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Product Family Design for Changeable Learning Factories

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Abstract

Educational and research manufacturing systems, such as learning factories, provide an environment to learn, test and implement new product solutions and system paradigms. When learning factories are equipped with the capabilities of Changeable Manufacturing Systems (CMS), they can be used for investigating and teaching the changing effects on product design by manufacturing system reconfiguration, planning and control. Existing design approaches of new products respond to the change in customer, functional or market requirements. This paper presents a new approach to develop products for Changeable Learning Factories by identifying a suitable product family and designating corresponding product variants that show the limits of the existing system capabilities and demonstrating different system configurations based on its features for changeability.

Keywords: Learning Factories; Changeable Manufacturing Systems; Product Development

1. Introduction

Current challenges in industry are e.g. resulting from increasing product variety, dynamic customer requirements and shortened time to market. Learning factories can provide an environment for engineers and practitioners to become trained and experienced for these challenges in manufacturing [1,2]. A learning factory can consist of a physical learning environment and a digital environment in order to simulate production processes realistically. Both physical and digital environments should be linked to support the adaptability and the improvement of each environment [1,2].

In this article, the iFactory a Changeable Learning Factory that is located at the Intelligent Manufacturing Systems (IMS) Centre (University of Windsor, Canada) will be studied. It is designed and constructed to provide changeability enablers such as mobility, modularity, scalability, universality and compatibility which are also main features of Changeable Manufacturing Systems.
methodology versus a methodology that aims at developing products for CLFs. Traditional methods would take customer needs as their input and would synthesize a manufacturing system configuration according to required product family variants and manufacturing processes. Process plans of the actual production are issued according to the operational constraints of the manufacturing process such as precedence, sequencing and availability. In a new design methodology focusing on product development for CLF, manufacturing system configuration would be analyzed to recognize its capabilities and its processing constraints. Based on that system profile, a portfolio of potential product features, which can be produced using those capabilities and adhering to the identified constraints, can be developed and a family of product variants can be established in a reverse design fashion.

2. Product Design Requirements for the iFactory

The product design requirements for the iFactory are different from requirements for traditional products. Figure 2 gives an overview of these differences.

A traditional product and its attributes are determined by the intended function of the product. Thus, the production processes including production equipment and logistic means as well as production environment are defined by the product attributes. In contrast to this, possible products for the iFactory are determined by the attributes of the production environment. That means the product characters such as weight, shape, complexity, structure, dimensions etc. have to fit the pre-determined capabilities and constrains of the learning factory. These capabilities and constrains are given by the installed manufacturing processes, production equipment and logistic means.

Furthermore, products for the iFactory should support the best possible transmission and application of educational and research content. A traditional product is sold to realize profit. Hence, normally market and customer requirements determine the product and its design.

A traditional product is a real commercial product that performs a physical function. At the end of its operating life, it can be disposed of, reused or recycled completely or in parts. In general, products for learning factories should be disassembled and re-used after a process cycle. For this, the product can be simplified in a convenient way. The simplification should reduce complexity of the product. However, it should remain very close to reality.

Moreover, the creation of a large number of product variants must be possible and they should support the capabilities of the learning factory. Selecting a family of products among many others should be based on best representation of system capabilities. Best adhering family of products should score highest regarding the closeness of its design features and manufacturing processes to the ones offered by the system. The function of the product itself is not the focus of this case study.

Fig. 1. The IDEF0 models of (a) traditional product and manufacturing system design vs. (b) design for CLF. (c) Product selection and Synthesis for CLF.
3. Approaches for Product Development

Based on the outlined requirements, the state-of-the-art in terms of existing approaches for product development was investigated. For this, procedural (with serial processing of development steps), concurrent or parallel (through multiple fields) and directed (for a specific target) development approaches for new products were examined. In addition, methodologies concerning product variety and Changeable Manufacturing Systems (CMS) were explored.

Hubka and Eder [10] developed an approach of six phases. These are 1) clarify the assigned specification, 2) establish the function structure, 3) establish the concept structure, 4) establish the preliminary layout of the product, 5) establish the dimensional layout of the product, and finally 6) detail the selected design.

Reduction of time to market and improvement of product quality are the aims of “Concurrent Engineering”. The approach is to consider processes of the product life cycle (like product planning and design) and to partly execute them simultaneously. For example, the steps “Concept development, testing and evaluation”, “Prototype development testing and evaluation”, “Pre-launch”, “Launch” and “Project evaluation” are partially executed simultaneously [11,12].

“Design for X” is a compilation of design methods where the design is optimized concerning a specific property of the product (e.g. cost, quality, lead time, efficiency, flexibility) or a specific phase of the product life cycle (parts manufacturing, assembly, distribution). This feature or phase is represented by “X”. An example for “Design for X” is Design for Manufacturability” (DFM), where the product design is optimized for the manufacturing processes. “Design for assembly” (DFA) contains design steps to reduce the complexity and the amount of assembly processes [13]. Another example is “Design for Disassembly” (DFD). DFD includes the principles of “selection and use of materials”, “design of components and product architecture” and “selection and use of fasteners”. The aim is to reduce time and costs and to increase the quality of disassembling processes for maintenance, recycling or reuse [14].

To satisfy customer needs and requirements and consequently to gain additional market shares, products are increasingly offered in variants. This often causes conflicting goals regarding storage cost and time to delivery as mentioned by ElMaraghy et al. [15]. “Design for Variety” (DFV) is an approach to decrease costs and time to market for products with large portfolio and to increase customer satisfaction. One principle within this approach is the evaluation and implementation of product structure modularization and platforms [15].

Another approach to handle high product variety is “Adaptable Design” where existing products are changed by adding or removing some components. So, the product can be adapted to changing requirements although the product structure itself does not necessarily have to be modular [16, 17]. “Reconfigurable Design” is considered a part of “Adaptable Design”, where several different products are substituted by a single one.

Whereas “Adaptable Design” can be formed by a modular product structure, products developed according to “Modular Design” are not necessarily adaptable to changing product requirements. “Modular Design” allows reducing the costs and effort for product development, design and manufacturing [18, 19].

Where the common module of a set of products is the product platform, it is called “Product Platform Design” or “Product Family Design”. The same product platform is available in all variants of the product design [20, 21].

It became evident, that there are design methodologies that are partly suitable for the requirements of Changeable Learning Factories. However, they need to be adjusted, modified in parts and completed by some problem-related steps. So, a new product development approach will be developed based on a combination of the basic ideas of the following four product development approaches:

- Procedural model of the design process by Hubka and Eder [10]
- Design for manufacturability and concurrent engineering [11, 12]
- Adaptable design [16, 17]
- Design for Disassembly [14]

The new approach will be suitable for the different requirements of products for learning factories. Here, the capabilities of Changeable Manufacturing System will be considered.
4. Product Development for Changeable Learning Factories

4.1. Development Approach based on the State-of-the-Art

Since the new product must be suitable for the capabilities of a Changeable Learning Factory, basic information about the manufacturing system must be collected initially. For this, the methods and tools from the “Procedural model of design process” will be applied. The system requirements will be analyzed and specified in detail. This approach also supplies methods to determine the preliminary product structure and to identify existing ways of their representation. The definition, design and modeling of rough design drafts as well as detailed drawings of the product modules will also be done according to this design approach.

“Design for manufacturability” provides tools which consider the capabilities of the existing manufacturing system during the product development and design process. These capabilities provide important input information for the development process like maximum operable product dimensions or product weight.

According to “Concurrent engineering”, also the steps of the new design procedure will partially be executed simultaneously. For example, the investigation of the existing production system, the development of the product requirements as well as the investigation of the processes and the material flow will be executed simultaneously.

To create a learning and research environment that is close to reality, the new product should also be close to reality. Therefore, an existing industrial product should be adapted to the capabilities and requirements of the Changeable Learning Factory. For this, the principles of “Adaptive Design” will be applied. A conceivable way of adaption is simplification of the real industrial product.

After finishing a research or learning activity, the product needs to be disassembled for reuse. “Design for disassembly” will be used to develop a product that allows multiple test cycles with low effort for preparation of the product.

4.2. Product Development Procedure

The new procedure will be structured in five phases that are shown in Figure 3.

1. Investigate the existing system & determine the use objectives
2. Specify requirements & compile ideas for new products
3. Establish product structure & pre-select feasible new products
4. Establish design drawings & process and layout configurations
5. Prepare product manufacturing, manufacture & test the new product

Fig. 3. Overview of the design procedure

In phase 1 the existing Changeable Learning Factory and its capabilities and requirements such as technical characteristics, processes, material flows and operations should be investigated. In addition, the objectives of the Changeable Learning Factory regarding educational and research content will be determined.

Based on the results from phase 1, in phase 2 the requirements for the new product as well as the requirements for the processes and layout configurations will be outlined. Moreover, ideas for the new product must be compiled within this phase.

The new product ideas will be specified within the phase 3. For this, the product structures will be identified, described and represented. Accordingly, the part lists should be created. In order to pre-select a new product, the variants will be evaluated according to the predetermined objectives and requirements.

Phase 4 contains steps to select the new product, to define and roughly draft product parts, process and layout variants and to evaluate product options. Based on this, the new products will be designed and the process and layout configurations specified including modeling of product variants, processes and layouts.

During phase 5 of the development procedure, the manufacturing process will be prepared and executed. This includes the testing of the new product and validation.

4.3. Case Study

To develop and to test the development procedure, a case study will be executed. Here, a new product for the iFactory shall be developed. The iFactory is part of an industrial research and learning laboratory at the Intelligent Manufacturing Systems (IMS) Centre at the University of Windsor, Canada [1,9]. The iFactory contains a modular and changeable assembly system produced by FESTO Didactic.

The iFactory is made up of reconfigurable modules with different processes, concepts and layouts for different product variants. By changing the layout it is possible to execute many different operation sequences. For communication and media supply, standard interfaces are used. Hence, the system is equipped with topology feedback, whereas an automated identification of the layout configuration is possible by a Supervisory Control and Data Acquisition (SCADA) system.

Current iFactory Product and its Variants

The current product of the iFactory is an office desk set, as shown in Figure 4, (a). By combining 2 different kinds of product base plates with the items cups (11 variants), clocks (4 variants) and desk lights (3 variants) using 3 different mounting positions, more than 10,000 product variants can be created. The carrier base plate, work piece pallet and product base plate are linked by positioning pins and corresponding holes. Additionally, the work piece pallet is equipped with RFID tags, which allow the tracking of the process and the production operations.
New Products for iFactory

For the development of a new product there are constraints depending on the existing system that have to be considered. For example, the product dimensions of the new product cannot exceed 237x157x120mm (length x width x height) and the product weight must be less than 2.5 kg.

Using the new product design procedure, a product is going to be developed that fits to these constraints. Furthermore, the product must be designed to explore changeability and the relations between product variants and corresponding processes and layout configurations. It should be possible to gain, learn and teach knowledge like methods and tools about these research areas.

For this, the new product must have appropriate criteria to design and realize different product variants and the possibility to simplify the product structure and the design for product variants. Here, the defined system objectives as well as the capabilities for teaching and research have to be considered. Thus, some of the desirable features of the new product(s) can be defined as follows:

- Development of the part shapes and interfaces according to Design for Manufacturability, Design for Assembly and Design for Disassembling
- Synthetic or metal materials
- Product architecture have to provide possibilities for fastening, handling and assembly sequences, planar open sub-assemblies or recursive sub-modules

Further requirements exist for the parts interfaces regarding disassembling and reuse. Thus, the components must be easily and quickly removable without the use of any special tools. The process and layout configurations need to support the simulation of different manufacturing scenarios for Changeable Manufacturing Systems. For this, switching between process variants have to be possible by adaptable assembly processes for the new product.

There are two fundamental approaches for the development of a new product for the iFactory. The first approach is related to the modification of the current product. This can be done by changing the field of application from an office appliance to e.g. a domestic appliance. For this, the product base plate can remain unchanged while the items are replaced by other items like soap dispensers or tooth brush holders. Other functions can be added by the application of additional holes, threads, parts and interfaces. The second approach is to find a completely new product and to elaborate the product structure. This approach will be chosen for the new product of the iFactory.

Here, two product ideas have been compiled which are shown in figure 3. First is a suspension strut including a shock absorber for a car chassis. Product variants of the suspension strut are characterized by car brand, type, dimensions, fasteners as well as suspension and damping rate. The second product idea is a side mirror of a car. Here, the product variants can be realized by e.g. shape, color, orientation, direction indicator, heating. According to the number of colors and shapes, about 10,000 product variants can be realized for the side mirror.

To evaluate these product ideas and to identify the best possible solution, a value-benefit-analysis will be executed. For the identified solution, the product design and process and layout configurations will be developed.

5. Conclusions and Outlook

Engineers and practitioners in modern industries are faced with dynamic requirements of global markets. To cope with these requirements, the development and advancement of learning factories can be crucial. Since the learning factories provide a close-to-reality research and education environment, they can lead to significant benefits for the industry in various sectors.

In research facilities all over the world, different kinds of learning factories have already been implemented. They are used to conduct high quality research and to support the industry.

One example is the iFactory implemented at the Intelligent Manufacturing Systems (IMS) Centre at the University of Windsor in Canada. This “factory-in-a-lab” contains a Changeable Manufacturing System which can be physically rearranged to build a wide range of possible layout configurations. Consequently, also a wide range of product variants is feasible.
Using the new development procedure, the iFactory should be equipped with a new product or product family that exploits and supports the full range of the available capabilities. Since the learning factory is used for research and education applications that are relevant for the industry, the new product will be as similar as possible to a real industrial product. Traditional products have to fulfill an expected function which influences the design, shape, structure and features of the product. A manufacturing system within an industrial environment is planned and constructed according to these requirements determined by the product. In contrast to this, products for learning factories are developed to support the capabilities of the existing production environment in terms of the best possible transmission and application of educational and research contents. Additional requirements arise from the disassembly and reuse of the product for multiple research- and learning cycles.

The new design procedure will consider these requirements to establish a best possible research and education environment.

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7. References