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EcoDesign for Production Plants

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Abstract

Due to rising energy prices and stricter regulations of carbon dioxide emissions, it is not sufficient to optimize energy consumption only during the utilization of products; production has to become more energy efficient, too. In order to reduce the energy demand, energy concerning aspects must be considered early in the development process of the production plants. In these phases, attributes that are responsible for the later energy consumption are predetermined. But the energy demand is often not in focus of the development process. For that reason a methodology for the development of energy efficient production plants is currently being developed by the authors.

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1. Motivation

Due to rising energy prices, stricter regulations of carbon dioxide emissions and efforts to reduce environmental impacts, it is not sufficient to optimize energy consumption only during the utilization of products; the whole lifecycle has to be considered. The production, as a part of it, has to become more energy efficient, too. According to Seefeldt et al. [1], the potential of energy savings in the industry are remarkable. Several approaches aim to decrease the energy consumption during production, when the plant is already built up. For additional energy savings, energy concerning aspects must be considered early in the development process of the production plants. In these phases, attributes that are responsible for the later energy consumption are predetermined. But the energy demand is often not in focus of the development process. There are tools and methods in order to plan production plants with the focus on quality, costs and so on, but energy efficiency, as a possible concurrent target, is not considered enough. Some approaches optimize the energy consumption of the factory by material combined with energy flow simulations [2] or improve the energy efficiency by reducing energy transformation steps of components [3].

This paper discusses the question, how the energy consumption of the use phase of a production plant can be considered in its development process. For this reason, methodologies from environment oriented product design - EcoDesign - are applied on the development of production plants, focusing the energy consumption. While the total energy demand is not completely covered by renewable energy, energy consumption has an important impact on the environment. Later on, other inputs and outputs and environmental impacts are going to be examined. The planning process for plants, according to the digital factory VDI 4499 [4] by the Association of German Engineers, is taken as the basis for the development of energy efficient plants for this research. Respective tools and software from the digital factory are integrated, in order to handle the complexity of the system.

In section 2, the current state-of-the-art for the fields adjacent to this research (i.e. production plant development, product development, EcoDesign, and energy efficiency in production/manufacturing) is shown. In section 3 an integrated approach for the development of energy efficient production plants is described. A virtual model that displays the energy

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consumption of the production plant is needed to assess the product lifecycle more exactly in early development phases.

2. State-of-the-art

In this section the state-of-the-art of the different domains is described. The focus is on the process models and the IT-Support.

2.1 Production plant development

A general planning process for production plants is described e.g. in VDI 4499 ÈDigital FactoryŠ [4] (figure 1). The digital factory is based on three objects: product, resource and process (PPR). The plant is the resource to create the product in the process. These three objects depend strictly on each other. The VDI 4499 guideline provides a planning process for these resources.

The different domain specific development phases are executed in parallel to accelerate the development process. A further step to reduce development times is the virtual commissioning of the plant. The maturity of the control software can be increased, collisions can be detected and accessibility can be ensured. For that reason the time for the real commissioning is shortened.

The attributes, determined in the product development have a huge impact on the development of the corresponding production plant. Thus these fields are closely linked to each other. Figure 2 shows the correlations between product development and production planning and development [5].

An integrated approach in order to develop production systems out of the principle solutions of the products is shown by Gausemeier et al. [6]. The principle solutions of the product determine the conceptual design of the production system. The results constitute the principle solutions of the production system. These solutions have to be concretized in the next steps and integrated to an overall system. An efficient development of production plants requires a virtual model of the system in order to ensure the predetermined attributes and functions. Standard three dimensional mechanical CAD tools are not enough. Moving parts have to be simulated in order to check the functions of the plants. Furthermore, a hardware-in-the-loop simulation of the programmable logic controller - also called virtual commissioning - has to be performed.

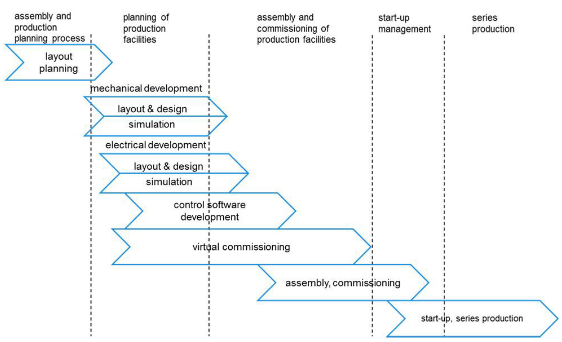

Fig. 1 planning phases of a production plant similar to VDI 4499 [10]

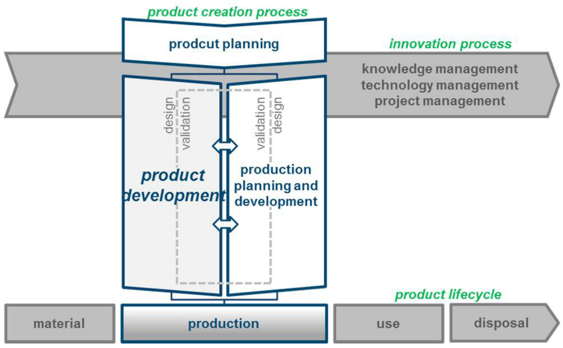

Fig. 2 product development process according to Stoffels et al. [5]

For these tasks, tools like Teconmatix [7] or DELMIA [8] with additional software are commonly used, for example. In the field of production it would be desirable to estimate the energy consumption of a production plant during production early in the development phase, by simulations. But nowadays only manufacturer of components simulate the energy consumption of their products, for example with mathematical models.

2.2 Product Development

In order to support design engineers, a lot of different methods and approaches for the development of products emerged. A formalized and long established methodology is the VDI 2221 guideline [9]. The approach is segmented in three phases: conceptual design, embodiment design and detail design.

This process model is, however, not sufficient to handle complex multi domain products - mechatronic products. For this reason, the VDI 2206 guideline [10] was implemented. It is based on a V-model that begins with the system design phase. Subsequently in the domain-specific design phase, further concretizations are executed in the appropriate domain, by using for example the VDI 2221 [9] methodology. The acquired results have to be integrated in the last phase - the system integration. The process has to be iteratively performed, depending on the complexity, to get the solution.

In product development there are a lot of different tools that support the engineers. Three dimensional mechanical CAD is an established tool to handle the complexity of products. Furthermore, CAE software is nowadays a standard in most companies to ensure required attributes and functions.

2.3 EcoDesign

According to ISO 14006, ecodesign is the Èintegration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout a product's life cycleŠ [11]. In the early stages of the execution of EcoDesign, a re-design of existing products was performed with the focus on reducing impacts on the environment, according to Diehl et al. [12]. Today additional approaches have been developed. Eco-Benchmarking e.g.

examines products of a competitor and transfers knowledge to own products in order to reduce the environmental impact. In contrast, Eco-Innovation enables new evolutionary products with fewer effects on the environment, by using ecologically oriented methodologies in the development phase [12]. As an example for Eco-Innovation, an approach to reduce the later energy consumption of vehicles by using a mechatronic system simulation in early development phases is shown in [13].

In order to get environment friendly products, it is not sufficient enough, considering only the utilization phase of products. A lifecycle assessment (LCA) is required, in order to compare different products or product concepts to get the one with the lowest impact on our environment. According to ISO 14040 [14], all inputs and outputs and the environmental impacts of the system have to be considered and evaluated.

One possibility to consider environmental impacts in the design process is an environmentally oriented Quality function deployment (QFD). A QFD translates the ÈVoice of the customerŠ into technical product or process specifications [15]. Extensions of these methodologies in direction to EcoDesign are listed and compared by Schendel et al. [16]. One of these approaches is shortly discussed here.

The QFD for Environment (QFDE), according to Masui et al. [17] contains an ÈEnvironmental Voice of the CustomerŠ and environmental engineering metrics, additionally. Designers have to take account of them to integrate environmental aspects in the development of the product. Thereby the environmental impact of products can be reduced.

In the environmental oriented product development, tools for the lifecycle assessment of products are available µ for example GaBi [18]. In [19], an approach that integrates a lifecycle assessment into CAD is described. It focuses the Re-Design of products or the design of a product that is part of a product family, because data for a comparison are essential for this approach. With these data, user defined values like for example power, material and data like weight, volume and so on, derived from CAD, an estimation of the environmental impact can be executed. The normal LCA process needs a complex model and a lot of input data. The approach [19] is limited to the redesign of products and the development of similar products of a product family, but generates benefit concerning time.

Design for Environment is an equivalent term for EcoDesign. In contrast, design for sustainability often contains social aspects.

2.4 Energy efficiency in production/manufacturing

Energy efficiency is defined as the Èratio or other quantitative relationship between an output of performance, service, goods or energy, and an input of energyŠ, according to ISO 50001:2011 [20]. An approach to increase the energy efficiency of production plants is a material flow simulation combined with an energy flow, which is described by Putz et al. [2]. The interaction of the components of the production system has to be modeled for the simulation. For this task, the tool *Plant Simulation* from Siemens is used in [2]. Thereby load peaks can be detected and avoided, which affects higher energy efficiency.

Another approach [3] takes the optimization of handling systems - as a component of the production system - into account. The energy efficiency is increased, by reducing energy transformation steps. Furthermore, the energy demand of the production plant can be reduced, by switching the operating modes into more energy efficient ones, for example during production breaks. For this challenge, Priced Timed Automata are used by Stoffels et al. [5] to describe the system. These models can be simulated to get the best strategy for operating the production plant.

A further approach for reducing energy consumption in production is presented by Lind et al. [21]. The SIMTER approach provides on one hand a joint analysis of the impact on the environment together with a discrete event simulation, and on the other hand a virtual analysis tool to evaluate the level-of-automation combined with ergonomic studies [22]. This methodology aims to be used in the planning phase of the system. Data like for example the material flow are derived from visual components and processed in an Excel tool to assess the manufacturing system.

3. Approach

A lot of methodologies for developing products have been established. And nowadays EcoDesign for products is also a well-researched field. But production development has a wide range and is not so clear specified. Especially environmental aspects are often not in focus of the planners and designers.

The production plant itself can be seen as a product. Hence a methodology from the product development could be applied, but the requirements and the constraints may differ to a product. It depends on the view on the production plant. A manufacturer of high volume production plants, like machine tools can develop them according to a product development methodology, isolated from the product that is being manufactured on the machine. If an OEM or its supplier develops a plant, it strictly correlates with the production process and thus it is difficult to design it by a product development method.

The plant is based on mechanical, electrical and software components, thus it is a mechatronic system. Hence it would be possible to develop it by the VDI 2206 [10] methodology. The different design phases and the control program creation in the VDI 4499 [4] correspond to the multidisciplinary co-operation in the systematic embodiment design of technical products VDI 2223 [23]. Outgoing from these similarities of production and product development, it is useful to compare both fields. By applying methods from the product development to the production development process a benefit is generated. A further comparison of both fields: production development and product development is shown by Vielhaber et al. [24]. Furthermore it is worth to learn from EcoDesign in order to develop production plants with low impact on the environment.

While the total energy demand is not completely covered by renewable energy, energy consumption has an important impact on the environment. The percentage of renewable energy in the EU-27 in 2010 is 12.5 percent, according to Sturc [25]. By improving the energy efficiency of the production plant, the environmental effects are reduced. In countries with a higher rate of renewable energy, the correlation between energy consumption and energy related environmental impacts decreases.

There are a lot of methodologies that focus the reduction of the energy demand during production, but less, that consider energy concerning aspects in the planning phase. In the current work, only energy is considered, but the approach is being extended in further research. The shown approach takes the whole development phases into account. In each phase at a certain time there are selected methods to optimize the later energy consumption. The authors develop an overall methodology that supports the engineer to plan and design an energy efficient plant. Approaches from the field EcoDesign are applied on the development process of production plants.

In Figure 3 the lifecycle of the production and the lifecycle of the product are shown. They both overlap in one phase. The utilization phase of the production plant correlates with the manufacturing phase of the product. That is the period, where the environmental impact of the production hits the product. The target is to minimize the energy demand of the production plant to improve its own lifecycle assessment in order to reduce the lifecycle assessment of the product.

In the planning phase of the production plant, tools like QFDE [17] can support engineers considering environmental aspects early, by translating the environmental voice of the customer into technical specifications. In the further concretization, the base for the development phase is a virtual model of the plant with an energy monitor to visualize the energy consumption. It is reasonable to predefine important parameters with values from literature, especially for early phase, when some undefined values are needed. Respective tools provide different kind of simulations, but there is an additional need for an energy monitor that simulates the energy demand during the development, basing on the virtual model. Out of this data an early lifecycle assessment, focusing energy can be executed. This assessment is concretized in the development process why the simulated data become more and more exact. In the domain specific phases, methodologies from the different disciplines are applied. When the mechanical and electrical design is frozen as far, it is possible to use methods in order to develop an energy efficient control program, for example according to Stoffels et al. [5]. By applying different methods outgoing from the planning, energy efficiency of the plant can be increased and as a result, the environmental impact of the production decreased.

The generated energy data is provided to the product development. Hence an early lifecycle assessment for the product, with the later correlating production plant is enabled. Data from previous production systems are only necessary for the time before the production development starts. From this point more exactly energy data are generated out of the virtual model. This circumstance improves the quality of the lifecycle assessment of the product that is going to be produced.

Due to the fact that the product development determines respectively restricts the production process to a certain degree, it is necessary to consider the energy consumption of the later production process. The generated energy data can help the product designer to develop products that are energy efficient produced.

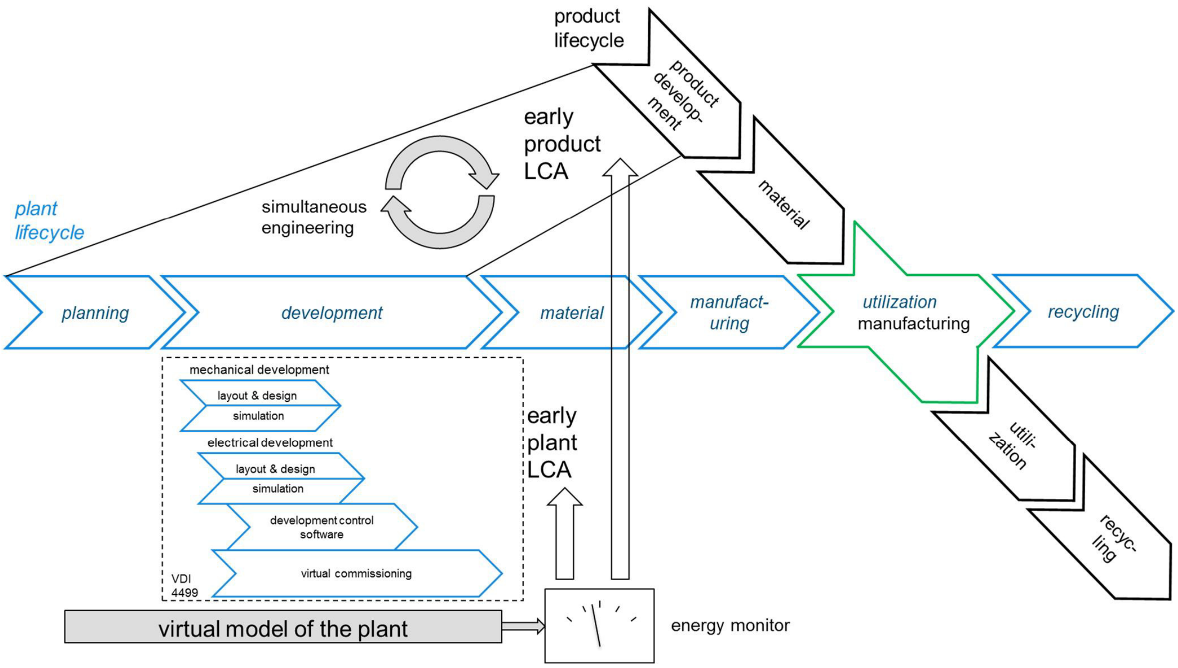

Figure 3: development process for energy efficient production plants, integrated to the lifecycles of product and plant

4. Conclusion and Outlook

There are a lot of methodologies and approaches in the field of product development, but less for production development. Furthermore the target of reducing environmental impacts is often more in focus of the product development than of the production development. But a lot of effort is put in optimizing the energy demand of existing production systems. For example, operating modes can be switched into more energy efficient ones, during production breaks. Furthermore load peaks can be detected by simulation and avoided. Further energy savings can be realized in the production development process. Out of this reason a methodology for the development of energy efficient production plants is currently developed by the authors. Therefore approaches from different domains, starting with product development through energy efficiency in production were examined and benefits applied to the general development process according to VDI 4499 [4]. Figure 3 shows the general view on the product and the production plant lifecycle. There are selected methods for each time interval during the lifecycle of the production plant. A virtual model combined with an energy monitor that simulates the energy consumption of the plant, supports the engineer. With this data early lifecycle assessments can be executed in order to determine the environmental impact. As shown in figure 3, the energy consumption of the plant during utilization directly correlates with the energy consumption of the manufacturing of the product. So a lower impact on the environment of the production plant results in a lower impact of the product.

Furthermore, the simulated energy data also helps the product designers to develop products that can be produced environment-friendly. This paper is a first step of research focusing analysis, followed by a more detailed contribution. For the beginning, only energy relating aspects are considered. In further work other impacts on the environment and other lifecycle stages are also covered. The methodology will be applied on an exemplary plant for the assembly of vehicles. This will be presented in a follow-up contribution.

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