and gears
- Support of automated access options for the library content using various applied descriptors or metadata (e. g. OAI-PMH service)
- Support for researchers and developers during the development of solutions for special synthesis or optimizing problems

## 3. Implementation of the DMG-Lib

For the implementation of this ambitious concept a consequent cooperation between information, computer and usability scientists as well as engineers, librarians and experts of mechanism and gear

science is necessary. This is the only way to collect, enrich and present the complex domain specific heterogeneous information resources according to the user requirements.

### 3.1 Enrichment of the information resources

The following information sources are digitized and integrated in the digital library:

- Literature relevant for mechanism and gear technology (monographs, journal articles, etc.) from different libraries and private collections,
- Solid mechanism and gear models of the Universities in Aachen, Dresden, Chemnitz and Ilmenau,
- Images and slides of gears available in the project partners archives,
- Technical drawings (outlines, technical blueprints, technical principles and calculation instructions),
- Training materials of the departments involved in the DMG-Lib project.

The literature sources are usually scanned with 300 dpi resolution and 256 grayscales and saved as TIFF files. For the scanned resources metadata according to the Dublin Core standard are stored in the production database (dublincore.org). In addition the documents are classified according to technical aspects. For further processing of the digital raw data a layout and text analysis is necessary. For the identification of the physical structure (text blocks, images etc.) as well as the individual characters in the documents the commercial software ABBYY-Finereader is used (www.abbyy.com). The software is embedded in a self developed application framework called AnAnAS (Analyse-Anreichungs-Aufbereitungs-Software). Other applications developed in the DMG-Lib project identify the logical structure (headlines, labels of figures etc.) more and more automatically. The storage of the metadata in AnAnAS is based on the METS-Standard (www.loc.gov/standards/mets).
Different metadata are added to the documents like administrative (scanned document, document source), descriptive (e.g. Dublin Core) and structural (connection between the content and other meta-data like figure references) information. The result of the structural and layout analysis is the identified logical structure of the document. This information can be used in further processing steps like the automated generation of links and tables of contents as well as the ranking of full text search results. For the enrichment of scanned documents an animation generator was developed, which allows the simulation and the variation of drawings, images and models in an easy and fast way (see Fig. 4).

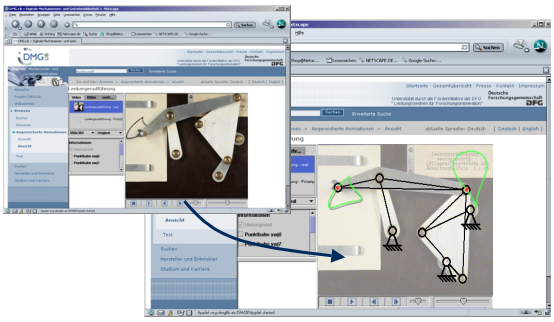

**Figure 4. Enhancement of a video by an overlaid simulation-based animation created by the animation generator**

An export to CAD and special analysis software systems will be available as well. Base for the export and the animation generation is a special XML-based file format in which the structural and geometric description of the displayed gear is stored [Döring et al. 2006]. These abstract model descriptions provide rich information for various search criteria for example the number of elements of the gear.
The analysis of the simulation results provides further information describing the function of the gear like the transmission behavior. This functional information is important for the implementation of a

problem oriented information retrieval. To the individual models, animations, images and literature resources experts can attach further metadata like detailed descriptions, crosslinks and other annotations. This information will be edited either in the AnAnAS system during the processing of the digital raw data or in specially designed interfaces directly in the production database. The production database was developed using MySQL and content is now continually added. The bottleneck in the workflow of the DMG-Lib project is the clarification of copyrights.

### 3.2 DMG-Lib Online Portal

The portal is the internet based communication and presentation interface between the user and the DMG-Lib (see Fig. 5). For an user adequate design and implementation an evaluation of the usability was performed which is oriented on the Usability Engineering Lifecycle [Mayhew 1999]. According to this method a requirement analysis and expert interviews have been carried out to develop a conceptual model of the DMG-Lib portal. In March 2006 the prototypic online portal on www.dmg-lib.org was activated. It currently serves as a platform for usability tests. Beside the interactive search option in the web portal the content of the DMG-Lib can be accessed with an OAI-PMH web service as well (www.openarchives.org/OAI). In January 2007 the DMG-Lib portal included about 50 books, 700 demonstration models, 80 biographic entries and more than 40 enhanced images and videos.


**Figure 5. DMG-Lib portal**

### 3.3 Multimedia Applications of the DMG-Lib

Parallel to the internet portal interface other interactive multimedia applications are developed like the multimedia timeline and the virtual mechanism and gear museum. The timeline application gives users a multimedial overview of important persons, inventions and publications in the historical development of mechanism and gear science. Users will be able to directly access corresponding information resources, for example available books of selected persons in the library. Beside traditional browsing and retrieval methods these applications provide alternative ways to access the knowledge stored in the library. Prototypes of these applications are integrated in the DMG-Lib portal and are currently tested by the user community.

### 3.4 Searching and Browsing

Searching and browsing are the central accesses to all information in the DMG-Lib. For both variants the text-based search is a basic functionality to find all kinds of information from the different sources. The search for mechanisms is supported by several input forms, which are based on [Niemeyer 2003]. Different aspects of search (functional, structural, bibliographic etc.) are possible (Fig. 6). This allows specific selections for instance by specifying the number of mechanism links, of the driving and driven movement, of the mechanism dimension (planar, spheric or spatial) etc.

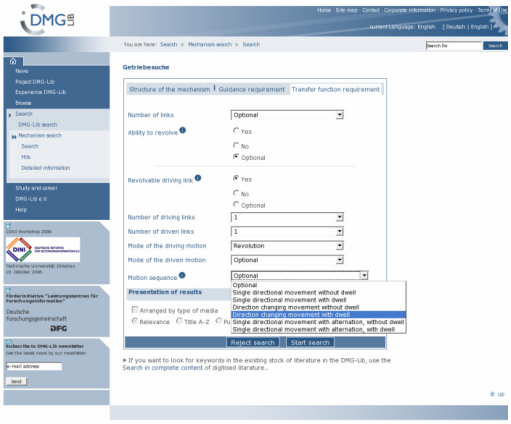


**Figure 6. Example for a text-based search**

For the representation of found documents during the browsing and searching process special viewers are available. All information about persons and metadata are presented in html pages. For the work with full texts (Fig. 7) and enhanced / enriched animations (Fig. 4) browser-embedded applications exist.

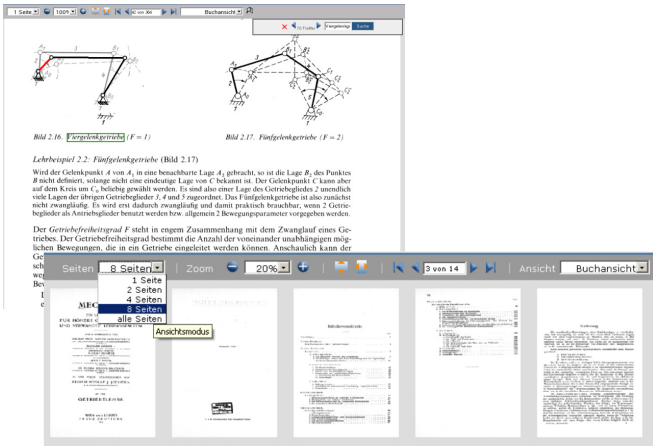


**Figure 7. Book viewer for one or more pages, which supports full text search and embedded interactive animations**

### 3.5 Semantic Information Retrieval

A further field of research is the retrieval in heterogeneous information resources using different mechanism and gear hierarchies like the structural system of Reuleaux [Reuleaux 1875] or other classification systems of well known publications (e. g. [Kammer der Technik 1978]). A visualization and an efficient navigation over these classifications can help users to get a systematic overview over the huge amount of existing mechanisms and gears. However, the identification and modeling of these classifications and relations between the different technical terms are quite complicated, because for example different opinions of experts and authors, synonyms and foreign language translations have to be considered.

To solve this problem semantic web technologies can be used. With the help of Topic Maps, as a special kind of semantic networks, the knowledge of mechanism and gear science can be generalized

and explicitly modeled in a semantic meta-layer [Park 2003], [Pepper 2000]. With the extensive descriptive power of Topic Maps, all relevant concepts (representing technical terms) and relations between the concepts of this application domain can be modeled. Additionally, valid contexts (e.g. a technical term is relevant for a specific time period or a specific publication), alternative names and other relevant semantic information can be included. Furthermore each concept in the semantic meta-layer is linked to all relevant information resources available in the library.
With the help of this semantic meta-layer the different hierarchies can modeled and visualized. This enables a user to decide which structuring system he wants to use for navigation. Currently a Topic Map based "Semantic Information Retrieval ENvironment for digital libraries" (SIREN) is developed to support the complex development process of the semantic meta-layer and the information retrieval process [Goodall 2003], [Markscheffel et al. 2006].

## 4. Use cases in the designer's work

As described above the digital library is work in progress. Some of the results are already visible in the portal and can be used by the different communities (engineers and designers, teachers, students, historians etc.). Other content as well as portal features are still under development. Some examples:

- The internal project database includes over 1000 authors and scientists relevant to the DMG - Lib and over 2000 documents (books, articles, etc.) from which over 1000 are scanned.
- Tools for post-processing the digital resources and the enrichment become more and more effective. Thus in the next time the number of literature resources as well as mechanism descriptions available for users in the portal will grow strongly.

In the next years thousands of resources will be provided in the portal.
This section describes use cases. Some of them can already be tested in the DMG-Lib portal. Others are tested internally only or are planned to be available in the future. In the following text the use cases are sorted according to the current state of development.
In the context of engineering design the focus lies on the development of motion systems. The DMG-Lib is designed as a knowledge and solution database which supports (from the engineering designers point of view) the finding of a solution idea for a certain motion task. This is or will be done especially by supplying:

- fast access to interesting sections in the literature concerning examples, design rules and calculation schemes as well as
- retrieval of solutions from the database of mechanism descriptions according to criteria given by the user.

**Today's use cases**

At the moment approximately 700 model descriptions are stored in the DMG-Lib. For the *retrieval of mechanism descriptions* different criteria can be used, for example:

- dimension of the mechanism,
- type of motion at the driving link,
- type of motion at the driven link,
- possible limitations in the range of rotation,
- number of mechanism elements,
- orientation of axes and
- special features of a motion curve (e.g. symmetry, linear parts).

Guidance and transfer function requirements are distinguished. The criteria can be defined in input forms as shown in Fig. 6. In some cases the retrieved mechanisms can be directly a solution in other cases they give ideas how the problem can be solved.
Currently most of the literature shown in the portal is in German. Thus german engineers as well as engineers which are able to understand german texts may search, find and use engineering knowledge in the portal. A multilingual interface, the integration of content in other languages and a multilingual retrieval is described below.

Besides simple browsing a text search is supported. The searchable text covers metadata from literature, persons and mechanism descriptions as well as full texts (Fig. 8). For occurrences in literature the book viewer interface can be used. It shows the occurrences and allows to iterate them (see Fig. 7). The viewer is displayed in the internet browser (java script) and shows pixel images in a selectable resolution. To some figures animations are attached which can help to understand the movement of the shown mechanisms or even to detect differences between a depicted curve and the curves which would be generated by the depicted mechanism.

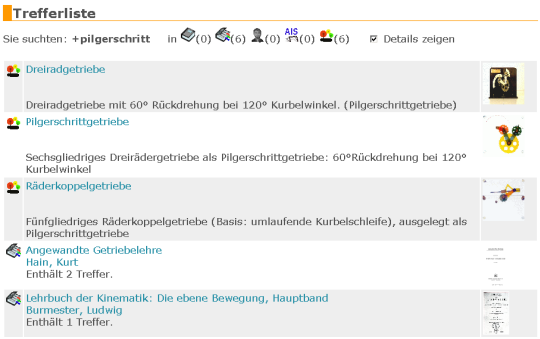


**Figure 8. Result of a term-based search with hits in metadata and full text**

**Medium term use cases**

The more formally the knowledge was written down by the authors, the better it can be understood by users in other languages. Formulas, equations, figures can almost always be understood by readers which have an according technical background. The problem for such readers is to find the relevant sections in the provided literature. Therefore multilingual search will be supported in the near future. The semantic network is used to translate the search terms so that information written in other languages can be found.

Some English documents are already in the portal (e.g. written by Robert Stawell Ball). The amount of *content in non-german languages* will be enlarged in cooperation with international partners. Thus the probability increases that an engineer will find texts in his native language (or a language he understands well).

Furthermore a *multilingual interface* is planned, where users may select one ore more languages. The phrases and selected administrative content will be translated by international partners. Of course it will never be possible that at every time each menu item, comment or help text is available in each supported language. But the user of the DMG-Lib will possibly get most of the interface in his preferred language (e.g. in French) and other parts in a well supported “fallback” language (e.g. in English, or any other language he has selected as further languages too).

Further medium-term features (resulting in use cases) are based on the formal description of mechanisms, which will be provided in an XML format. An SDK (software development kit) which supports reading and writing of such files is under development. First tools developed with the SDK support the export of mechanisms to SVG (visualization as scalable vector graphics) and ADAMS. The *export to motion simulation software* like ADAMS may become a very important use case. The engineer selects a certain mechanism (e.g. after narrowing the set of interesting mechanisms by searching according to some criteria) and exports it to the simulation system available at his workstation. Here he can check the dynamic behavior and possibly change the behavior by modifying some parameters.

The *export to CAD systems* was also often asked by engineers. First tests to generate a preliminary embodiment based on the descriptions of mechanisms stored in the DMG-Lib are made. The exporter uses a common interface which was implemented for Autodesk Inventor and Solid Works. Nevertheless it will be possible to write own exporters, e.g. based on the SDK, which generate

mechanism descriptions in other target formats. Thus generally each engineering designer will be able to import mechanisms into his CAD system and use them as starting point for a more detailed design.
It was mentioned before, that the resources of the DMG-Lib are very heterogeneous. A further use case concerns interactive documents. Based on teaching material *calculation* sheets are developed, which can be downloaded and executed if the according software (MathCAD) is available. Besides the use as interactive teaching material these sheets can be used by engineers to perform calculations according to their design problems too.
When the descriptions of mechanisms are available for export interfaces, these descriptions can be used for a more detailed search too. A medium-term use case will be the *search for certain structures* or solution principles (defined by well known symbols). That means the user may define a set of mechanism elements and how they are linked to each other (a simple Web-Interface will be provided for this) and then ask if such a mechanism is stored in the database or if mechanisms exist, which include such a structure. This will allow to search for information about mechanisms where the name is unknown or where the semantic net has not enough stored synonyms and translations. Based on the database of formalized descriptions for mechanisms shown in the DMG-Lib (figures, photographs, animations) and the description given by the user a search can be performed which is not based on texts. Internally algorithms for graph or sub-graph isomorphism are executed. After finding occurrences of the searched structure and according names the search may be continued using such names.

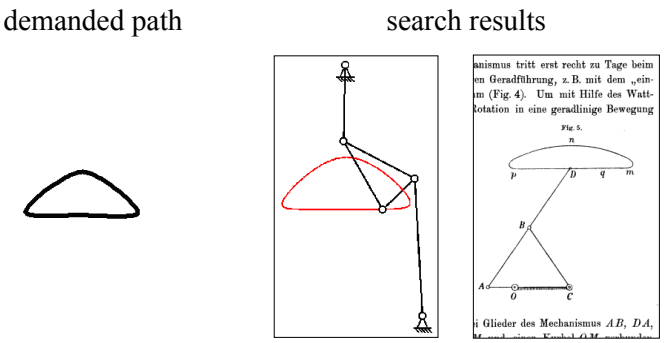


**Figure 9. Example for sketch-based search for mechanisms**

**Long-term use cases**

The most interesting use case seems to be the search for solutions based on graphical input like transfer functions or motion curves. It will be very intuitive for engineers to sketch a path and then ask for mechanisms which can move a point on this path (Fig. 9). To narrow the result a sketch of the usable space for the mechanism, curves for velocity and acceleration or allowed/disallowed mechanical elements could be specified by the user too. Obviously such a search can not be implemented easily. But a large database of reasonable (a lot of examples have practical background) and analyzable (the formal description allows simulations) mechanisms gives a great chance to solve (or at least tackle) the important problem of *structural optimization* in a long term project.
After finding a set of matching mechanisms for the best fitting ones the parameters may be optimized to meet the needs as close as possible. It is supposed that this parameter optimization is mostly performed by the user according to his special problem with his software tools.
A further long term goal is that the DMG-Lib shall become a portal

- for communication between engineers and manufacturers (e.g. integration of product catalogs),
- for design services (solution finding and optimization) and
- for heterogeneous knowledge concerning movement design.

## 5. CONCLUSION

In this paper the DMG-Lib project is presented, a digital and interactive library for mechanism and gear science. Aims of this project are the collection, preservation and suitable presentation of the worldwide existing knowledge about mechanisms and gears. Outstanding features of the digital library are the powerful and user-oriented internet portal and the integration of a large number of very heterogeneous information resources relevant for this field of application. The extensive post-processing and enrichment of the digital data with various additional information like animations or constraint-based models is also important. Combined with the development of new interactive multimedia applications and a semantic information retrieval environment, the DMG-Lib provides users with an innovative access to the stored knowledge in the library. This supports engineering designers in finding ideas for design solutions, calculation procedures, adequate technical terms, detailed structural and functional descriptions, historic publications in different languages, etc. The DMG-Lib helps young people to discover interests in mechanical engineering as well as opens doors for further education possibilities. The DMG-Lib project is an example for a modern knowledge space and fulfils one of the key tasks in today's information society, satisfying user's needs for getting an efficient access to required information.

The DMG-Lib project is financed by the "Deutsche Forschungsgemeinschaft" (German Research Foundation).

### References

*Borgman, C., Kovcs, K., Sølvberg, I. and editors, Proceedings of the Fourth DELOS Workshop Evaluation of Digital Libraries: Testbeds, Measurements and Metrics, Budapest, Hungary, 2002.*

*Brix, T., Döring, U., Trott, S., "DMG-Lib – ein moderner Wissensraum für die Getriebetechnik", "Knowledge extended: die Kooperation von Wissenschaftlern und Bibliothekaren und IT-Spezialisten", 3. Konferenz der Zentralbibliothek (KX'05), Jülich, Germany, 2005, pp. 251–262.*

*Döring, U., Brix, T. and Reeßing, M., "Application of Computational Kinematics in the Digital Mechanism and Gear Library DMG-Lib", "Special issue on CK2005, International Workshop on Computational Kinematics. Mechanism and Machine Theory", 2006, 41(8), pp. 1003–1015.*

*Goodall, G.A., "A Time for Digital Libraries",*
*http://www.deregulo.com/facetationpdfs/aTimeForDigitalLibraries.pdf, 2006.*

*Kammer der Technik, "Begriffe und Darstellungsmittel der Mechanismentechnik" (engl.: Technical terms and representations in mechanism theory), Kammer der Technik, Suhl, Germany, 1978.*

*Markscheffel, B., Thomas, H. and Stelzer, D., "TMwiki – a Collaborative Environment for Topic Map Development", "3rd European Semantic Web Conference (ESWC 2006)", Budva, Montenegro, 2006.*

*Mayhew, D. J., "The Usability Engineering Lifecycle – A Practitioner's Handbook for User Interface Design", Morgan Kaufmann Publishers Inc., San Francisco, 1999.*

*Niemeyer, J., "Methodische Entwicklung von Prinziplösungen bei der Auslegung ungleichmäßig übersetzender Getriebe unter Verwendung eines praxisorientierten interaktiven Wissensspeichers", Shaker Verlag, Aachen, Germany, 2003.*

*Park, J. and Hunting, S., "XML Topic Maps: Creating and using topic maps for the web", Pearson Education Inc., New Jersey, 2003.*

*Pepper, S., The TAO of Topic Maps. http://www.ontopia.net/ topicmaps/materials/tao.html, 21 January 2007.*

*Reuleaux, F., "Lehrbuch der Kinematik", Vieweg, Braunschweig, Germany, 1875.*

Dr.-Ing. Torsten Brix
Ilmenau University of Technology, Dept. of Mechanical Engineering, Engineering Design Group
P.O.Box 100565, D-98684 Ilmenau, Germany
Tel.: +49 (0)3677 69 1263
Fax.: +49 (0)3677 69 1259
Email: torsten.brix@tu-ilmenau.de.