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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.

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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.

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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 to maintain high quality standards for the introduction of novel technologies. In addition, the risk of high initial costs for the implementation of new manufacturing technologies within the existing machinery has to be taken into account.

High-wage countries in contrast are characterized by a high automatization level and a highly acclaimed technological expertise [13]. Though, high-wage countries are subject to the need for innovation that has to be fulfilled in order to withstand the global pressure of competition. With this new technology introduction high-wage structures can be compensated and technology leadership can be maintained. The consequence is a clear division of competences. However, the core expertise and differentiation capacity will remain within the development sites mostly existing in high-wage countries, also including production plants for a quick and effective market launch [6]. In the last instance, the technology launch for low and medium wage countries will require additional time and progress to achieve an acceptable technological degree of maturity.

1.2. Vision of Integrated Production Technology

One option to increase productivity and flexibility at the same time is to generate new integrated production technologies. For this purpose, different disciplines need to be brought together in the research and development phase. Therefore, a high expertise of the processes and the material properties is provided. Synergetic effects may be exploited by combining processes to increase accuracy and productivity [14].

Demonstrators, so-called Multi-Technology-Machine-Tools (MTMT), fulfilling these requirements have been developed and built for research application within the underlying project. Thus, various processes can be implemented and combined in a single setting. Two of the corresponding MTMT systems which have been developed in the scope of the subproject *Integrated Technologies* will be explained in detail below.

The objective of the developed *Multi-Technology-Machining-Center* is to combine additive and material removing technologies for metal processing to react highly flexible to current market demands [15]. The cornerstone of this flexible machine system is a 5-axis moving column milling center with two equally assembled work spaces, each including a rotary tilt table. An integrated machine tool spindle can operate in both work spaces sequentially for machining operations. Additionally, a handling robot with different laser processing units was implemented, inter alia for laser deposition welding which is able to operate simultaneously to the conventional milling process [16]. The demonstrator shows additional manufacturing process possibilities while operating: laser hardening, laser structuring and laser deburring. Thus, several processes become feasible at the same time, increasing productivity and the value-added share. The second demonstrator is set up as a *Hybrid-Sheet-Metal-Processing-Center*. 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.

Table 1. Overview of existing MTMT systems and their properties

Producer	Technology combinations	WS	TI	SimMan
Adams General Power GmbH FXT 1600, *unknown*	turning, milling, grinding with rotational tool, hardening	1	S, D, T	○
Albrecht Röders RFM 500, *2001*	drilling, milling	1	S, D	○
Boehringer (MAG): NG 200 Laser, *2004*	turning, laser welding	1	S, D, T	○
Monforts Uni-Cen 504 Laserturn, *2008*	turning, drilling, laser-assisted surface tempering and coating	1	S, D, T	○
EIMA Laserline (*Hybrid-Sheet-Metal-Processing-Center*) at RWTH Aachen University, *2009*	incremental pressing, stretch forming, milling, laser trimming	1	S, T	●
KUKA Kr-16, Chiron Mill 2000, (*Multi-Technology-Machining-Center*) at RWTH Aachen University, *2009*	milling, laser deposition welding, hardening, structuring, deburring	2	S, D, T	●
Chiron Mill 2000, *2009*	drilling, power machining	1	S, D	○
Matsuura Lumex Avance 25, *2011*	milling, sintering	1	S, D, T	○
DMG Mori Seiki Lasertec 65 3D, *2013*	milling, deposition welding	1	D, T	○
Hamuel Reichenbacher HSTM-B-1000, *2013*	turning, milling	1	S, D, TR	○
Monforts RNC 400 Laserturn, *2013*	turning, hardening coating through thermal spraying	1	S, D, T	○
DMG Mori Seiki Lasertec 4300 3D, *2015*	milling, deposition welding	1	D, T	○

***Legend**: WS = work space quantity; TI = technological interactions; SimMan = simultaneous manufacturing; S = static; D = dynamic; T = thermal; TR = tribological; ● = yes; ○ = no*

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.

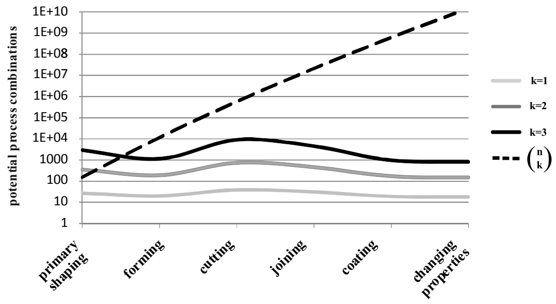

Fig. 1 Combinatorial diversity based on an adequate technology combination

A regulatory scheme for systematic conceptualization of MTMT systems in early stages of product development is needed to reduce complexity and development effort significantly. Therefore, module-oriented machinery and control concepts with varying process technology modules are investigated. Basic approaches and prediction models for the investigation of interactions in MTMT are pursued in this contribution. Moreover, the potential for standardization within product development has to be exploited to minimize the effort sustainably.

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].

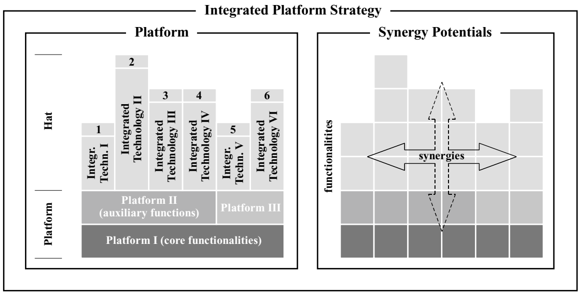

Fig. 2. Principle of a modular platform strategy for integrated machine tools

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

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]. 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.

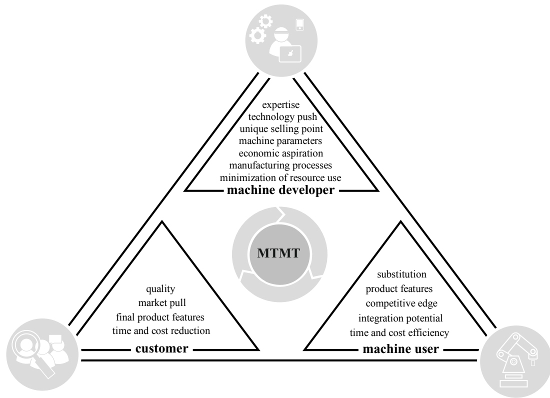

Fig. 3 Influencing triangle in the development process of MTMT

To address these diverse questions efficiently a functional platform strategy is valuable to keep the development effort and costs at a minimum and to maximize the degree of re-usability for future tasks.

2.2. Platform and Module Design for MTMT

Bringing several processes, showing deviating process characteristics, together in one machine system is challenging regarding mutual interactions and the effort for integration. Therefore, a robust and flexible concept is essential. Potential technology interdependencies influencing the development process of MTMT have already been discussed in [25], [26]. These preliminary considerations have reached the following conclusions. Principles for a modular structure and design of MTMT:

- A determination of commonality of requirements (synergy potentials) which can be summed up in the underlying platform according to Figure 2.
- Aiming for a high level of system homogeneity, primary manufacturing technologies from the same main group have to be combined, considering Table 1 and [25].
- Taking account of the mechatronic structures of the machine system.
- Clear definition of module limits depending on the function package the customer needs. Therefore, expandability has to be guaranteed.
- To guarantee separability and extensibility a standardized interface design is considered necessary (software and hardware based) addressing the fundamental idea of Industry 4.0 for a holistic digitalization and networking of the machine systems and components.

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.

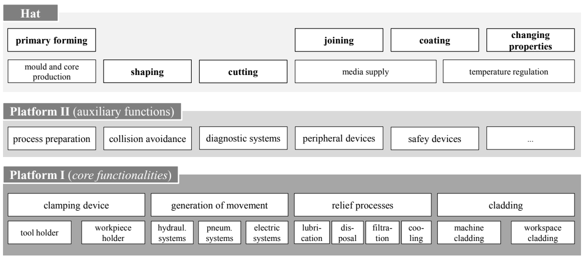

Fig. 4. Functional Platform Strategy for MTMT

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.

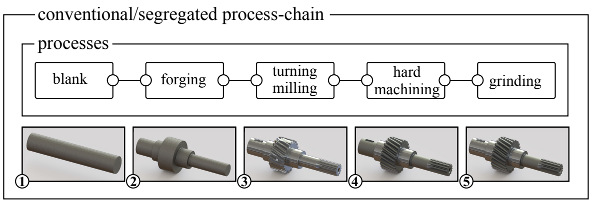

Fig. 5. Conventional process-chain for a pinion shaft

Taking this simplified process chain as an example for application, several questions arise regarding process integration and technical convergence. The main issues are listed below:

- What resources are available during product development? (know-how, time and financial means)
- Which technology combination should be realized in one system? (2+3, 3+4, 4+5, 2+3+4, etc.)
- How many processes should be combined taking into consideration an increase in productivity and economic efficiency compared to conventional manufacturing? (2, 3 or 4)
- How should the machining operations be performed? (machining sequence)
- What are the main considerations from technological point of view to bring complementary manufacturing technologies together? (interactions, synergy potentials)

Challenges arising for the realization of this specific component occur during process integration, e.g. chip removal or laser integration for the hard machining process when combining steps three and four. Accompanying functionalities that become necessary are inter alia appropriate safety regulations and handling operations. This process combination reduces waiting times for the curing procedure and enables the basis for a significant competitive edge. In the next step the preliminary considerations are going to be abstracted and the scientific issues addressed in a flow chart. Two variant paths have been proposed in Figure 6 considering the initial position. One option is to focus on the product characteristics in early stages of product development, another possibility is to enforce a specific combination of processes to open up unused potentials.

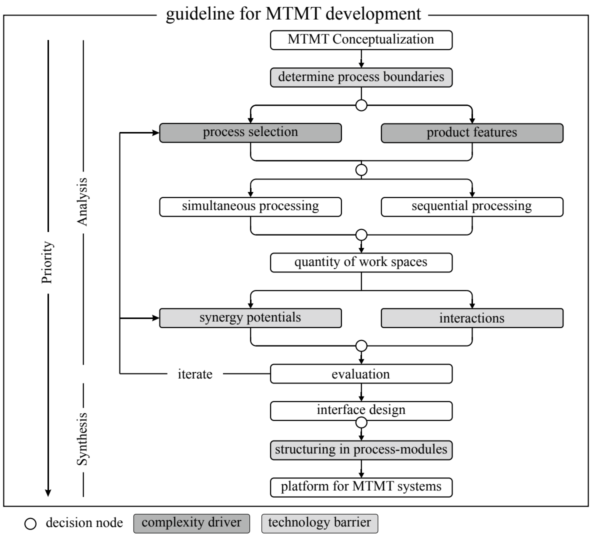

Fig. 6. Key scientific issues during product development of MTMT

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. Then, functional similarities of the different technologies to be combined have to be examined and their interactions (positive or negative) have to be evaluated. Finally, an 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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References

[1] Meier H, Schröder S, Kreggenfeld N. Changeability by a modular design of production systems – consideration of technology, organization and staff. In: 46th CIRP Conference on Manufacturing Systems 2013 p. 491-496.

[2] Pahl G, Beitz W, Feldhusen J, Grote K H. Konstruktionstechnik: Methoden und Anwendung erfolgreicher Produktentwicklung. Berlin: Springer, 8th ed. 2013.

[3] Schiffer M. Szenariorobuste Produktarchitekturgestaltung. Aachen: Apprimus, 2013.

[4] Schuh G, Arnoscht J, Völker M. Product Design Leverage on the Changeability of Production Systems. In: 45th CIRP Conference on Manufacturing Systems 2012 p. 305-31.

[5] Baumgart I. Modularisierung von Produkten im Anlagenbau. Aachen, 2004.

[6] Friedli T, Schuh G. Wettbewerbsfähigkeit der Produktion an Hochlohnstandorten. Berlin: Springer, 2012.

[7] Bauernhansl T. Industrie 4.0 in Produktion, Automatisierung und Logistik. Wiesbaden: Springer Vieweg, 2014.

[8] Brecher C (Hrsg). Integrative Produktionstechnik für Hochlohnländer. Berlin: Springer, 2011.

[9] Arnoscht J. Beherrschung von Komplexität bei der Gestaltung von Baukastensystemen. Aachen: Apprimus, 2011.

[10] Rudolf S. Produktionsgerechte Baukastengestaltung. Aachen: Apprimus, 2013.

[11] Bohl A. Kennlinien der Produkt- und Produktionskomplexität. Aachen: Apprimus, 2015.

[12] Spena P R, Holzner P, Rauch E, Vidoni R, Matt D T. Requirements for the Design of flexible and changeable Manufacturing and Assembly Systems: a SME-survey. In: 48th CIRP Conference on MANUFACTURING SYSTEMS 2016 p. 207-212.

[13] Gausemeier J, Lanza G, Lindemann U. Produkte und Produktionssysteme integrativ konzipieren. München: Carl Hanser, 2012.

[14] Brecher C. Advances in Production Technology. Heidelberg: Springer, 2015.

[15] Brecher C, Breitbach T, Du Bois-Reymond F. Qualifying Laser-integrated machine tools with multiple workspace for machine precision. In: Proceedings in Manufacturing Systems 2013 p. 1-8.

[16] Brecher C, Klocke F, Breitbach T, Do-Khac D, Heinen D, Karlberger A, Rosen C-J. A hybrid machining center for enabling new die manufacturing. In: WGP 2011 p. 405-413.

[17] Hirt G, Bambach M, Bleck W, Prahl U, Stollenwerk J. The development of incremental sheet forming from flexible forming to fully integrated production of sheet metal parts. In: Advances in Production Technology 2015 p. 117 – 129.

[18] Tönissen S. Economic Efficiency of Manufacturing Technology Integration. Aachen: Apprimus; 2014.

[19] Schmid A, Löwer M, Katzwinkel T, Schmidt W, Siebrecht J, Feldhusen J, Brecher C, Du Bois-Reymond, Rey J. Life Cycle of Multi Technology Machine Tools: Modularization and Integral Design. In: 26th CIRP Design Conference 2016 p. 719-726.

[20] DIN 8580. Fertigungsverfahren. Begriffe, Einteilung. Deutsches Institut für Normung e.V. Berlin: Beuth Verlag 2003

[21] Göpfert J. Modulare Produktentwicklung. Wiesabden: Deutscher Universitäts Verlag, 1998.

[22] Shoval S. Dynamic Modularization throughout System Lifecycle Using Multilayer Design Structure Matrices. In 13th Global Conference on Sustainable Manufacturing – Decoupling Growth from Resource Use 2016 p. 85-90.

[23] Schuh G, Arnoscht J, Völker M. Product Design Leverage on the Changeability of Production Systems. In: 45th CIRP Conference on Manufacturing Systems 2012 p. 305-31.

[24] Schmid A, Katzwinkel T, Schmidt W, Siebrecht J, Löwer M, Feldhusen J. Reconfigurability and modularization for integrated machine tools based on functional analysis: a systematic approach. In: 14th International Design Conference 2016 p. 1367-1376.

[25] Schmid A, Katzwinkel T, Siebrecht J, Feldhusen, J. Anforderungsgerechte Gestaltung von Multi-Technologie-Plattformen. In: 13. Gemeinsames Kolloquium Konstruktionstechnik 2015 p. 221-230.

[26] Schmid A, Jacobs G, Löwer M, Katzwinkel T, Schmidt W, Siebrecht, J. Datenbankbasierte Kompatibilitätsbewertung technologieintegrierender Werkzeugmaschinen. In: 14. Gemeinsames Kolloquium Konstruktionstechnik 2016 p. 240-250.

[27] Neugebauer R. Werkzeugmaschinen: Aufbau, Funktion und Anwendung von spanenden und abtragenden Werkzeugmaschinen. Berlin: Springer 2012.

[28] Brecher C, Weck, M. Werkzeugmaschinen 1 – Maschinenarten und Anwendungsbereiche. Berlin: Springer, 6th ed. 2005.