INTERNATIONAL DESIGN CONFERENCE - DESIGN 2012
Dubrovnik - Croatia, May 21 - 24, 2012.

LIGHTWEIGHT MECHATRONICS DESIGN: AN INTEGRATED APPROACH

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Keywords: lightweight design, mechatronic design, product development methodology, integrated approach

1. Introduction

One of the primary goals for a responsible and sustainable handling of natural resources and for a limitation of the climatic change – caused by the greenhouse effect – are savings in fuel and energy and the reduction of atmospheric greenhouse gases such as CO_2. At the automotive sector for example, CO_2 emissions of recently registered cars are not allowed to exceed a limit of 120 grams per kilometre according to new guidelines of the European Union from 2007. Parallel to the regulation of the CO_2 emissions the fuel consumption is reduced. In contrast to this economisation strategy, growing safety requirements, power enhancement and rising customer demands in comfort effect a permanent increase of the car weight, e.g. the weight of VW Passat in 2005 (6th generation) is more than 50 per cent greater than the one in 1975 (1st generation) [Goede 2007]. These aspects are often realized by the use of mechatronics. By now, the mechatronic proportion of weight in car amounts more than 20 per cent, the proportion of added value even more than 40 per cent. It must be assumed that this percentage will significantly increase in the future – regarding the hybrid- and electro-mobility. To solve the problem of weight increase lightweight design plays an important role. It is necessary to start lightweight arrangements in order to reduce the weight of a car because all driving resistances except of the aerodynamic resistance depend on the mass. With the weight reduction the fuel consumption will decrease and an environmentally conscious use of resources and energy will be triggered.
The passenger car as the representative example of a mechatronic product shows that the increasing percentage of mechatronics is contrary to the idea of weight reduction and savings in fuel and energy – but only at the first sight. A precise consideration of the topic shows that there are some innovative answers to reduce the weight of the overall system "car" by the application of mechatronic components and systems, e.g. drive-by-wire, smart structures or adaptronic systems. For this purpose, it is essential to point out the possibility of an integrated product development of both the disciplines, mechatronics and lightweight design – the so-called lightweight mechatronics design which requires a novel and special procedure during product development.

1.1 Focus of the research

The relation between mechatronic and lightweight-oriented product development in case of a common use will be investigated in this research, of which a part is presented in this paper. The research begins with a review of the definitions and different methodologies for product development of the two disciplines mechatronics and lightweight design which are separated from each other. Thereby, deficits and potentials during the development and the application are identified and described. The definition of the term "lightweight mechatronics design" as well as first challenges and methodical approaches for a product development complete the first part of the research. Furthermore, the apparent conflict of lightweight design and weight increasing mechatronics will be more closely analysed. In particular, some examples of the use of mechatronics to decrease the weight will be given and systematically classified. Based on these facts, new concepts are developed, validated and optimized. In the further progress of the research, established product development methodologies of the two disciplines – in the area of mechatronics for example the VDI guideline 2206 or the spiral design model, in the area of lightweight design a methodology based on the VDI guideline 2221 – will be investigated with regard to their suitability for the development of light mechatronic products. These results are the basis for a self-contained product development methodology and for design principles in the field of lightweight mechatronics design. The new approach will be illustrated on one example. The focus of the methodology does not lie on sub-products of a complete system, but rather on the complete system itself. Moreover, existing IT-tools and systems of both disciplines are analysed. Out of this, requirements of simulation and computation tools will be generated which could be applied in the development of lightweight mechatronics products. Based on these facts, some research questions are rising:

- How do the framework and the methodology of lightweight mechatronics design have to look alike? Which requirements are necessary?
- Which influence do the disciplines mechatronic design and lightweight design have on this novel framework?

1.2 Approach and structure of this paper

This paper presents an approach to the non-explored field of a common product development of the two disciplines mechatronics and lightweight design. It begins in chapter 2 with a literature review of the definitions and descriptions of both areas. Potentials and deficits are presented. Based on the need for action, an approach for the framework "lightweight mechatronics design" is given in chapter 3. It deals with the definition of the term lightweight mechatronics design as well as the description of the potentials rising up and of the structure of the development methodology for lightweight mechatronic products. Requirements needed for this type of product development are depicted before finishing with the challenges and further research questions regarding lightweight mechatronics design.

2. State of the art

2.1 Mechatronic design

2.1.1 Definition of mechatronics

Traditional research proposes a lot of different definitions of the term "mechatronics" which has now developed over 40 years. On the one hand, mechatronics is seen as an independent, self-contained engineering discipline, on the other hand as an intelligent combination of already existing disciplines, namely mechanical engineering, electric engineering and information technology. Due to the development of the term mechatronics over more than 40 years, mechatronics contains not only the product as a synergetic result of these three known fields, but also the process of origination, in fact the conceptual design, the manufacturing and the fulfilling of the desired requirements. According to the VDI guideline 2206 [VDI 2004], mechatronics is best described by the explanations of Harashima, Tomizuka und Fukuda [Harashima 1996], as "the synergetic integration of mechanical engineering with electronic and intelligent computer control in the design and manufacturing of industrial products and processes". This and even more not mentioned definitions have one thing in common: a mechatronic system in general consists of a basis system, sensor, actuators and the processing of information without neglecting the external conditions.

2.1.2 Methodology according to the VDI guideline 2206

As an example of the development of mechatronic systems, the VDI guideline 2206 is shortly depicted. It is mainly based on three elements:

- on the micro-level the general problem-solving cycle
- on the macro-level the V model

- predefined process modules for handling recurrent working steps in the development of mechatronic systems.

This guideline is meant to be a supplementation to the existing guidelines VDI 2221 ("Systematic approach to the development and design of technical systems and products") and VDI 2422 ("Systematical development of devices controlled by microelectronics"). It should characterise the design methods of mechatronic systems in analogy to the sector-independent, generally applicable VDI 2221. The mechatronic approaches of the VDI 2242 should be improved and developed into a universal cross-domain guideline.

Problem-solving cycle as micro-cycle

The problem-solving cycle whose origin is in systems engineering structures the procedure in the development process and can adapt the process planning to the characteristics of each development task. This cycle consists of several sub-steps, starting with a situation analysis or an adaption of goals. Next, alternative solution variants are generated and optimized in an analysis-synthesis-step. After another solution analysis and an assessment one or more solution alternatives are constituted and concretized. The concluding step is the planning of the further procedure or the learning.

V model as macro-cycle

The V model characterises the generic procedure for designing mechatronic systems. The number of runs through the macro-cycle depends on the characteristics of the specific development task. The macro-cycle consists of different process modules. Starting point is the fixing of requirements which are based on an actual development order. The requirements are the basis of validation for the later product. Based on the requirements, a cross-domain solution concept which is described by physical and logical operating characteristics is generated by breaking down the overall function into main sub-functions. The concretisation of this jointly developed solution concept takes places separately in the involved domains. The outcomes from the different domains are brought together to an overall system to allow an investigation of the interaction. The system characteristics are checked on the basis of the specified solution concept and the requirements. It has to be ensured that the actual system properties coincide with the desired ones. The above-mentioned development phases are flanked and supported with the aid of models and computer-aided tools for simulation. The result of a finished macro-cycle is the product. Here, it should be noted that a mechatronic product is generally never the result of only one macro-cycle, but also a certain number of cycles which represents the product maturity. For example, maturity degrees are the different specimens, prototypes or the pilot-run product.

Process modules for recurrent working steps

Process steps and working steps which keep recurring in the framework of the VDI guideline 2206 during the development process of mechatronic products can be described in the form of predefined process modules. That includes modules system design, modelling and model analysis, domain-specific design, system integration and the assurance of properties. A more detailed explanation of these process modules can be found in [VDI 2004].

2.1.3 Potentials of and challenges through mechatronics

Potentials of mechatronics

Mechatronics achieves its success by taking advantage from the synergies of the three classical engineering disciplines. This interdisciplinary perspective generates success potential to create new products and applications [Jendritza 2003], [Möhringer 2005]. There are: improvement of functions and behaviour of technical systems; reduction of space, weight and cost; integration of more functions; increasing of dynamics; realisation of new functions; creation of self-optimizing, intelligent systems; monitoring and human-machine-interaction; advancement of the cost-benefit ratio; extension of durability and reliability; holistic and interdisciplinary view of the product.

Requirements for the application of mechatronics

To tap the full potentials of mechatronics and to establish new possibilities driven by mechatronics certain requirements has to be fulfilled – compared to existing, non-mechatronic solutions [Jendritza 2003]. There are for example: function benefits referring to efficiency, noise and package; no weight and cost increase; safe and reliable handling under changing external conditions (e.g. temperature, vibrations, accelerations, …); fulfilment of safety requirements, laws and guidelines; easy service, handling and recycling.

Deficits in mechatronic product development

Despite these benefits some deficits and problems of the mechatronic product development cannot be neglected. During the development of mechatronic products interaction between the individual domains are insufficiently considered wherein the system boundaries between the domains are not clearly defined. Moreover, the crosslinking of computer-aided tools for simulation is missing in the domains as well as in the system. Very important is the insufficient acceptance and application of the development of mechatronic products in most industrial sectors.

2.2 Lightweight design

2.2.1 Definition and requirements

The definition of the term "lightweight design" has developed – comparable to the definition of mechatronics – over time. As a consequence different definitions are given in the literature [Schmidt 2004]. First, the lightweight design is described as only a weight decrease of a construction without bringing more details up. Second, lightweight design is a symbiosis of economic package solution characterised by the optimum use of materials and an adapted design in consideration of best possible savings in natural resources. Finally, the definition in [Wiedemann 2006], which will be the perspective of this paper, perceives lightweight design as the application of strategies, methods and tools for a selection of the design, the construction and the choice of materials with the aim of a mass reduction of products considering the differently rated criteria costs, function, economy and ecology.

The development of lightweight products is a complex and interdisciplinary process. A multitude of requirements have to be fulfilled, e.g. demands of the society, politics or the market. There are especially criteria of the ecology (for example consumption of resources, recycling), the safety, customer acceptance (replaceability, ease of maintenance) and styling. [Henning 2011]

2.2.2 Strategies, techniques and methodology

Strategies

Lightweight design strategies are needed to generate new and optimized structures. They unify a goal-oriented application of different lightweight construction methods, material and manufacturing technologies and allow support during the development process of lightweight products. In literature, there are miscellaneous denotations for these strategies. They can be classified as follows [Henning 2011]:

- Conditional lightweight design: New lightweight potentials of a certain structure arise out of a critical review of all requirements from external conditions of the society, politics and the customer markets. Depending on the requirement it will be divided into purpose lightweight design, savings lightweight design and eco-lightweight design.
- Lightweight material design: The given requirements for the structure have to be realized by using the lightest material. However, the different material properties and thus, the associated constructive changes have to be kept in mind. A differentiation can be made between basic material lightweight design and composite lightweight design.
- Manufacturing lightweight design: Weight saving potentials arise in various processes of production, manufacturing and assembly.
- Form lightweight design: Adapting of components to a novel structure with an optimal force distribution and a shape of minimal weight could result in weight savings. It is differed in structural lightweight design and form lightweight design.

- Conceptual lightweight design: The weight of the overall system will be reduced by systematically investigating certain structures and modules and adapting to the whole or a subsystem. Depending on the point of view the conceptual lightweight design is subdivided into systemic lightweight design, functional lightweight design and modular lightweight design.

To achieve an optimum lightweight product, multiple strategies can be applied at the same time in combination.

Techniques

These different lightweight design strategies can be realized by certain construction methods.

- differentiated design (additive connection of singular components to an overall structure)
- integrated design (structure based on one part)
- modular design (integration and bonding of function on modular level)
- composite design (combination of different materials with better characteristics)

Often, there is more than one which will be utilized.

Methodology and design guidelines

There is no special methodology to develop lightweight products. Existing methods, e.g. the VDI guideline 2221, the problem-solving cycle with its four phases or the value analysis according to the DIN standard 69910, are applied and adapted to the particular lightweight design task. [Klein 2009] describes a systematic procedure during the development process of lightweight products. In addition to the traditional four phases of design (clarifying the task, conceptual designing, layout designing, detail designing), an expert in lightweight design comes into play. He plays an essential role during the development process with his in-depth know-how and his ideal combination of theoretical basics and his practical experience. The expert is available over all the phases.

The so-called "value analysis weight" is in [Feyerabend 1991] suggested as a methodical weight reduction concept. Therefore, the well-known value analysis methods of DIN 69910 and VDI 2800, which have their origin in the analysis of costs, are adapted to the problem of weight. All tasks respecting costs are changed to the weight, for example weight-benefit analysis and technical-weight related evaluation instead of cost-benefit analysis and technical-economic evaluation. Furthermore, the value-analysis weight must review a given construction holistically through the single development and usage phases of a technical system. The phases, in which the requirements of functions have influence on the weight, have to be determined and methodically handled.

The "innovative lightweight design" [Schmidt 2004] structures the procedure for the methodical weight reduction into two phases: analysis and synthesis. The first stage includes the analysis steps in which the mass distribution, the key modules and the interrelations (e.g. via cause-effect diagram) are identified and weaknesses as well as the lightweight potential of the product are characterised. In the following second phase, strategies and arrangements for implementing a new product are chosen and innovative solutions are searched as well as risks and efforts are determined.

To realize good lightweight products it may be helpful to pay attention to design rules applicable for lightweight design. Their origin lies in the experience of lightweight engineers which have assembled these rules in a design catalogue [Klein 2009].

2.2.3 Potentials and problems of lightweight design

Potentials of lightweight design

With the aid of lightweight design, products achieve savings in different ways. Direct savings could be a lower consumption of fuel and energy, e.g. a car consumes approximately half a litre less if the weight is about 100 kilograms lower. Moreover, the resource usage and polluting emissions like greenhouse gases will be reduced. For this reason, lightweight design offers the possibility to develop sustainable and environmental-friendly products. Based on this, laws and regulations are complied. Beside these facts, costs will be minimized in the area of transport, assembly, production, maintenance and servicing. Furthermore, moveable masses can be reduced and thus dynamics increased, which brings advantages in various applications.

Problems of the lightweight design

The problems which arise in the design of lightweight products can be divided as follows [Schmidt 2004]. First, in the field of materials there are only limited possibilities to simulate the behaviour of materials because characteristics of the material are not available or hard to identify. Very often problems occur during the manufacturing in the expensive processing of materials. The largest deficits appear in the field of product design and development. Thereby, the analysis of significant influencing factors and of the lightweight potential is often very difficult and complex. Moreover, there is a lack of information and knowledge, e.g. a detailed catalogue consisting of constructive local, classified measures is missing. In addition, already existing precise solutions cannot be transferred to upcoming problems because the development tasks are often very varied. Moreover, well-directed supports for the usage of the synergies out of the lightweight design – because of a deficient definition of interfaces between the fields of materials, design and technology – and a continuous classification of rules and principles, which are in parts contrary, are missing. Not to be disregarded may the benefit-cost ratio that is oriented at the field of application. For example, in the aircraft and space industry lightweight costs of more than 100 € per kilogram saved are accepted, in contrast to around 5 € in the automobile sector.

2.3 Need for action

Through the literature study, potentials and deficits of mechatronic and lightweight design are found and emphasized. The mechatronic potentials permit the creation of innovative and novel products whereas it is necessary to keep lightweight aspects in mind especially in view of the currently existing strategies of economization. For this reason, there is a need to design mechatronic and light products in only one development procedure. This point of view will be considered in the framework "lightweight mechatronics design".

3. Lightweight mechatronics design

3.1 Definition of terms and classification

"Lightweight mechatronics" characterises in general mechatronic products which are developed regarding lightweight design principles to gain a weight optimum. On the one hand, the weight optimum can be reached by light mechatronic components themselves, on the other hand using mechatronic concepts to reduce the weight. Thus, lightweight mechatronics represent weight-optimized products. It must be ensured that a universal, generally accepted definition of mechatronics is not identifiable. Based on the definition of mechatronics given above [Harashima 1996], lightweight mechatronics is defined as "mechatronics in consideration of a weight optimum of the overall system". The word order of the term "lightweight mechatronics design" specifies that in the relationship of mechatronics and lightweight design the former plays a primary role. The literature study of methodologies of both single disciplines shows that the focus of mechatronic design is the creation of products and their functions ("design to function"), whereas lightweight design has its main task in the weight reduction assumed that the functions are retained and not downgraded ("design to weight"). The lightweight mechatronic design attempts to combine these two versions of "design to X". In this context, the generation of functions is considered more important than the task of weight optimization. Hence, lightweight mechatronics design is basically originated from the mechatronic design, whereas lightweight design is responsible for a systematical weight reduction during the development process.
Figure 1 shows which aspects have influence on the new discipline of lightweight mechatronics design. The requirements of both single disciplines impact the ones of the new design which will be focused later in this paper. The different arrows show that the mechatronic design is the basic module and lightweight design the module which affects the design procedure. In further research, it has to be made clear how deep this influence is; that means the impacts of the elements of mechatronic design – process models, methods, specification, modelling and simulation as well as organisation – on the

components of lightweight design – design and strategies, mechanics, materials, testing and manufacturing – and vice versa. It should be noted that the elements of both mechatronic and lightweight design have a different origin. Mechatronic design as an interplay of various disciplines unifies in its elements (process models, methods, specification, modelling and simulation, organisation) the aspects of its single disciplines whereas the domain-specific design of mechanics, electronics and information technology is mostly stand-alone and insufficiently connected with the other ones. On the contrary, lightweight design as a single discipline emphasizes particularly the relevance of materials, mechanics, manufacturing, testing and strategies.

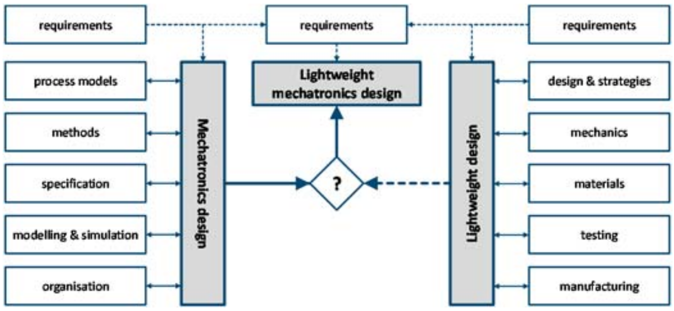

Figure 1. Influences on lightweight mechatronics design

3.2 Structure of a lightweight mechatronic system

The basic structure of a lightweight mechatronic system is very similar to the mechatronic one, see Figure 2. Additionally to all these constituents, the aspects of lightweight design are represented. The basic system – a mechanical, electro-mechanical, hydraulic or pneumatic one – and the sensor and actuator parts as well as the entire systems are optimized in the sense of lightweight design. The weight-optimisation of the overall system is only possible if the weight reduction is not only applied at the single elements but also in the interaction between. For example, if the basic system and the actuator are separately weight-optimized, but the connection between both has to be designed heavier, there is no benefit. Therefore, it can be stated that the system's overall weight should be first priority.

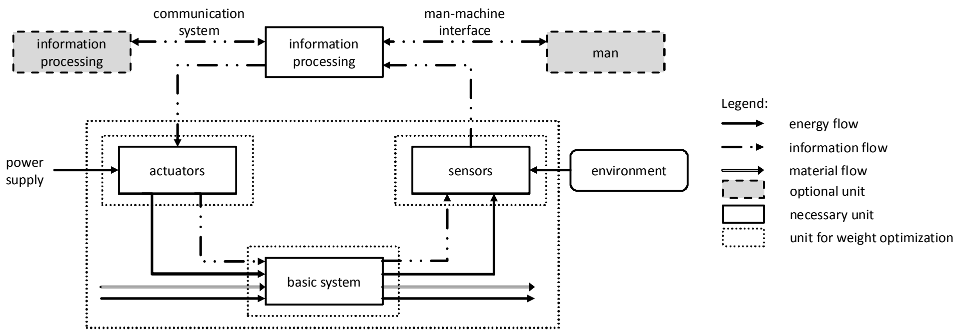

Figure 2. Lightweight mechatronic system

3.3 Potentials

The coaction in lightweight mechatronics design offers success potentials for the creation of new products and applications. There are three categories: technical, economic and ecological potentials. Predominantly, there are new potentials on the economic and ecological side whereas the technological ones are characterised by mechatronics. In detail, there are:

- Technical potentials: The functions and the behaviour of technical systems will be improved by increased dynamics caused by a weight reduction or by substitution of mechanical with light mechatronic components. Moreover, there will be new fields of application, e.g. in very light and small systems in the medicine technology or other fields. Furthermore, the innovation potential will be saved by new lightweight mechatronic products. During the whole development process it is possible to create a product of high maturity and high lightweight index. Thus, the number of development processes can be minimized.

- Economic potentials: With lightweight mechatronics product costs can be saved in two ways: First, there are direct savings in the consumption of resources and fuel, which is important considering the growing prices for mineral oil and gas. Second, the expenses during transport and assembly as well as expenses in maintenance are reduced due to a weight reduction of lightweight mechatronics. Moreover, an eased number of development processes allows a reduction of development costs and time.
- Ecological potentials: With a reduced weight mechatronic systems are able to save resources and the fuel and energy consumption which leads to savings in greenhouse gases like CO_2. Thus, laws and regulatory can be complied. Furthermore, the lightweight mechatronics design may aim for more sustainable and environmental-friendly products.

3.4 Methodology approach

3.4.1 Overview

Figure shows an overview of the framework of lightweight mechatronics design. The methodology is the basis to which the different elements are connected. It places special demands on the development process. These requirements are affected on one hand from mechatronics and lightweight and on the other hand from the combination of both disciplines. The methodology should be designed in such a way that beside the requirements of the two existing engineering disciplines the new ones are completely fulfilled. The determination of the demands can be seen in the following sub-chapter.
The methodology of lightweight mechatronics design links the elements – which are especially the process model, strategies and methods, system understanding, organisation, modelling and simulation as well as knowledge and communication – among each other. In view of the fact that lightweight mechatronics design is based on mechatronic design – as already mentioned above – the elements of the new methodology resemble the ones of mechatronic design whereas the aspects of lightweight design are regarded. The interaction between the several modules and the significance of the elements for the development process will be investigated in further research.

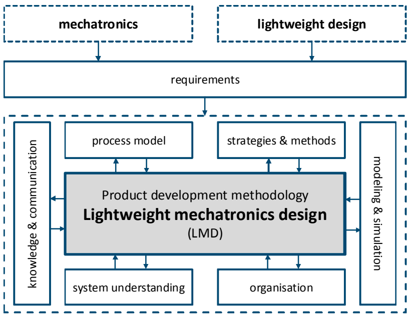

Figure 3. Framework of lightweight mechatronics design

3.4.2 Determination of the requirements on the methodology

Lightweight mechatronics design provides some exceeding new possibilities and great success potentials. At the same time there are challenges at the development process of lightweight mechatronics products which arise from the demands of mechatronics and lightweight design.
In the field of mechatronics the needs can be divided into two classes: requirements out of heterogeneity and of complexity. The complexity takes place in mechatronic systems owing to the interlinked cooperation of different knowledge domains and thus, a major number of interconnected elements. In detail, the requirements rooted in the complexity are: the procedure under the conditions of changing the level of detail and concretion, methods to structure and organize into a hierarchy, early modelling and simulation as well as integration and assurance of properties. The challenge to use the potential of cross-domain collaboration in a synergetic way and to get a global optimum brings the

requirements of the heterogeneity, which are in detail the cross-domain teamwork, cross-domain specification, partitioning as well as integration of models and tools. For further information and insight, see [Möhringer 2005].

Beside these aspects, requirements of the field of lightweight design have to be fulfilled. They can be separated in two classes: demands in the analysis step and in the synthesis step. In the analysis, it is key to recognize the connections of different modules and to estimate the lightweight potential and a reasonable benefit-cost ratio. Based on this, the status of the product in the product life-cycle is essential. For products in use it is possible to optimize certain components, for these in the medium term strategy to lighten a package and for those in the long-term strategy to analyse the whole system. The synthesis step includes other aspects. Based on the results of the analysis, the product has to be designed in the way that a mixture of all lightweight strategies is applied. Moreover, expert competences which has to be distributed is important to ensure a less difficult development process because of using and adapting existing solutions concepts of former developments. With an exact knowledge of the external conditions it is possible to generate early models to perform simulation processes. [Feyerabend 1991], [Schmidt 2004], [Klein 2009].

In addition to this, there are new requirements which are brought up because of the combination of mechatronic design and lightweight design. In detail, there are:

- Modularisation and partitioning: an overall optimum solution rises if the system functions are spread onto active principles and solution elements of the involved knowledge domains and simultaneously the product is modularised in such a way that a maximum possible weight reduction is achieved. The number of iterations and concepts should be minimized.
- Definition and assurance of the lightweight quality: the status of the lightweight quality has to be continuously checked with the help of a specified solution concept and the requirements of the product.
- Methods for structuring and giving a hierarchy: Suitable structures are necessary to reduce the complexity of the lightweight mechatronics systems. Furthermore, a hierarchy provides an indication of which lightweight strategies should be used.
- Early modelling and simulation: increasing complexity because of the connection of different domains of mechatronic design and lightweight design needs modelling and simulation of the system behaviour and the lightweight quality in an early development stage to investigate the multiplicity of possible weight-reduced embodiments.
- Knowledge: the distribution and the storage of knowledge for lightweight design are necessary to generate a catalogue with specified and classified measures and to ease upcoming development processes.
- Holistic view of the system: an overall optimum solution is only possible if, despite of the modularisation, an overview of the whole system is not be neglected.

3.5 Challenges

To describe the whole product development methodology for lightweight mechatronics design, some challenges rising in the research have to be clarified. First, the influence of the different disciplines – mechatronic design and lightweight design – symbolized by the question mark in Figure 2, will be described. The different elements of the methodology (process models, knowledge and communication, system understanding, methods and strategies, organisation structure, modelling and simulation) will be declared in detail regarding the requirements given above, starting with an approach of a process model in which analysis and synthesis step are involved and a lightweight index has to be defined. Based on this, the requirements will be assured on this process model. Moreover, the interaction between the lightweight-oriented modularisation and the mechatronics-oriented partitioning is not determined just like the handling with knowledge. The difficulty assuring the functional and lightweight properties as well as the simultaneous modelling and simulation of mechatronics and lightweight aspects is a task to resolve. Mechatronic concepts to reduce weight will be developed after fixing all outstanding issues.

4. Conclusion and outlook

Today, there is a need not to regard product development and methodologies for mechatronic and lightweight products separately. Just at the automobile industry with its luxurious, electric and hybrid vehicles weight reduction with a simultaneous consideration of the growing use of mechatronics plays a decisive role. In this paper, a novel combination of these two disciplines has been provided to meet the requirements of ecology and sustainability. After giving short explanations of both disciplines taken individually, a definition and a classification of the new field of lightweight mechatronics design have been depicted. Based on the success potentials of lightweight mechatronics, an approach for a framework of an integrated product development has been introduced, especially the structure of the methodology and the requirements needed to succeed. Finally, still existing challenges have been illustrated.

Regarding the research questions given in the introduction, the basic structure of the framework "lightweight mechatronics design" has been created. It consists of different elements which are connected in the most important task: the product development methodology, which is necessary to fulfil new requirements rising if the combination of mechatronics and lightweight design is regarded. These requirements come on the one hand from the single disciplines, on the other hand from the new perspective.

Forthcoming research will have to include a further development of the product development methodology presented and its elements. First, the process model and methods will be investigated and clarified. Based on this, the modules left will be specified. The completed methodology will be demonstrated and validated on a specific example at the end.

References

Feyerabend, F., "Wertanalyse Gewicht: Methodische Gewichtsreduzierung – am Beispiel von Industrierobotern", Fortschritt-Berichte VDI Nr. 201, VDI-Verlag, Düsseldorf, Germany, 1991

Goede, M., "Contribution of Light Weight Car Body Design to CO2 Reduction", 16. Aachener Kolloquium Fahrzeug- und Motorentechnik, Aachen, Germany, 2007

Harashima, F., Tomizuka, M., Fukuda, T., "Mechatronics – 'What Is It, Why, and How?'", IEEE/ASME Transactions on Mechatronics, Vol. 1, No.1, 1996

Henning, F., Moeller, E., "Handbuch Leichtbau – Methoden, Werkstoffe, Fertigung", Carl Hanser Verlag, München, Germany, 2011

Jendritza, D., "Modulare Türen mit mechatronischen Modulen", in Schmitz, G. (ed.), "Mechatronik im Automobil 2 – Aktuelle Trends der Systementwicklung für Automobile", expert-Verlag, Renningen, Germany, 2003, pp. 31-53

Klein, B., "Leichtbau-Konstruktion – Berechnungsgrundlagen und Gestaltung", Vieweg & Teubner, Wiesbaden, Germany, 2009

Möhringer, S., "Entwicklungsmethodik für mechatronische Systeme", HNI-Verlagsschriftenreihe Band 156, Gausemeier, J. (ed.), Heinz-Nixdorf-Institut, Paderborn, Germany, 2005

Schmidt, W., "Methodische Entwicklung innovativer Leichtbau-Produkte", Fortschritt-Berichte VDI Nr. 369, VDI-Verlag, Düsseldorf, Germany, 2004

Verein Deutscher Ingenieure, VDI guideline 2206, "Design methodology for mechatronic systems", Beuth-Verlag, Berlin, Germany, 2004

Verein Deutscher Ingenieure, VDI guideline 2221, "Systematic approach to the development and design of technical systems and products", Beuth-Verlag Berlin, Germany, 1993

Wiedemann, J., "Leichtbau – Elemente und Konstruktion", Springer-Verlag, Berlin, Germany, 2006

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