A Functional Platform Strategy for Integrated Machine Tools


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Abstract

Product modularization enables a combination of standardization and cost reduction without neglecting the concept of individualization. The major benefit is to maximize external diversity and minimize internal complexity by modular product structures. For a modular product structure and interface design of machine tools combining complementary manufacturing processes in a single machine system, a detailed understanding of the individual technologies and mutual interdependencies is essential to identify complexity and estimate the imminent development effort. Product configuration and conceptualization for integrated machine tools basically depend on the interactions of the manufacturing technologies and the required effort for realization. Platform concepts carry high potential for rationalization, due to similar structures and components and facilitate a fast and low-risk product development process in general. Consequently, a platform strategy from a functional point of view is presented to reduce the effort for product development in order to open up new manufacturing technology combinations. Complexity drivers and technological barriers preventing technology integration are included in the assessment for a methodical combination. Therefore, a holistic requirements management forms the basis for sustainable developing activities for integrated machine tools and enables a detailed description of functional dependencies. An evaluation is carried out by an established process chain for a machining process.

Keywords: functional platform strategy, systematic product conceptualization, product architecture design

1. Introduction and Motivation

One option to react to changing requirements is to apply the principle of modularization [1]. The key objective of platform concepts and modular design is the decoupling of internal complexity for more profitable product manufacturing and external diversity to improve the positioning in the market. As a result, a reduction of development and manufacturing costs, due to economies of scale is guaranteed [2]. The coordination of individual modules enables the combination to diverse designs without additional technical effort, providing the application of developed product components into various product variants [2]. Moreover, restructured product architectures in the form of module and platform strategies are utilized by various companies to provide competitive and customized products [3]. Companies have to face dynamically changing boundary conditions. Key aspects which have to be addressed are the increasing degree of variance, complexity and shorter product life cycles [4]. A crucial competitive factor for enterprises nowadays constitutes the individualization of products to increase the customer satisfaction. However, the necessity for a higher degree of standardization becomes imminent [5].

In this field of unresolved tension, functional analysis and synthesis constitutes a central component for assistance and evaluation of complex technical systems, such as Multi-Technology-Machine-Systems, throughout the engineering design process.
1.1. Perspective for High-Wage Countries

Superior manufacturing technologies represent a central component of core expertise to compensate low-wage structures. The major motivation to introduce novel integrated manufacturing technologies consists in high innovation and cost reduction potentials as well as an increase in productivity [6], [7]. For manufacturing companies the adaptation of new trends regarding manufacturing and production technologies right on time is a vital requirement to ensure competitiveness [6]. Successful production in high-wage countries depends on a sustainable and future-oriented strategy and appropriate technologies adopting this approach [8]. Though, enterprises in high-wage countries have to face the challenge of providing individual, innovative and high-quality products at competitive costs. In general, flexible production systems are qualified to solve this dilemma.

The transition to modular systems represents a potential solution, fulfilling differentiated customer requirements with simultaneous exploitation of scale effects [9]. Due to the increasing intensity of global competition associated with the rising cost pressure, standardization measures are a suitable starting point [10]. Enterprises in high-wage countries frequently meet the globalized price competition with differentiation strategies, e.g. modularization or variant management [11]. Complex market dynamics due to shorter innovation cycles and rising unpredictable prognoses result in manufacturing systems with maximum flexibility. The demand is not only in high-quality products at low costs but also to react agile and flexibly to changes of the market [12].

The technology push of Multi-Technology-Machine-Systems will become mostly prevalent for high-wage countries to address the need for individualized manufactured products and at the same time be able to manage the development effort for implementation. The emphasis comparing all production sites has different characteristics. The production site differences have a significant impact on the technology rollout. On the one hand low or medium wage countries have untapped markets, an economically prosperous environment and offer significant cost benefits. On the other hand these production sites are characterized by a high fluctuation rate and the necessity for the same qualification of employees. The forming-process is based on a CNC-controlled incremental sheet metal process. For this purpose, a conventional portal milling machine, which has been extended by four modules for stretch-forming with two axes each, represents the machinery platform. A hemispherical forming head forms the required component contour gradually out of the clamped sheet. Furthermore, a laser has been integrated for local heating to increase the formability and enables a subsequent trimming [17]. However, no systematic engineering design methods have been utilized during product development to set up these introduced MTMT systems. The research progress to optimize the functionality of the introduced demonstrators is still in progress.

Currently, there are further operative MTMT systems on the market. In addition to the already mentioned demonstrators the most important MTMT systems including their main characteristics can be seen in Table 1.
The significance of Table 1 can be described as follows:

- Most of the combinations consist of different manufacturing main groups with complementary character, e.g. milling/turning with laser assistance or alternating additive processes.
- Machining processes are represented in each listed MTMT. The focus of these manufacturing processes is on conventional machining. Consequently, a transfer to additional processes is appropriate.
- The majority of the introduced MTMT are assisted by at least one laser technology, except Adams General Power GmbH FXT 1600 and Chiron Mill 2000. The demonstrators at RWTH Aachen University which have already been described in more detail above are also suitable for simultaneous processing.
- Apart from the Multi-Technology-Machine-Center each MTMT consists of one work space.
- The level of technology-integration is relatively high.

The effect of process-specific interactions has to be assessed already during product development to determine the behavior between interactions and corresponding response. However, it should be considered, that an economic application of different technologies is limited to low batch sizes and prototyping, which has already been emphasized by Tönissen [18]. To reduce innovation cycles significantly, a systematic identification of interactions during processing has to be performed to minimize the scope for solutions [19]. As can be seen in Figure 1, the spectrum of combinatorial options for machinery and processes is enormous, depending on the selection of appropriate technology combinations. Depending on the processes involved (k) with regard to the available options (n) the scope of solutions is rising significantly according to the main groups in manufacturing [20]. Taking into account all 154 currently existing manufacturing technologies (the dashed line in Figure 1 represents the binomial coefficient) a valid selection will face instantly the problem of combinatorial explosion. To manage this diversity effectively, formalized approaches and methods for systematic development of MTMT are required.

2. Differentiation Strategies

In general, modularization is the design of a system of relative autonomous subsystems [21]. Modularization approaches are primary addressed during product development, and usually maintained throughout the entire lifecycle of the product. However, different modularization architectures for different lifecycle phases can be vital [22]. Complex tasks made up of multiple steps are typically subject of a learning curve [2]. Consequently, referring to Figure 2, a platform strategy for basic functionalities of machine tools and process specific modules seems appropriate, according to [18]. Across diverse manufacturing technologies synergy potentials can be exploited, e.g. control aspects or workpiece/tool fixation or movement, mainly represented in Platform I (core functionalities). Based on this investigation, manufacturing technologies with a high a degree of similarity can be combined to minimize development effort and time. Furthermore, the compensation of process specific interactions by means of corresponding measures, e.g. laser safety devices, can equally be modularized, represented in Platform II (auxiliary functions). Moreover, depending on the process combination further modules (Platform III) could support the idea of process-specific modularization of MTMT systems. Process-specific characteristics can be found in the hat-modules of Figure 2. On this basis a profound investigation of relevant influencing factors can be carried out. Within product development of
production systems a paradigm shift from flexible to changeable production is visible within production management [1], [5]. An in-depth analysis of every existing manufacturing technology and their mutual interdependencies form the basis of this systematic approach. Therefore, drivers for change have to be examined and their impact has to be assessed [23].

Therefore, new technology potential has to be opened up. Product development has to fulfill both perspectives, market and machine user. For this purpose process and product expertise need to be provided in the concept phase.

Fig. 2. Principle of a modular platform strategy for integrated machine tools

Fig. 3 Influencing triangle in the development process of MTMT

2.1. Essential Influence Parameters

Potential influencing factors during product development are manifold. The field of tension during development which can be seen in Figure 3 containing the following three major components: machine developer, machine user and in the last instance the customer. The main emphasis of this contribution is on the development aspect. Nevertheless, it is essential to satisfy customer and user requirements in terms of quality, product features and machine parameters in equal measures. Customers increasingly demand high quality at low costs within short development cycles. Implied claims arising from the field of tension are the need for novel end products or manufacturing solutions (market pull) [2]. From machine user point of view, the integration and extension of novel MTMT technologies into the current product portfolio are key factors for success. Depending on identified customer requirements in the market either specific product characteristics or manufacturing technologies are needed during product conceptualization (technology push) [8].

Fig. 2. Principle of a modular platform strategy for integrated machine tools

An examination and application of appropriate approaches for the representation of interdisciplinary models is mandatory. Therefore, reference architectures and extensible developing guidelines have to be derived [24]. For this purpose, the following information is requested:

- An essential derivation of technological process boundaries and an analysis of MTMT appropriate product requirements are needed. Appropriate process boundaries have to be drawn for MTMT.
- Currently changing market situations have to be considered in the description models used.
- Why have specific technologies not been combined so far? Therefore, the question has to be addressed: which technological barriers have to be overcome during product conceptualization? A starting point from a developer’s point of view is the required product characteristics.

2.1. Essential Influence Parameters

Aiming for a high level of system homogeneity, primary manufacturing processes from the same main group have to be combined, considering Table 1 and [25].

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Objectives for MTMT systems to be achieved during product conceptualization:
A limited variant diversity is aspired regardless which processes are combined.
A defined and appropriate amount of reference architectures has to be determined (hat).
A recognition of standardization potentials is needed to minimize innovation and time to market cycles (platform).

Taking into account the statements and general specifications mentioned above a transfer into a platform can be achieved according to Figure 2. One potential form of representation is shown in Figure 4. The functional requirements of the individual main groups have been determined with the help of [26], [27]. The form of representation is hierarchical. In general, the aim is to provide a universal representation for each conceivable combination. A further development is pursued in future work.

Fig. 4. Functional Platform Strategy for MTMT

2.3. Methodological Approach for MTMT Modularization

In order to implement and transfer this strategy into a method for product conceptualization of MTMT, an established process chain for a machining process with subsequently hard machining is closely investigated for feasibility, shown in Figure 5.

Fig. 5. Conventional process-chain for a pinion shaft

The objective of the methodological procedure in Figure 6 is a platform for a specific manufacturing combination. Starting point are either product features the final product should have or manufacturing technologies which should be combined, provided that process expertise is available at an adequate level. The decision for a simultaneous or a sequential processing procedure of the technologies depends on the work piece characteristics and is closely linked to the amount of work spaces. For simultaneous manufacturing in one work chamber the functional integration is correspondingly higher.

Fig. 6. Key scientific issues during product development of MTMT
appropriate interface design and the determination of robust process modules are performed to guarantee compatibility and exchangeability. The option for iteration provides the opportunity to repeat previous steps and decisions in order to achieve the desired quality.

3. Conclusion and Outlook

The implementation of integrated manufacturing technologies strongly influences the traditional development and design process. An adaptation to different preconditions is the main challenge, e.g. small lot sizes or the specific and systematic coordination of individual manufacturing processes. Specific modules have been presented with an emphasis on functional dependencies. The functional platform provides a basic structure to minimize the effort for varying requirements. This methodical approach provides the opportunity of high reproducibility, sustainability and is essential to ensuring the quality during product development. It will be possible to develop potential process combinations from various main groups. The ideal situation constitutes an opportunity to generate complex work pieces that cannot be realized with conventional methods from an economic point of view. Next, different modularization architectures for different lifecycle phases should be determined to offer an additional value not only in the use phase but also over the complete lifecycle of MTMT systems. Therefore, further established process chains in different processing stations should be addressed during examination to clarify different perspectives and technological obstacles. Thus, concrete user demands and needs can be deduced and integrated. Another important matter of fact is the assessment and design of mechatronic modules and the determination of relevant system boundaries. Further and more concrete decision models for the individual stages of MTMT development are expedient.

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