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DECISION BASED VARIABLE MECHATRONIC DESIGN PROCESSES

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ABSTRACT

Mechatronics design is about integration of mechanics, electronics and software. As new functionality in products is realized to a large extent through integration of mechanics, electronics and software the need for knowledge integration between these disciplines becomes central. Thus, the innovation and product development process has to be able to cope with low and high degrees of innovativeness in the same organization, for the same portfolio. After a brief wrap-up of recent concepts of innovation processes, the authors describe the specific characteristics of mechatronics design. Using the “degree of innovativeness” a key tailoring criterion, the authors will show how the existing and proven concept of idea management and innovation processes proposed by Thom as well as the staged-gate process proposed by Cooper have to be expanded to support mechatronic systems design and development. In the end, using this approach the development of a new product, an electro-hydraulic compact axis, is briefly sketched within the context of the proposed process.

Keywords: mechatronic systems, design process, process variability, innovation, system model, degree of innovativeness, radical innovations, disruptive innovations, NPD, new product development, innovation process

1 INTRODUCTION

Mechatronics is focused on combining mechanical, hydraulic, electrical and electronic technologies with the objective of realizing functions that have not been realized before in the company’s product development. Experience shows that many successful companies are leading in one of these technologies. They have innovation processes[1] that have proven either in the field of hydraulics, electrical drives, etc. However, when it comes to the development of mechatronic products, technologies that are fundamentally new for the organization are integrated into the product (see also Pahl/Beitz [1], Ulrich/Eppinger [2] and Otto/Wood [3]). Thus, the process has to be run in a different or tailored way, to be able to cope with these types of innovation. A typical example is the integration of control algorithms into a high-precision, electro-hydraulic compact axis in an organization that is used to developing conventional hydraulic products (cylinders, pumps, …) . These axes are highly nonlinear and from the control theory point of view nearly always a challenge, so technologies that are new for the organization like non-linear control algorithms and software have to be incorporated into the product. As a result the innovation process must be run differently than in case of the development of a hydraulic cylinder driven by a pump and an electrical motor.

Key questions that are critical for the successful implementation of an innovation process are:

- How do you make sure that this process that has already proven successful for numerous innovations also supports features and technologies that are drastically new for the R&D and application engineering organization?
- How do you make sure that the key product features that are “radically new” for the organization are properly defined in the concept phase and met later in the development (e.g. positioning accuracy, dynamic behavior, … as well as unit costs)?
- How do you make your existing innovation process fit for mechatronics?

Addressing these challenges requires the existing stage-gate process to be adapted in a way to meet the challenges posed by mechatronics features that are radically new for the organization.

[1] In our terminology innovation process covers all steps from idea generation to market launch, thus including what is conventionally called new product development process (NPD).

2 INNOVATION AND PRODUCT DEVELOPMENT PROCESSES: BACKGROUND AND RELATED WORK

The innovation process can be divided into different phases, spanning from the first idea to the market launch. Due to this partitioning the process becomes more transparent and the specific steps can be worked out more methodically. The following sections comprise two of the most prevalent concepts of innovation processes that are described in the literature and used in corporate environment.

2.1 Model of Thom

In his fundamental work Thom has systematized and described how innovations come into being in the corporate environment. Thoms model (Thom [4]) has been the basis for many other refinements such as the models of Geschka [5], Model of Brockhoff [6], Model of Pleschak / Sabisch [7] and the Model of Witt [8].

In this paper we start off with the model of Thom [4] due to its high clarity and simplicity. Thom's model is based on a flowchart (Fig 1) with three main steps (Thom [4], Vahs and Burmeister [9]).

- Idea generation
- Idea acceptance
- Idea realization

To these three phases of the evolution of an innovation we can attribute three different working products:

- Idea: thought, conception, epiphany or imagination of people (according to Vahs and Burmeister [9])
- Idea concept: Description of the idea (customer benefit, technical solution) as well as the plan how to realize the idea and introduce it into the market (marketing mix, business plan)
- Innovation: Realization of the idea concept as an economically viable product[2]

Phases of the innovation process		
Main phases		
Idea generation	Idea acceptance	Idea implementation
Definition of the search field	Idea evaluation	Realisation of the new idea
Idea detection	Preparation of implementation plans	Sale of new idea to target customers
Idea proposal	Decision on one implementation plan	Check on acceptance
Working product		
Products idea	Idea concept	Innovation
Designation in literature		
Idea management	Idea management	Innovation management

Figure 1. Three Phases of Thom [4]

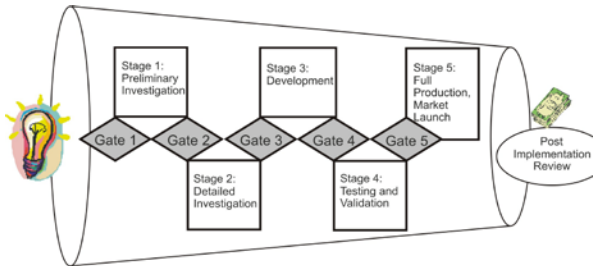

Figure 2. Typical third-generation stage-gate-process (Cooper [22])

Thus, the first two parts of the process deals with idea management (Böhme [10] and Thom [4]) with the objective of gathering and refining the idea. These stages are challenging when the new idea (for a new product or new features) covers technology fields where the organization has little experience. Here, the challenge will be to make sure that the process does not reduce the highly innovative topics back to what the company "always has been doing" or in the words of Christensen: "when firms have a single process for all the various forms of innovation, what comes out the other end of the process looks like what has been approved in the past, and it all looks like sustaining innovation" (Christensen/Raynor/Anthony [11]). In order to address this issue one has to make transparent and clearly define what "highly innovative" or a "high degree of innovativeness" is. This will be done in one of the following section with the focus on those innovations that are named "technological" (Zahn/Weidler [12])[3].

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[2] In this paper the authors follow the established definition of innovation. An innovation has to be successful, if not it is merely an invention (Hauschildt [13], Canter [14]).

[3] Categorizing other types of innovations, e.g. business innovation will be covered in a later publication.

In one point we will have to expand the idea management view prevalent in literature. Although Thom does not specify what are the ideas covered by the “idea management”, most publications interpret idea management as dealing with “improvement suggestions from workers and employees” (Spahl [15]; Wahren [16], Krause [17], Ridolfo [18]). In this process however, idea management explicitly deals with ideas for new products and new technologies that drastically enhance the features of the product and enhance product performance. The flexibility of product development process was also shown by MacCormack and Verganti ([19], [20]).

2.2 Model of Cooper

Cooper and Kleinschmidt classify models into several generations of process models (Cooper [21]). The first-generation “phase-review-processes” were developed by NASA in the 1960s. Later they identified a standardized approach for development projects as critical success factor. They called this standardized approach a “game plan” (Cooper and Kleinschmidt [22]). A principal role of design engineers in each stage of product development is to make decisions. All of decision making activities cannot wait until every aspect of the design is complete. The decision-making is under uncertainty, because many details are not defined in the considered phase. This can be a problem, because the stage-gate process represents a structure, where only the gates are related to decision making.
In Cooper’s second generation process detailed recommendations are implemented to enhance the success of a company. In the third-generation process (Fig 2) stages and gates are not strictly sequential and less detailed than in the second-generation. The latter represents rather guidelines and offers therefore more flexibility for specific implementations. To speed up the product development process some steps have to be done in parallel (Simultaneous Engineering), which was taken into account in the easier third-generation. Figure 2 shows a typical third-generation stage-gate-process with five stages and gates.

2.3 Improvement potential of the existing approaches to innovation processes

Recently there has been some criticism concerning the implementation of the stage gate processes in corporate environments (Becker [23]). This concerns on the one hand the static process flow as well as the “on/off” treatment of the decisions in the gate. One the other hand – and that is more important – the Stage-gate approach is reported to inhibit innovation.

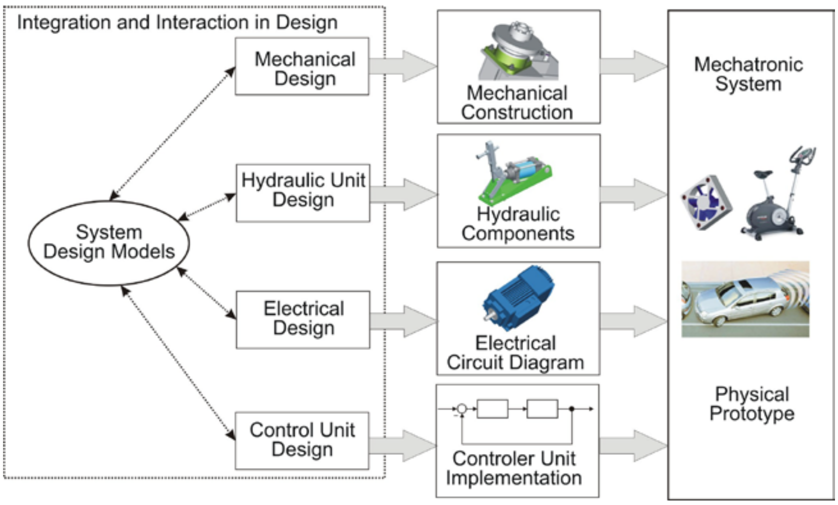

Figure 3 Mechatronic Design Methodology

Our experience shows that these problems happen, when the same process with the same stages and the same gates is used to develop products with drastically different levels or “degree of innovativeness”. Of course for a completely new product, that e.g. integrates intelligent functions, the technology risks and the product concept have to be evaluated in a much more detail than when a hydraulic drive is improved to ensure it meets the current state-of-the-art customer requirements. But if the development of a classical hydraulic product is treated with the same level of detail as in case of a product with new intelligent functions, then the development of the hydraulic product is hindered unnecessarily. Any mechatronics innovation process must be capable of handling both scenarios. One of the key-issues in the development of modern mechatronic systems is the strict integration of mechanical, control, electrical and electronic aspects from the beginning of the earliest design phases on, as it can be seen in Figure 3. This procedure may seem simple at first glance. But how does an organization which has experience with only 1-2 of the 4 mechatronic technologies set up the product concept for customer requirements that come up due to technological progress, e.g. when the customers suddenly ask for intelligent, compact actuators with advanced control functions instead of conventionally built actuators that are merely hydraulic based or combine an electromotor with a hydraulic pump.

The development of the concept of a product novelty is much more challenging because of

- Less know-how in new technologies, higher risks
- Lack of established and "running" network of suppliers
- Lack of established and "running" network of technology partners

3. MECHATRONIC DESIGN PROCESSES

In order to improve the existing approaches towards better support for mechatronic innovation and design processes we propose to introduce a certain variability of the innovation processes and system modeling depending on the "degree of innovativeness" of the product to be developed.

3.1 Approach for a decision based variable mechatronic design process

Figure 4 shows the basic structure of the innovation process as well as the key deliverables of the individual stages. Stages 0-2 deal with the generation, formulation, analysis and selection of the product ideas. These stages correspond to the idea management phase (Thom [4]). In contrast to these stages 3-6 form the classical product development process ("idea realization" in wording of Thom [4]). The idea management and the product development parts of the process are separated by Gate 3 (Go). This is also shown by the key results of stage 1 which is a product concept and stage 2 which delivers a demonstrator that validates the feasibility of the key functionalities of the new product. The idea management is fed by the strategy planning process as well as by numerous interviews with lead customers and market influencers (e.g. associations).

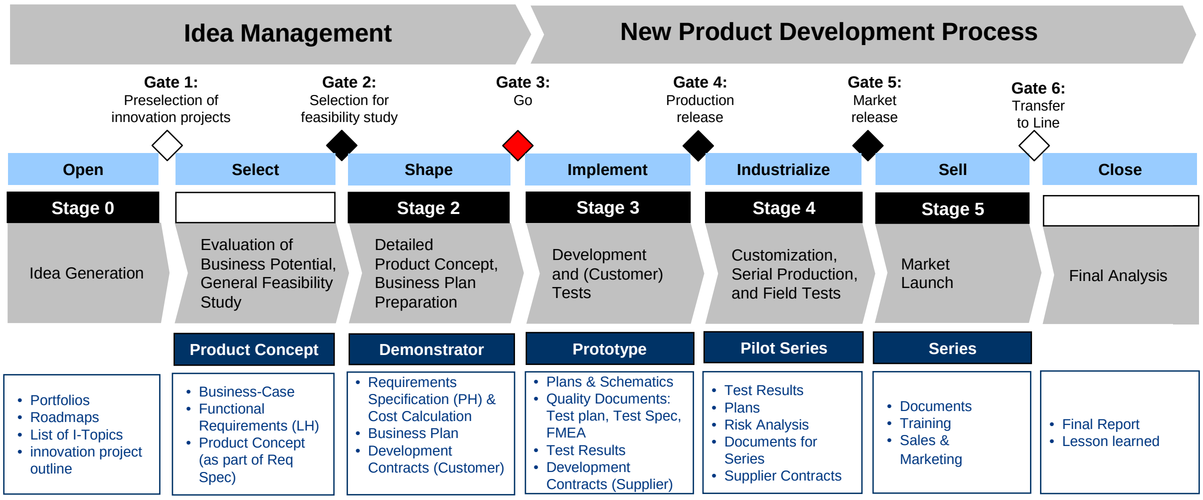

Figure 4 Basic structure of the innovation and product management process

In order to keep the process environment and the organization behind it simple, preferably one process should be implemented for different types of ideas, i.e. the improved version of an existing product should be supported by the process as well as drastically new product ideas which combine the existing technology basis with new technologies, e.g. intelligent motors or intelligent compact axes for forming machines.

Thus, the process must be adapted – or tailored –depending on the "degree of innovativeness of the ideas" i.e. how innovative the ideas are compared to the existing and traditional product and technology basis of the company. Before explaining the term "degree of innovativeness" the tailoring of the process will be described.

Figure 4 shows the "full blown" version of the process for products with a high degree of innovativeness. These are products which use technologies that are new for the company. For this type of ideas in addition to the Functional Requirements also a Product Concept is developed. The product concept covers the key topics of the requirements specifications:

- Architecture of the system including the rationale for selection
- Structure of the subsystems specified in the architecture incl. key data such as performance, unit costs, etc.

The cost calculation for the product as well as the timeline and cost estimated for the R&D project will be done using the product concept. Based upon the product concept, the business plan and the validation of the product functionalities with the demonstrator, the product development will be started.

The literature generally recommends the product concept to be part of the requirements specification (Schmelzer [24], Amelingmeyer [25]). According to Balzert ([26], pp. 446-448) the requirements specification are the realization on the basis of the functional requirements.

This works well for improvement of products that are familiar to the organization. We propose to develop the requirements specification in two steps for products that utilize new technologies new for the organization, i.e. product with a high "degree of innovativeness":

- First the product concept should be developed in stage 1
- After the principal feasibility has been evaluated, the Requirements Specification should be developed in Stage 2 starting with the product concept.

The pivotal milestone is Gate 3 (Go) which corresponds to the "point of no return in aviation". Experience shows that it is very difficult to stop a product development without irritating or even de-motivating the organization. Therefore, utmost care must be taken in the idea management phase to make sure that the go-decision is made based on solid information from both market and customer side (business plan) as well as the technology side (product concept, validation).

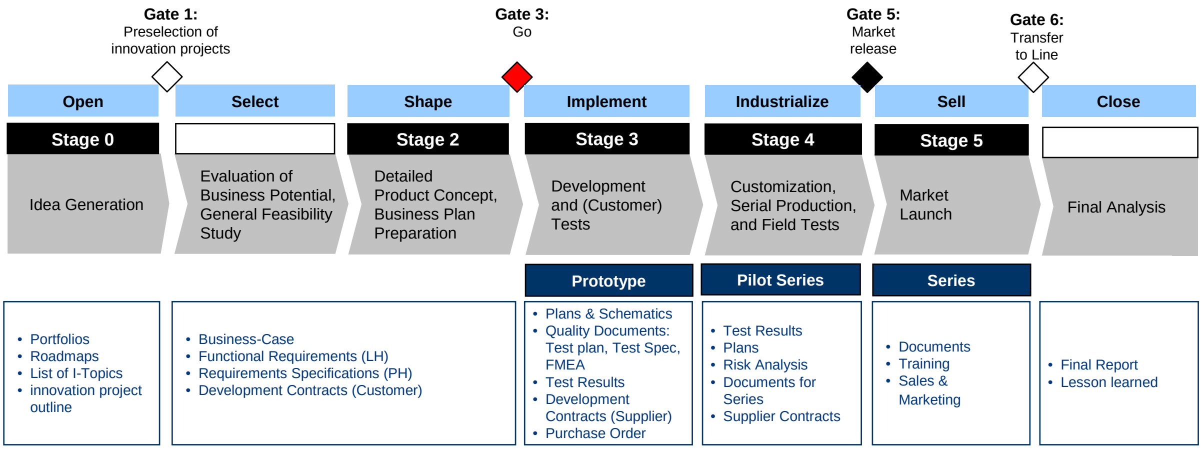

Figure 5 Simplified Process for "low degree of innovation"

For products that are an enhancement of existing products, e.g. a cost-efficient version of an existing electro-hydraulic axis or an electromotor, the process can be simplified by skipping Gate 2 and Gate 5. As the product to be developed generally is a further version of an existing product a product concept is not necessary. Likewise, a simple business case will be enough as long as no new markets are addressed by the product. Thus, the evaluation of the product idea as well as the generation of the product concept can be done in parallel. This also applies to the realization and industrialization of the product. As it is a further version in an already existing product family, the development of the new product as well as the means for production can also be done in parallel. The simplified version of the process for "low degree of innovativeness" is shown in Figure 5. This simplified process can be used for more innovations focusing on improvement of existing products using the familiar technology basis and not on drastically enhancing the product features using new technologies.

3.2 Distinction between low and high degree of innovativeness

As discussed before, the key tailoring criterion is the "degree of innovativeness". Almost every R&D engineer and marketing responsible wants to be on the side of the products that are more innovative and thus perceived to be more valuable for the company. Therefore, for customizing an innovation process the criterion "degree of innovativeness" has to be more systematized and related to objective facts that are transparent for those involved in the NPD process.

Numerous criteria have been proposed in the literature to distinguish between low and high degree of innovativeness concerning innovations. The four key criteria we see are the

1. the newness of the equipment required
2. newness of the skills required by the team
3. the advancement in technological performance, e.g. speed increase of factor 10 and
4. the risks implied by the new technologies for the organization.

These criteria have been derived from the dimensions proposed in the literature to determine the technology position in a technology portfolio. Following a brief review of the literature consulted is given:

1. This criterion is already applied in ADL 1991 [27] to determine the technology position in a technology portfolio. It was also proposed to be used to determine the degree of innovativeness of a product or technology (Schlaak 28], Anderson/Tuschmann [29]).
2. The strongly technology focused view of the 1990s (see ADL [27]) was later expanded to also include the skills and competences in the organization (Gatingon et al [30]; Amara et al [31])
3. The performance of the technology is also proposed by ADL [27]. Later the advancement of the performance of a technology was used by Leifer et al. [32] to determine product ideas with a high degree of innovation.
4. The newer a technology to be used in the NPD, the higher the risks for the project. As a result for all projects in any R&D project portfolio the R&D resources must be distributed between the projects in a way that the failure risk is minimized (ADL [27], Farrokhzad et al. [33], [34]). This idea applies also for mechatronic development projects. Therefore, following the works of Gatignon et al [30] and Leifer et al [32] the technology risks were also included as criteria.

Whenever the new features of the product as specified in the requirements specification causes a significant leap along these criteria, the degree of innovativeness is high and the process for a high degree of innovations is applicable.

These criteria were determined in a literature screening followed by a methodological analysis concerning their suitability to be used in the innovation process:

- coverage: It must be possible to categorize the innovations typically encountered in the automation and machinery industry by the selected criteria (and not only in the company)
- operationalization: The criteria must be easy-to-use, transparent for the organization, suitable to be used in the tools for a innovation process

In the beginning, when mechatronic design processes are introduced in companies with a long tradition in (electro-)mechanics or hydraulics, the key products with mechatronic features have a high degree of innovativeness according to these criteria. A typical case is the use of simulation, e.g. modeling and in parallel the design and construction of the experimental set-up to extract the related parameters. Another case is the development of intelligent low power electrical motors with PLC (programmable logic controller) and master-slave functionalities. Both cases require the project teams to develop know-how in electronic control and software. The equipment (e.g. simulation platforms) to be used in the development process is new and the manufacturing technologies needed for the mechatronically enhanced product imply certain obstacles, like the robust integration of electronics into a brushless DC-motor. Another example is the use of software to realize safety functions that until now were implemented using mechanical constructions.

Later when the product families are established and different versions are derived from the base product, these derivatives become “existing products” and will be enhanced using the simplified process.

3.3 System Modeling

Mechatronics design is the disciplinary integration of mechanics, electronics and software. As new functionality in products is realized to a large extent through collaboration of mechanics, electronics and software the need for knowledge integration between these disciplines becomes central. Design of embedded systems such as intelligent sensors, communication and power systems needs to be integrated into mechanical design and also developed to be maintained and reused. Software and hardware platforms change due to new technology and new technical interfaces emerge which lead to new challenges for the research and development function. The interactions between product developers from the different disciplines are hindered by

- insufficient interdisciplinary knowledge of the development team
- missing common platforms for modeling of complex systems
- newness of the technology for the organization
- underestimation of the investments necessary to harness the new technologies

As many sub-systems are delivered by suppliers, there is a need for both a horizontal integration within organizations and a need for a vertical integration between the sub-system suppliers and the suppliers of the full systems. Some of these aspects about mechatronic design are also discussed by VDI-2206 [35], Isermann [36], de Silva [37] or Bishop [38]. For example, VDI-2206 is devoted particularly to the design methodology for mechatronic systems and suggests carrying out the development process of mechatronic systems according to the so-called V-model. After analyzing all requirements on the total system, the sub-functions and sub-systems are defined (left branch of the V-model). They are to be developed simultaneously by the cooperating development teams. After verifying the sub-functions and testing the sub-systems, they are integrated step by step (right branch of the V-model). Then the performance of the integrated system is checked. If it has to be improved, the initial operation phase will be repeated (iterative process). Since the uncertainties in a detailed model of a product under development may be so high that its benefits compared to a simpler model is insufficient, very accurate modeling is often not necessary. Models have to be clearly defined, manageable and described in a consistent manner, so that they are suitable for serving a specific purpose (Alvarez Cabrera [39]). Miatliuk [40] proposes the usage of hierarchical system technology in mechatronic design. The considered main aspect is the evaluation of changes in one subsystem resulting from modification in other subsystems. This is only possible with the usage of overall system models, which includes the reduced main properties of the subsystems. In addition Gausemeier discussed in [41] a domain-spanning methodology for conceptual design of mechatronic systems. A holistic description of the principle solution is promoted, where all relevant aspects such as requirements, function, shape etc. have to be covered.

There are different ways of modeling a system; however, the principles of model efficiency dictate that the simplest model which will suffice should be preferred. For the building and usage of a simple, efficient and valid model, there are no formal rules. Therefore previous experience plays a major role. Some building criteria for model structures are as follows:

- Design phases: For different phases of the product life-cycle, models with different objectives and detail are required. The need for some models is particularly high in certain, very specific stages of the product life cycle (e.g. requirement models, design sketches, models for simulation). In the concept phase, very rough models are typically useful, as it is still based on incomplete information. However, during the design and development phase, the models become increasingly detailed and refined, thereby increasing their information content.
- Integration and modularization: It is appropriate to divide complex machines and installations in sections, spaces, design and processing zones, assemblies, subassemblies, structured individual components, etc., where relationships exist between them. In complex systems the modularization facilitates a systematic overview and allows more transparency, while still allowing for parallelization of the work throughout the product development process. The decomposition of the system into modules and their representation by models also leads to a modular structure of the overall model. For the investigation of systems and system elements, it is always necessary to “virtually” connect sub-models so as to portray the operational characteristics of the interfaced sub-systems.
- Disciplines (domains): The investigation of systems requires the treatment of different, very specific views of the system (system aspects) arising from different needs of the different professional disciplines (domains).

All the aspects presented above can be discussed by analyzing the simple case study, a clamping device (Figure 6). The positioning and configuration of clamping devices used in various machines or stations of a production line for car bodies is a current question from automotive engineering. Clamping devices have the job to fix different sheet metal parts quickly to one another at an exact position and with a pre-defined clamping force. After the parts are fixed, they are joined together e.g. by welding. The criteria for such clamping units are Compact size of clamping device, flexibility in use and operation, closing speed, high reproducibility and accessibility.

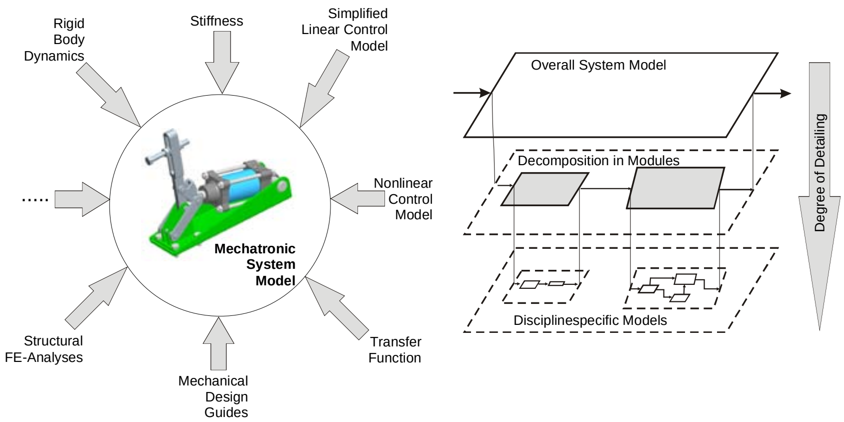

Figure 6 Different system views on a clamping device

Ideally, the whole system is in the form of a cross-domain model. The problem is that the different disciplines, different modeling approaches and models or model descriptions use their integration still leaves something to be desired. Moreover, within the disciplines information and data with high detail that are only partially in other disciplines are needed. The challenge is that the knowledge of the entire system does not equal the sum of knowledge from the corresponding domains. The domain knowledge must therefore be generalized (abstracted) and integrated. Examples can be seen in Poelman [42], Vermaas [43], Hutcheson [44] and Eder [45].

System design and evaluation are important topics for which improved tools and knowledge are ever claimed by the engineering profession. A system may be defined as an assembly of sub-systems, hardware and software components, and people designed to perform a set of tasks to satisfy specified functional requirements and constraints. An electro hydraulic linear actuator has been investigated using the described modeling approach. Starting with a design and functional model the system performance has been verified and later validated with a prototype. Using the measurement results of the prototype detailed domain specific models of the electric and hydraulic parts could be established. These models are used for two reasons: First domain specific multi criteria optimization processes are started to determine the parameter sensitivity and the optimization potential and second the main influencing parameters can be identified. These results are finally used to set up a cross-domain model now involving only the key parameters to allow an overall optimization. The current simulations show promising results.

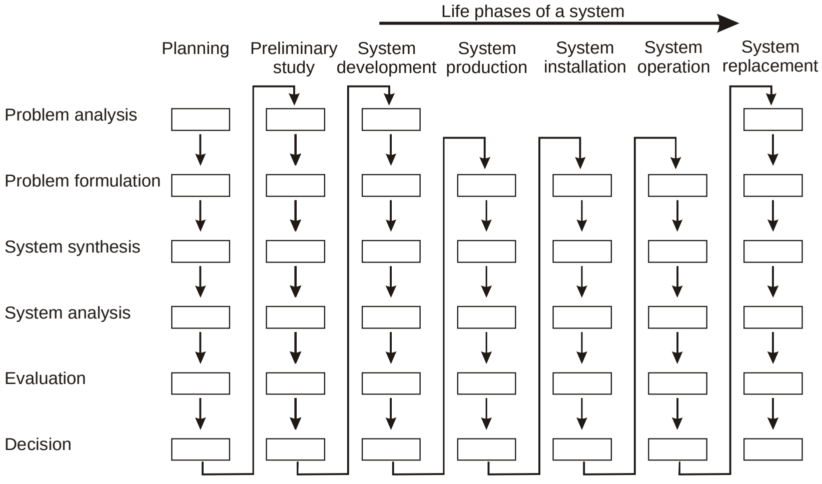

Figure 7 System design (according to [1])

In each stage of product development, a key task of designers is to make decisions. If the engineers lack an overview of the multidisciplinary system, they must consult experts in the other fields. Decisions help to bridge the gap between an idea and reality, and are made on the basis of information from many sources (and disciplines). As a rule, we must accept that, in most cases dealing with design, not all of the information required to arrive at the optimal decision is available. Some of the information may be "hard", i.e., based on scientific principles, whereas other information may be "soft", i.e., based merely on the designer's judgment and experience.

In order to reduce the uncertainty the product concept is setup and stabilized in interviews with customers and leading market experts early in the beginning of the innovation process (Phase 2 according to Pahl/Beitz [1]). By going through the evaluation step with the customers in the "Preliminary study phase" much of the open issues are clarified and the number of design variants drastically reduced. Once the concept has gone through these customer interviews (meetings) and the feasibility technically validated with a demonstrator the development process will be done only for this one design. This helps to reduce the number of iterations in the phases following the "System development" phase.
Analogue to Pahl/Beitz [1], the generic system design model represents the phases which are listed below:

1. Planning:
2. Preliminary study of the system: In this phase, main aspects such as requirements, functions, etc. are discussed.
3. System development: In this phase the discipline-specific design of mechatronic products is focused. Therefore the main engineering aspects of disparate engineering disciplines are considered.
4. System production: Properties such as the manufacturing property, etc. are discussed.
5. System installation: Several properties such as the assembly and transportation properties are discussed
6. System operation: This phase deals with the operation of a mechatronic product machine and considers process as well as quality points of view and also topics like ergonomics and safety.
7. System replacement

The presented approach in chapter 3.1 with the definition of low and high degree of innovativeness will focus on the decision phase in Figure 7.

4. APPLICATION

The mechatronic design process described above was used to develop a novel generation of intelligent actuators for forming machines in an organization that is already market leader in state-of-the-art hydraulic actuators for CNC press brakes. In this section the development activities are described and related to the model recommended by Pahl/Beitz [1]. Analysis of market environment and innovation trends showed that electro-hydraulic compact axes are a promising field for improving the performance of the customer machines. For this reason the development of an intelligent, electro-hydraulic compact axis was initiated. It is a long stroke actuator especially designed for press brakes and forming presses, but – in an enhanced version – can also be used in massive forming machines of tonnage up to 500 tons (related Pahl/Beitz [1], phase 1).
The actuator contains an electromotor, a pump as well as a cylinder. It is also equipped with two tanks that allow a pre-tension usage. The actuator has an integrated controller that receives key parameters like position, speed and force from the CNC controller. Using non-linear adaptive and predictive algorithms, the position and the force of the actuator is controlled.
In a first step, parallel to formulating the functional requirements, the product concept was defined.
After analyzing the energy efficiency of different architectures the actuator was realized using a variable speed drive instead of controlling the fluid by using proportional valves. These concepts as well as the details were cross-checked with leading customers in EU and Asia and the final product architecture was selected as the single architecture to be developed after the "Go" for development. Consequently, substantial development efforts were saved and the development was concentrated on the concept favored by the customers. Using advanced electro-hydraulic simulation platforms (e.g. Simulation X [46]), the feasibility of the product concept and especially of the control algorithms was validated.
Both, the functional requirements as well as the product concept were discussed with selected lead customers. In the beginning of stage 2 it was clear that the estimated costs were too high. In several cost reduction workshops the costs were drastically reduced almost to the level specified in the list of functional requirements. Simultaneously a function demonstrator was designed to validate the key functionalities of the product, especially the "intelligent" features that were new, like "precision of positioning", reduction of bending time by 30% due to optimization of speed ramps, etc.
According to phase 2 of Pahl/Beitz [1] the costs reached the required level and the key features mentioned in the functional requirements validated by the demonstrator the "Go" for the development

was given and the start of the development was approved. During this process the results were regularly discussed with selected lead customers. Prior to the "Go" five lead customers were won to test the pre-series of the actuator before the next lead show for the bending and forming industry. This makes sure, that a pretested product will be exhibited on the show not only on the company's booth, but also in the booth of some of the customers.

5. CONCLUSION AND FUTURE WORK

Innovation processes, especially the stage-gate versions, have proven successful in the industry. Practical experience as well recent analysis in literature shows that the concepts have to be used in a more flexible way in order to be able to cope with innovations that utilize technologies that are new for the company. Following the stage-gate concept of Cooper we developed an innovation process that covers both the idea management phase as well as the innovation management phase, i.e. the product realization. For products with a lower "degree of innovativeness" some of the gates can be omitted, thus making the process more efficient. For technology innovations, we propose to determine the "degree of innovativeness" using the criteria that are used for determining the technology position in technology portfolios. We also propose to develop the requirements specification in two steps. The core of the requirements specification, that we call product concept, should be developed parallel to the function requirements. Once the feasibility of the product concept is evaluated, e.g. using simulation, a demonstrator should be set-up for an experimental validation. The requirements specification should then be developed parallel to the experimental validation. The new process concept was tested when developing a new generation of intelligent compact axes for bending and forming machines. In 6 months it was possible to develop a product concept and validate the feasibility of the key features in the functional requirements. Future work will especially focus on expanding the view on "degree of innovativeness" from technology innovations to business (model) innovations.

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