Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 70 (2018) 469–474

www.elsevier.com/locate/procedia

28th CIRP Design Conference, May 2018, Nantes, France

Reference Products in PGE – Product Generation Engineering: Analyzing Challenges Based on the System Hierarchy

Albert Albers[1], Simon Rapp[1]*, Nicolas Heitger[1], Friedrich Wattenberg[1], Nikola Bursac[1]

[1]*IPEK – Institute of Product Engineering at the Karlsruhe Institute of Technology (KIT), Kaiserstraße 10, 76131 Karlsruhe, Germany*

* Corresponding author. Tel.: +049-721-608-47185; fax: +049-721-608-46051. *E-mail address:* simon.rapp@kit.edu

Abstract

PGE – Product Generation Engineering describes that new products are developed based on reference products by three types of variation: carryover variation, embodiment variation and principle variation, where the two latter ones together form the share of new development. Existing approaches relate development risks to the share of new development and the organizational origin of the used reference products. However, several observations suggest that the level of the system structure, which is affected by the new development activities, is also an influencing factor. The contribution at hand aims at a more detailed investigation of this influence. For this purpose a case study is used, covering the first two generations of the dual mass flywheel. Based on this case study an existing approach for the estimation of development risk in PGE is extended to depict the system level, which is subject to new development activities, as an influencing factor. The extended framework is then applied on the development of the system of objectives for a new product generation of an automotive OEM. The framework is capable of displaying the development risks that had been encountered in the development of the first two DMF generations. However, further evaluation using more examples, stays necessary. The framework can serve as a basis for the early derivation of measures which have to be taken as next steps for the handling of identified risks.

Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.

Keywords: Development risk, System analysis, Innovation, Validation

1. Introduction

On November 16th 2017 Tesla, Inc. presented two prototypes of his semi-truck "Tesla Semi" [1]. Outnumbering conventional, diesel driven rivals in several categories of technical and economic data it is believed to become a true innovation. However, it is likely that Tesla will still have to tackle several challenges before serial production can start. The amount of those challenges will probably be greater than in a "standard" truck development project. On the one hand this finding seems obvious due to a certain uniqueness of the project. On the other hand, as the Tesla Semi consists not only of new developed subsystems but uses subsystems from reference products such as Model 3 engines for the wheels, the Tesla Semi can be described as PGE – product generation engineering and thus by the same approach like a conventional truck development. Of course the Tesla Semi might be a very prominent example, but development projects where development risks turn out to be greater "than usual" occur regularly. This contribution describes characteristics which lead to such increased risks. This may allow earlier identification of possible risks and the derivation of corresponding measurements in future development projects.

2. State of the Art

2.1. Changing Product Structures and Risk Estimation

The Kano model distinguishes between three different categories of qualities that allow a product to fulfil the customer's needs. Must-be qualities, one-dimensional qualities and attractive qualities. While the developer will face customer dissatisfaction when demanded must-be qualities are not being delivered, there will be no positive reactions when those quality

Peer-review under responsibility of the scientific committee of the 28th CIRP Design Conference 2018.
10.1016/j.procir.2018.02.046

standards are met. The one-dimensional qualities are adding more customer satisfaction the more they are fulfilled and vice versa. Attractive qualities can create costumer excitement when being realized but will not affect the customer's satisfaction when not being fulfilled. Over time one-dimensional and attractive qualities degrade towards must-be qualities [2]. For product development this means that new risks have to be taken to develop products that create customer satisfaction and excitement by delivering new one-dimensional and attractive qualities. In terms of marketing new products have to be developed to achieve or maintain a competitive advantage [3].

In general developers try to keep the risk of product development projects as low as possible by proceeding from existing and known solutions towards less known solutions [4]. Lack of experience with new systems leads to increased risk [5]. On the one hand, incremental innovations that are often sufficient for market success add relatively minor risks whereas radical innovations cause higher risks and offer only few possible ways for synergies [6]. On the other hand, a certain degree of risk has to be taken to develop new products. Thus, the question is how risk throughout changing product structures can be estimated.

In their work Eckert et al. introduce a method to predict change propagation in complex design projects [7]. Consistent with the fundamental idea of PGE – product generation engineering they underline that "product development involves the steady evolution of an initial design". In terms of PGE – product generation engineering this initial design can be either a previous generation of an existing product or any other product that serves as a reference for the new product. The degree to which certain changes propagate through a product varies from product to product. The product complexity is the defining factor that influences the change propagation. To handle this challenge among different products Eckert et al. introduce the change prediction method. This method consists of three major steps and guides the developer from an initial original product to a final modified product. The first step includes the development for of product risk matrix. The authors derive risk from a combination likelihood of change and impact of change. Furthermore, potential propagation paths are being generated to reveal the propagation of changes through up to four steps of the product's components. These potential propagation trees allow to compute matrices of combined likelihood and combined impact of change. Following, these two matrices can be multiplied to calculate the combined risk for each sub-system. The results of this step are being represented in the product risk matrix that summarizes the results for all sub-systems.

Browning and Eppinger understand risk as a factor that is based on changes on the input of the activities in product development. Thus, they describe product development "as a complex web of interactions, some of which precipitate a cascade of rework among activities." [8] Therefore, their model is based on activities that create certain deliverables. These deliverables are being exchanged and characterized by uncertainty concerning their duration, cost, improvement curve and risk. Based on that they reveal opportunities to trade cost and schedule risk comparing different process architectures.

2.2. PGE – Product Generation Engineering

Product development is PGE – Product Generation Engineering [9]: new products are always developed based on already existing products. Thus, a new product can always be described as a recomposition of systems that are derived or adopted from existing products. This allows for the first time to describe product development on the basis of reference products and to classify activities that are accompanied with doing so. Some subsystems and parts of the system structure of a new product are carried over from those existing products, while others are developed new, using the existing products as a starting point. The activity of carrying subsystems over includes changes in the interfaces to other subsystems due to integration in the new system context and is thus called carryover variation (CV). New development activities consist of embodiment variation (EV) and principle variation (PV). The systems which are used in any way as a reference for the activities in the development process are called reference products (RP). Reference products are not necessarily only preceding products of a company which are currently in the market. Competitors' products, products from other branches or research or a company's concepts which never came into to the market can serve as reference product as well. Reference products are used both, for the definition of development objectives and requirements and for the technical realisation of the product itself [10]. In the first case reference products not necessarily need to be existing products. Hypothetical products, such as forecasted competitors, can also be used to describe differentiation objectives.

There are different possible criteria to distinguish different types of reference products or their use, respectively: first, from the perspective of the individual company or development department there are "internal" and "external" reference products. Internal reference products have been developed by the same department or at least within the same company. Thus not only the product itself is available as a reference but also the product documentation, experiences, testing reports etc. External reference products are accordingly products from outside the company [11]. In many cases there is a "basic" reference product which is dominant in terms of being the reference for most of the structure and subsystems of a new product generation [12]. This can typically be observed at different car generation in automotive industry, for example. Furthermore for products with a great variety in variants there is usually a variant reference product which is the basis for all the different variants [12], which are developed out of that basis with the same activities like a new product generation. The main specific characteristics of variants are a comparatively small share of new developed subsystems and co-existence in the market with their reference product. But in general includes the development of product variants the same phenomena which are described by the PGE approach. Furthermore are the transitions between individual development states of a product similar to development of product generations. As a consequence, are those individual development states perceived as "development generations".

Risks and challenges in a development process can i.a. be traced back to the share of new developed subsystems, thus the share of embodiment and principle variation, and the extent to which the reference products for a development project are internal or external reference products [13] (cf. fig. 1): a greater share of new developed subsystems increases development risks, mostly due to technical reasons, a greater use of external reference products carries the risk of a less detailed understanding and less available information which can serve as a basis for the development of the new product generation.

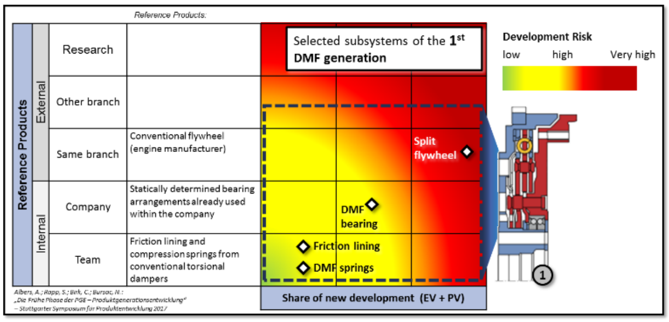

Fig. 1. Visualisation how the share of new development and the organisational origin of reference products tend to influence the development risk (modified, based on [13])

Several examples for the different types of variation in PGE, challenges that come along with these variations and the role of reference products can i.a. be found in the description of the development of several generations of the Dual Mass Flywheel [14].

3. Need for Research

The first generation of the Dual Mass Flywheel (DMF) is an example of a highly innovative product. Main reference products were conventional torsional dampers and flywheels, but for the first DMF generation there was no preceding generation. As a consequence the development of the first DMF generation was accompanied by great risks and challenges. However, in the development of further DMF generations the preceding generations could be used as reference products. As a result there were less risks than in the development of the first generation.

Looking at the automotive industry similar examples can be found. On the one hand in most developments of a new product generation of a car a preceding product generation is the main reference product. For certain subsystems on lower system levels other reference products are used, for example to bring features from higher vehicle segments to lower vehicle segments. In this way airbags, ABS and ESP came from premium cars to small cars. On the other hand there are development projects like the first Tesla Roadster. Several reference products (Lotus Elise, laptop power cells) were used in this case, too. But there was no reference product on the top system level. In this respect being similar with the development of the first DMF generation the development of the first Tesla Roadster was also coming along with great challenges, resulting i.a. in multiple delays of the start of production. Those examples show that looking at the system in development [17] the system level which is affected by new development activities, seems to be an important influencing factor for development risks.

The current approach to estimate the development risk in PGE is based on the share of new development of individual subsystems of a new product generation and the organisational origin of the reference product. The observed influence of the system level seems to be not depicted adequately yet. Hence the following research questions are examined in this contribution based on using the first DMF generations as a case study:

- In which way does the system level on which variations occur due to new development activities, affect the development risks in the case of the development of the first two DMF generations?
- How can the existing approach for the estimation of the development risk in PGE be extended to take different system levels into account?
- How can the extended approach be applied to describe and analyse development projects?

A long-term goal in extension of those question is not only the estimation of development risks but the derivation of measures to handle those risks when deciding which concept out of different available alternatives should be detailed.

4. Case study and extended framework for the estimation of development risks in relation to different levels of the system in development

4.1. Case study dual mass flywheel

The dual mass flywheel (DMF) is a subsystem in the power train of many modern vehicles. It reduces rotational vibrations which are caused by combustion engines. For this purpose, it consists of two rotating masses which have a roller bearing or sliding bearing between them and which are connected by springs. In general, it can be considered to be a certain type of vibration absorber. In a powertrain the DMF is placed between the combustion engine and the clutch. Attached to the DMF is i.a. a gear rim for the sensor which measures the rotational speed. The DMF has already been described in detail and investigated in course of a case study looking at several generations of the DMF [16]. Back then the focus was on the different variations in the development of those generations and related risks. Detailed insights are possible in this case as one of the authors was personally involved in the development of the considered DMF generations. For the contribution at hand the point of view is slightly changed and variations and reference products in the development of the first two DMF generations are investigated with respect to different system levels. Therefore a system structure for the DMF generations is needed first. The chosen structure is displayed in fig. 2. The level of detail in terms of the number of system layers and subsystems per layer has been limited due to clarity and comprehensibility. Included in the structure is the car as the supersystem that

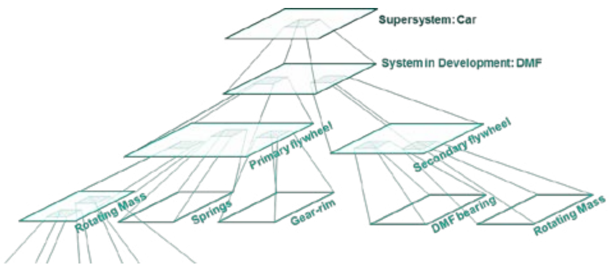

Fig. 2. DMF system structure used for the case study.

Subsequently the development of the first two DMF generations is described in terms of reference products and variations or new development shares, respectively, referring explicitly to this system structure with focus on the system in development and its subsystems.

For the first DMF generation there was no reference product available on the top system level as there was no previous DMF generation. However, reference products were used for the first sublevel: The primary flywheel, which is directly attached to the crank shaft of the engine and the secondary flywheel, which is connected to the friction clutch, were both developed based on a conventional flywheel on the one hand and a conventional torsional damper on the other hand. In this process "splitting" the original flywheel implied a great share of new development on the top system level and the first sublevel as the system structure new to a great extent. Nonetheless on the second sublevel subsystems such as the compression springs or the double row deep groove ball bearing could be carried over from reference products, which were available within the development team (conventional torsional damper) or at least within the company (bearing). As a result, especially of the new development share and the use of external reference products on high system levels, the development of the first DMF generations was accompanied with great risks. They manifested i.a. in early failure of DMF bearings and DMF springs. Consequently the second generation was developed.

For the second DMF generation the first generation could of course be used now as a reference product which provided the system structure in terms of a split flywheel on the top system level and the basic structure of the primary and secondary flywheel on the first sublevel. Major new development activities were made on the second sublevel by introducing a lubrication for the springs and changing the bearing principle to a statically undetermined bearing arrangement [16]. This as well included challenges and risks for the development process, but they were related more to those individual subsystems instead of the whole system.

4.2. Extended Framework

The case study of the DMF indicates that the level in the system structure which is affected by variations is an influencing factor for the development risk and can thus be used to estimate this risk early in the process. However, the current approach for risk estimation in PGE as shown in fig. 1 does not depict this relation. Therefore the authors propose to add a third axes to this framework referring to the different system levels of the system in development. For the two DMF generations fig. 3 and fig. 4 show the resulting new layer when using "Share of new development" as second axis.

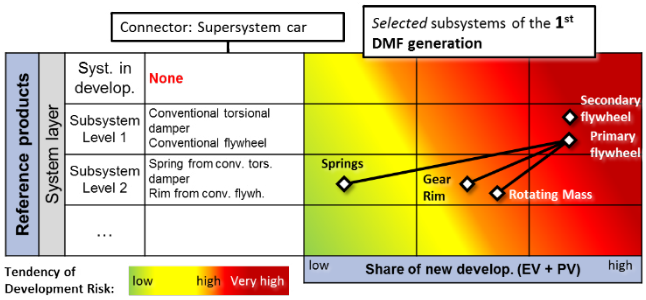

Fig. 3. Proposed framework extension with visualisation of development risk depending on share of new development and affected system level. Using the 1st DMF generation as an example.

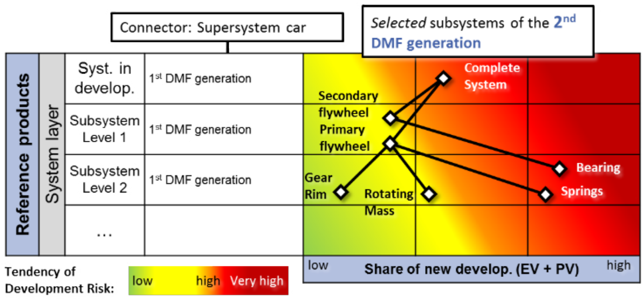

Fig. 4. Subsystems of the 2nd DMF generation in the extended framework.

Furthermore a separate risk scale was added to display the general need to consider risk that might be induced from the supersystem. However, a deeper investigation on this aspect has to be subject to future works. An example for risks induced by the supersystem can be the challenges that result for the DMF manufacturer form new power train topologies (hybrid or electrical), for example. In terms of system models describing the relation between function and embodiment this can be explained by the change of connectors of the system in development to the supersystem. Connectors represent and summarize the influences on, or more generally speaking, the context of a system [15]. The colour gradient visualizes the observed tendential relation to development risks.

Taking the dimension "origin of the reference product: internal/ external" as second dimension, fig. 5 and fig. 6 display the third 2D layer of the framework for the first two DMF generations.

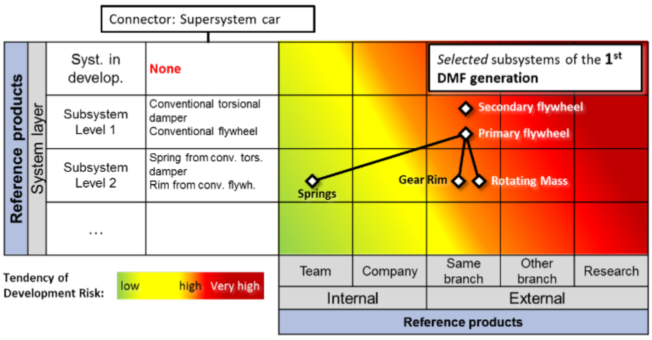

Fig. 5. Development risk for the 1st DMF generation depending on the system level and the organisational origin of the reference product.

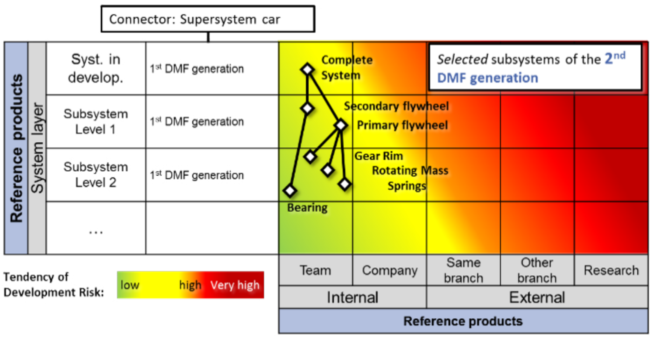

Fig. 6. Subsystems of the second DMF generation. Now the 1st DMF generation serves as a reference product on the top system level. Development risks are mostly due to the share of new development, cf. fig. 4.

4.3. Application: Development of system of objectives for a new product generation of cars

The application of the extended framework can be applied by the case of the development of the system of objectives for a new generation of cars by an OEM. The system of objectives is developed on different system levels – the complete vehicle view is the top level; the different subsystems arrange themselves on the subordinate layers. The SiD depends on the specific development task and the corresponding department.

In principle, the development of systems of objectives is done top down and typically starts with the complete vehicle view. If there are former product generations from the same model, existing product profiles need to be evolved. Therefor the previous product generation serves as basic reference product. For the initial development of objectives this reference product provides information about desired characteristics as well as specific information about the realizing subsystems. External reference products like competitors' cars also serve as reference products. They especially provide information about main differentiation targets.

The complete vehicle objectives are concretized within the different departments and development teams. The different development departments derive objectives for their disciplines from the parent objectives. For example, the development team for the breaking system needs to concretize the objective "best in class breaking performance" to requirements on their system level and their specific SiD. Often reference products from the system level above (complete vehicle) can be used to describe these objectives for the SiD (i.e. reducing breaking distance about 2% compared to previous product generation). Other reference products might be taken into account for the SiD after further investigation. For example, external reference products as core competitors (i.e. better breaking stability then core competitor X). Especially when new principle solutions are needed the scope for reference products needs to be opened out ("How did the competitor realize the breaking performance?"). With further process and the consequent target specification uncertainty is more and more reduced. For the investigation of subsystems on a module and component level reference products are handled differently. On this level precise information about technical solutions are relevant and need to be determined. For example, to improve the breaking performance in the breaking system one solution might be a variation in the surface of the breaking disk. Not all reference products provide this information. For example, there is only little or no information about the technical solution at the subsystem level of a predicted competitor. Hence, the greater the need for specific information, the lower the degree of uncertainty. Therefore, internal reference products often serve as reference products on subsystem levels.

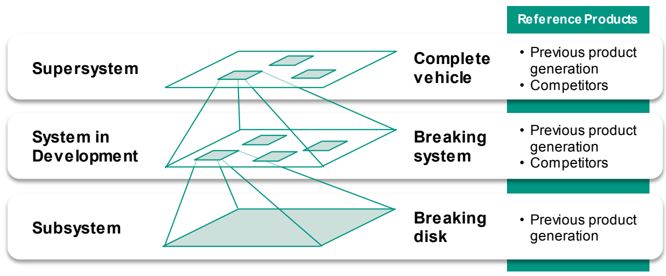

Fig. 7. Different layers and according reference products in the development of the system of objectives for a new generation of a breaking system by an OEM

In summary, the example shows that different reference products on different hierarchical levels are used in the process of target definition and that these reference products can vary over time. The example also shows, that information from higher system levels need to be analyzed and summarized in the connector. The information provided by the supersystem is a major source of uncertainty for the SiD.

5. Discussion and Outlook

Looking at fig. 3 – 6 one it becomes obvious that only the combination of all three axes gives a total risk estimation which fits to the observation of the case study. Only looking at the system level and the organizational origin of the reference product would for example lead to an underestimation of development risks. The presented framework was developed based on the case of the DMF. An investigation of more cases is necessary. The proposed approach of risk estimation is presumably done sometimes based on intuition. However, only the formal and explicit description of those relations by the presented frameworks allows for systematic methodical support and makes this approach transferable and applicable to development projects in different companies and branches. Using the framework gives hints in which cases and for what reasons an increased development risk has to be expected. Important new development activities in this cases can be about the development of new interfaces between subsystems which are taken from different reference products and are connected for the first time, for example.

Current and future works aim at a further specification of the relation between development risks and different variations and reference products in PGE. This includes the identification of the different types of variation in PGE across different system levels as well as a consistent calculation of the share of new development. Therefore corresponding methods for system analysis in PGE have to be developed, including for example the standardized definition of system levels. Furthermore there are probably more sources of development risks than described by the approaches which are considered in this contribution. This will be subject to future work as well as deriving appropriate measures to handle those risks. Quantifying these relations is probably more challenging and might be possible only for individual companies but not in a general way. In addition and as indicated before a profound risk estimation requires also to take the supersystem into account or the connector of the system in development to the supersystem, respectively. This aspect has to be investigated in future research. The process for the definition of the systems of objectives shows that the share of new development and the used reference products are determined iteratively. As changes regarding one system level affect other system levels on the one hand and as different people are often accountable for those system levels in companies it is necessary to develop process and communication models for the use of the framework continuously during the whole development process.

While analysing development risks it is important to keep in mind that chances come along with risks. Greater risks due to greater new development shares, the use of external reference products and greater changes in the system structure might be the basis for great chances leading to very successful innovative products.

The Tesla Semi is PGE because it is based on reference products. But it is the first electric semi-truck generation of Tesla, Inc. and thus lacks a reference product on the top system level. The presented framework visualizes that as a consequence development risks are presumably greater than in a conventional truck development project as there are bigger differences in the system structure compared to those from the reference products.

References

[1] https://techcrunch.com/2017/11/16/this-is-teslas-big-new-all-electric-truck-the-tesla-semi/ (15.12.2017)

[2] Hölzing, Bauer: "Die Kano-Theorie der Kundenzufriedenheitsmessung", Gabler, 2008

[3] Brown, R. "Managing the 'S' Curves of Innovation", Journal of Business & Industrial Marketing, Vol. 7 Issue: 3, 1992

[4] Ehrlenspiel, Meerkamm: "Integrierte Produktentwicklung", Hanser, 2013

[5] Lindemann, U.: "Methodische Entwicklung technischer Produkte", Springer-Verlag Berlin Heidelberg, 2009

[6] Seidel, M.: "Methodische Produktplanung", Universität Karlsruhe (TH), 2005

[7] Clarkson, j., Simons, C., Eckert, C.: "Predicting Change Propagation in Complex Design", ASME 2001 Design Engineering Technical Conferences, 2001

[8] Tyson R. Browning and Steven D. Eppinger: "Modeling Impacts of Process Architecture on Cost and Schedule Risk in Product Development", IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, VOL. 49, NO. 4, 2002

[9] Albers, A., Bursac, N., Wintergerst, E.: „Product Generation Development – Importance and Challenges from a Design Research Perspective“, In: New Developments in Mechanics and Mechanical Engineering, 2015

[10] Albers, A., Haug, F., Heitger, N., Arslan, M., Rapp, S., Bursac, N.: „Produktgenerationsentwicklung – Praxisbedarf und Fallbeispiel in der automobilen Produktentwicklung“, 12. Symposium für Vorausschau und Technologieplanung (SVT), 2016

[11] Albers, A., Gladysz, B., Heitger, N., Wilmsen, M.: „Categories of product innovations – A prospective categorization framework for innovation projects in early development phases based on empirical data“, CIRP Design 2016

[12] Peglow, N., Powelske, J., Birk, C., Albers, A., Bursac, N.: “ Systematik zur Differenzierung von Varianten im Kontext der Produktgenerationsentwicklung”, Gemeinsames Kolloquium Konstruktionstechnik 2017

[13] Albers, A., Rapp, S., Birk, C., Bursac, N.: „Die Frühe Phase der PGE – Produktgenerationsentwicklung“, Stuttgarter Symposium für Produktentwicklung (SSP), 2017

[14] Albers, A., Bursac, N., Rapp, S.: „PGE – Product Generation Engineering – Case Study of the Dual Mass Flywheel“, International Design Conference DESIGN 2016

[15] Albers, A., Sadowski, E.: „The Contact and Channel Approach ($C\&C^2$-A) - relating a system's physical structure to its functionality“,An Anthology of Theories and Models of Design : Philosophy, Approaches and Empirical Explorations, A. Chakrabarti (Ed.), pp. 151-171, 2014.

[16] Albers, A., Bursac, N., Rapp, S.: “PGE – Produktgenerationsentwicklung am Beispiel des Zweimassenschwungrads”, Forschung im Ingenieurwesen, 81 (1), pp. 13-31, 201

[17] Albers, A., Behrendt, M., Klingler, S., Matros, K.: „Verifikation und Validierung im Produktentstehungsprozess“, Handbuch Produktentwicklung, Lindemann, U. (Ed.), pp. 541-569