21ST INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED17
21-25 AUGUST 2017, THE UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, CANADA

AN APPROACH TO ANALYSE THE POTENTIAL OF TAILORED FORMING BY TRIZ REVERSE

Brockmöller, Tim; Mozgova, Iryna; Lachmayer, Roland
Leibniz Universität Hannover, Germany

Abstract

Within the "Collaborative Research Centre" 1153 a new technology called Tailored Forming (TF) is developed. With TF load adapted hybrid high performance components which consist of two different materials can be manufactured. The subproject "Configuration and design" aims to design optimized TF components to derive design guidelines. Therefore, a computer aided optimization environment is developed. To reduce the optimization time a method to determine the feasibility to develop and manufacture components by means of the TF technology is required. To determine the potential of the TF Technology the new method TRIZ Reverse, which is based upon the "Theory of Inventive Problem Solving" (TRIZ) has been created. TRIZ Reverse uses the traditional process of contradiction solving in reverse. At first it has to be analysed for which of the 40 Inventive Principles TF provides a solution. Subsequently, the contradiction matrix is reduced according to the identified principles for TF and important parameters for the optimization can be determined. This paper describes the scheme of an optimization process for the development of TF components and demonstrates the TRIZ Reverse method.

Keywords: New product development, Optimisation, TRIZ, Computational design methods

Contact:
Tim Brockmöller
Leibniz Universität Hannover
Institute of Product Development
Germany
brockmoeller@ipeg.uni-hannover.de

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 4: Design Methods and Tools, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

Companies have to develop innovative products and business models in order to respond to global competition. Continuously, advanced or new technologies for production processes are developed. Thereby, new possibilities to create innovative products are given. Accordingly, if the right time to launch novel technologies is missed, other competitors gain an advantage, which will have a negative influence on the competitive ability. However, not every advanced or new technology is useful for every kind of product (Bullinger, 2008; Brauckmann, 2015).

Within the scope of the Collaborative Research Centre (CRC) 1153 a new technology called Tailored Forming is developed. Here, different process chains for the production of hybrid high performance components are investigated. In the understanding of the CRC, hybrid high performance components are considered as load-adjusted solid components, which consist of different materials. In order to determine the fundamental potential of the Tailored Forming Technology, systematic methods are required. It is therefore the purpose of this article to demonstrate a new approach which is based on the "Theory of Inventive Problem Solving" (TRIZ) by Altschuller (1986) and is called TRIZ Reverse.

The present article is divided into seven sections. The following section two describes the Tailored Forming Technology and why the use of TRIZ Reverse is advantageous. The third section gives an overview of TRIZ with the focus on the contradiction matrix. Section four introduces the new TRIZ Reverse method. Section five describes how TRIZ Reverse can be applied at the example of Tailored Forming. The last section gives an overview of further application possibilities of the TRIZ Reverse method.

2 TAILORED FORMING

2.1 Tailored Forming Technology

Tailored Forming allows to realize components with locally adapted properties in each part of the component. Tailored Forming components are formed out of hybrid semi-finished workpieces, made of different materials. The investigated material combinations consist of various steel alloys or steel and aluminium alloys, respectively:

- Steel-Steel: C22 - 41Cr4 and C22 - X45CrSi9-3.
- Steel-Aluminium: 20MnCr5 - AW6082 and 41Cr4 - AW6082.

At the beginning of the process chain (Figure 1), two mono material workpieces are joined together by friction welding, ultrasonic aided laser beam welding or compound profile extrusion. In the next step, the semi-finished workpiece is formed either by cross-wedge rolling, extruding or die forging. After that, the hybrid solid components are heat-treated and the geometry is finished in a cutting process. Resulting, a high-performance component with locally adapted properties is available. Applications for such components are light weight constructions in particular (Behrens et al., 2016).

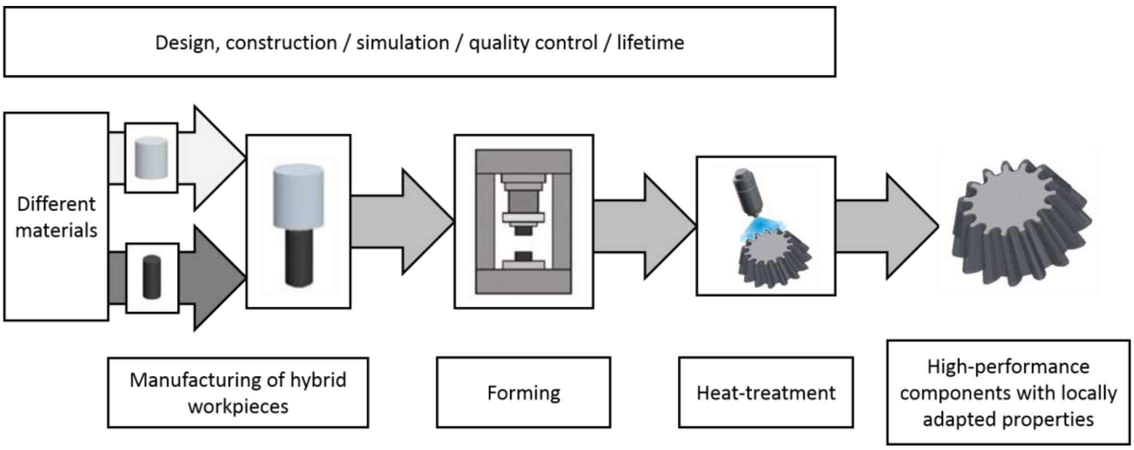

Figure 1. General process chain of Tailored Forming Technology, according to Behrens et al. (2016)

2.2 Optimization process

As depicted in Figure 1, design, construction and simulation are important parts of the Tailored Forming process chain. Within the scope of the CRC 1153, guidelines for designing Tailored Forming components are developed by analysing optimized Tailored Forming components. For the optimization, a computer aided engineering environment based on the "Generative Design Approach" (Sauthoff et al., 2014) is created. TRIZ Reverse is an additional tool to this environment. It is used in the beginning of the optimization process to preselect for which of the components the Tailored Forming technology is suitable (Figure 2).

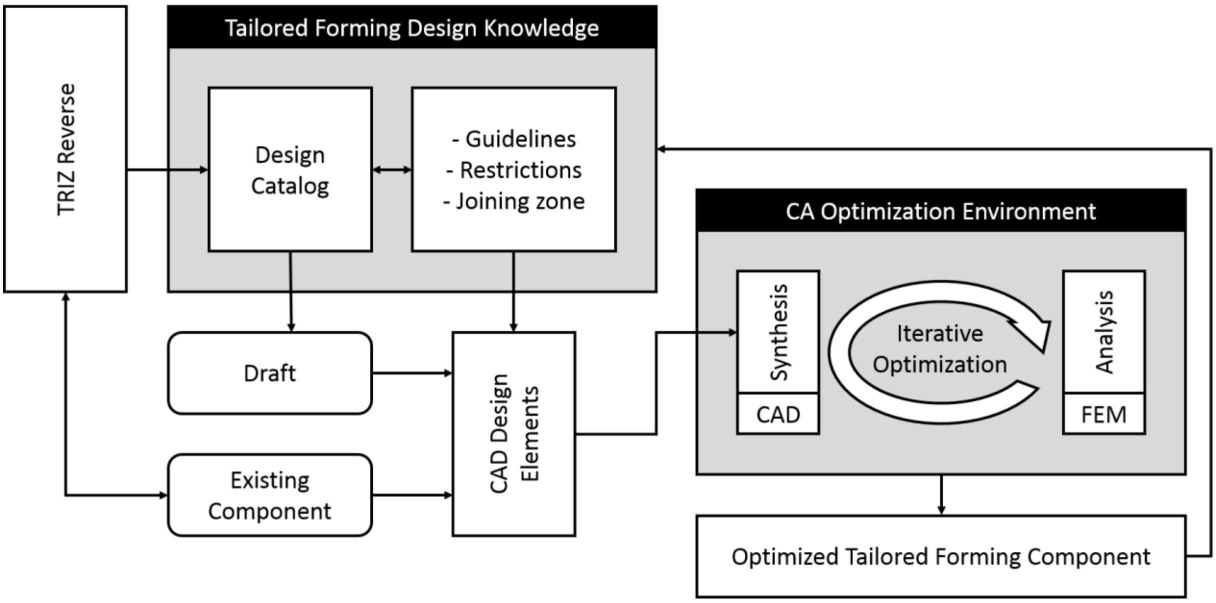

Figure 2. Computer aided environment for the optimization of Tailored Forming components

In the beginning, there are two possibilities: Either there is an existing component already or not. If there is no existing component, a draft is required. The draft is derived from the Tailored Forming design knowledge. The design knowledge consists, on the one hand of various case bases, which are provided by a design catalogue and on the other hand of guidelines, restrictions and joining zone concepts.

A case base is considered as constrains for problems/cases which have already been solved by the Tailored Forming Technology. If the requirement profile of the draft matches with a solved case, the case is used as the basis of the optimization. If none of the cases are appropriate, TRIZ Reverse is used to examine other existing components with a similar requirement profile for their Tailored Forming potential. When potential for Tailored Forming exists, these are added as additional cases to the database. To fill the empty design catalogue in the beginning, TRIZ Reverse is required. The case bases give only a rough concept. The knowledge for the detailing is formed by examined guidelines, restrictions and joining zone concepts. The guidelines describe how a Tailored Forming component has to be designed. The restrictions are mainly manufacturing restrictions, which influence the form of a component as well. The possibility to implement those restrictions in the computer aided engineering environment are described by Gembarski et al. (2016). The joining zone concepts describe the geometric form of the zone where both materials in the component merge and how the properties of the connection are translated for the computer aided engineering environment.

In the next step the derived draft is recreated by CAD design elements. Design elements are pieces of parametrized geometry and contain the knowledge of the guidelines, restrictions and joining zone concepts. They can be combined to form a 3D model of any component. The 3D model is given in to the computer aided optimization environment and iteratively optimized in consideration of defined requirements. After every iteration step, the individual design elements are varied parametrically or exchanged.

If the component already exists, TRIZ Reverse can be applied to examine whether the use of Tailored Forming is appropriate. For this case, the geometry of the component is recreated by the design elements and optimized in the computer aided optimization environment, e.g. in terms of weight. The optimized models are analysed and the gained knowledge is returned to the Tailored Forming design knowledge (e.g. as new guidelines) to be available for further tasks. Thus, the entire computer aided environment is learning with every optimization.

3 TRIZ

TRIZ was invented and developed by Genrich Altschuller between 1956 and 1985. It is a collection of methods to design innovative products in a systematic way. The knowledge for the methods is based on a research of patent specifications. Altschuller ascertained that in every patent specification, which contains an innovative solution, a contradiction of properties in an engineering system is overcome. As a result, Altschuller has developed methodological tools to identify and solve specifically contradictions in engineering systems. One of these methodological tools is the contradiction matrix in combination with the inventive principles (Koltze and Souchkov, 2011).

3.1 Contradictions and inventive principles

The contradictions in a system can be divided into engineering and physical contradictions. When the improvement of one property in a system causes the degradation of another property this is understood as the engineering contradiction. A physical contradiction exists when a parameter should have two opposed properties at the same time. For example, if the strength in a component should be improved, the weight usually increases. However, a light weight component with a high strength is intended. This is the physical contradiction and refers in this case to the amount of material. There should be as little material as possible so that the component features a light weight but at the same time sufficient material for a high strength.

The properties identified in the analysis of the patent specifications have been abstracted and generalized by Altschuller (1986). There are 39 general properties which can be used to translate any engineering contradiction.

The analysis of the patent specifications further revealed that similar solving mechanisms are always used to overcome the same engineering contradictions. These mechanisms are represented - generalized and summarized - by 40 inventive principles which provide a solution strategy for every known engineering contradiction but not a complete solution. They give only an idea how the contradiction can be solved. The quality of the solutions depends on the engineer's knowledge and experience. The physical contradictions can be solved by the four principles of separating contradictory demands (separation in time, space, upon condition and between parts and the whole) (VDI 4521, 2016). In this article, we focus on the engineering contradictions.

3.2 The contradiction matrix

The contradiction matrix (Figure 3) was created to use the inventive principles in a specific way. One or more inventive principles are assigned to every combination of properties, which describe an engineering contradiction.

Improving Parameter \ Worsening Parameter		1	2	3	…	14	…
		Weight of moving object	Weight of stationary object	Length of moving object	…	Strength	…
1	Weight of moving object			15, 8, 29, 34	…	28, 27, 18, 40	…
2	Weight of stationary object				…	28, 2, 10, 27	…
3	Length of moving object	8, 15, 29, 34			…	8, 35, 29, 34	…
…	…	…	…	…		…	…
14	Strength	1, 8, 40, 15	40, 26, 27, 1	1, 15, 8, 35	…		…
…	…	…	…	…	…	…	

Figure 3. Detail of the classical contradiction matrix, according to Altschuller (Koltze and Souchkov, 2011)

The input parameter for the contradiction matrix is one of the 39 general properties, which are called technical parameters. The improving parameters are listed vertically on the left side. The worsening parameters are listed horizontally on the top of the contradiction matrix. In the middle of the matrix, where the parameters converge numbers in the crossing fields indicate the inventive principles which are best suited to solve the contradiction. If there is no number, no engineering contradiction with this combination of parameters was found during the patent research.
The fields where the same technical parameters converge do not contain numbers as well. These are the physical contradictions, which cannot be solved with the contradiction matrix (Herb et al., 2000).

3.3 Today's use

The contradiction matrix described so far, is part of the so-called "classical TRIZ". These are the methods personally developed by Altschuller and have not been updated since 1971 (Koltze and Souchkov, 2011). In the past few years, a large number of new patent specifications has been written, so the contradiction matrix was extended by Mann and Dewulf (2003) on the basis of the new insights. This contradiction matrix contains the 40 inventive principles as well as the classical variant. However, the input parameters are rearranged and sorted in groups and the number is increased to 48. In addition, the new contradiction matrix provides at least one inventive principle for every combination of parameters (Koltze and Souchkov, 2011).
TRIZ is still used today in various fields. In the work of Albers et al. (2014), a new contradiction matrix with an independent patent specification analysis was set up for electric energy storage systems. Pokhrel et al. (2015) have extended the contradiction matrix with more specific inventive principles and properties based on an article research to develop a methodical tool for chemical process engineering. In addition, TRIZ is already used for the selection of technologies. Möhrle (2008) describes a TRIZ-based technology roadmapping.

4 TRIZ REVERSE

The combination of the terms "TRIZ" and "Reverse" is already used in the literature. This is a process in which the TRIZ algorithm is inverted and used for failure analysis and prediction, similar to the Failure Mode and Effects Analysis (FMEA) (Hipple, 2005). Glaser and Miecznik (2009) describe a TRIZ based application for reverse engineering in market research as an analogy-based strategy for new market opportunities (Glaser and Miecznik, 2009).
The TRIZ Reverse in this article is an approach based on the contradiction matrix (as of 2003) and the 40 inventive principles. For this purpose the original approach of contradiction solving is carried out in reverse order. Theoretically TRIZ Reverse can be used wherever the fundamental potential of new technologies or processes is to be determined. The reason is the fact that since Altschuller has defined the 40 inventive principles their number is constant. Although the contradiction matrix was updated in 2003 and 2010 by researching new patent specification (Mann and Dewulf, 2003; Mann et al., 2013). From this it can be concluded that the 40 inventive principles cover most of existing technologies.

At first, it is determined for which of the 40 inventive principles the examined technology provides a solution. Subsequently, the contradiction matrix is reduced to the fields in which at least one of the selected principles is a solution. Thereby, the combinations of engineering contradictions can be identified, which indicate the general application and optimization potential. Furthermore, the modified matrix can be used in the classical manner for already existing engineering systems in order to identify the potential of the technology. The further detailed elaboration also depends on the knowledge and experience of the engineer. The operating principle of TRIZ Reverse is explained in the following section by the example of Tailored Forming.

5 EXAMPLE APPLICATION FOR TRIZ REVERSE

In order to determine the application potential of the Tailored Forming Technology with TRIZ Reverse, the first step is to analyse for which of the inventive principles Tailored Forming provides a solution. The following four inventive principles have been identified:

- Principle 3: Local Quality.
- Principle 6: Universality.
- Principle 11: Cushion in Advance (Prevention).
- Principle 40: Composite Materials.

The principle of Local Quality is chosen since different materials are distributed inside a component by the Tailored Forming Technology so that the optimum properties are set in each area of the particular application.
Due to the use of different materials in a single component more functions can be integrated. For example, components can be produced from several materials, without the need to be mounted. So, Tailored Forming gives a solution for the principle of Universality.
For the principle of Prevention, a component which is exposed to a high rotation velocity is conceivable. The outer shell consists out of a material with a low density to decrease the moment of inertia. The inner core is made out of a material with a high strength. In case of a breaking shell the inner core would hold the component together.
The last identified principle, the principle of Composite Materials, is the Tailored Forming Process per se. Depending on the forming process, other inventive principle may be considered.
In the next step, the contradiction matrix is reduced by removing all the numbers that do not refer to one of the four identified inventive principles (Figure 4). Thereby, the contradiction matrix is modified and shows for which combination of parameters the Tailored Forming Technology provides a solution and for which it does not. These parameters can also be used in the optimization process.

Improving Parameter \ Worsening Parameter			physical parameters 1 Weight of moving object	2 Weight of stationary object	3 Length of moving object	...	10 Amount of substance	...
physical parameters	1	Weight of moving object		3, 40		...	40, 6	...
	2	Weight of stationary object	40			...	40	...
	3	Length of moving object				...	3	...
	...	...	...	...	...		...	...
	10	Amount of substance			3, 40	...		...
...	...	...	...	...	...	...	...	

Figure 4. Tailored Forming adapted contradiction matrix

In the following will be determined whether the Tailored Forming Technology offers the general potential to optimize an already existing solid-forming component with regard to the component properties. The considered component is a bevel gear.
The weight of the bevel gear shall be minimized on the one hand. On the other hand, the surface of the tooth flanks should have a high wear resistance. At this point there is a contradiction. If the weight needs to be reduced, less material has to be used. This can only be realised if the geometry of the component is changed fundamentally, e.g. by reducing the width of the bevel gear. However, this would reduce the rolling surface for tooth engagement, which leads to an increased wear. Another possibility for weight reduction is to change the material. For a material of lower density, e.g. Aluminium, the geometry of the bevel gear could be maintained. Here, the tooth flanks cannot be hardened, which also leads to increased wear.
In order to check whether the Tailored Forming Technology features a sufficient potential and the identified contradiction can be solved, the properties have to be translated into the input parameters of the modified contradiction matrix. The reduction of the weight is the property to be improved and is translated into the parameter "weight of a moving object". Increased wear is the worsening property and is translated into the parameter "Amount of substance". In the field of the contradiction matrix where

both parameters meet, a reference is made to the inventive principles No. 6 (Universality) and No. 40 (Composite Materials). So the Tailored Forming Technology is capable to solve the contradiction.

Figure 5. Bevel Gear; inner part aluminium, outer part steel

A conceivable concept contains an inner part made of aluminium to reduce the weight and an outer part out of a steel that can be hardened. In Figure 5, one of the demonstrators from the CRC 1153 is presented. It gives an idea how a bevel gear can be designed by using the Tailored Forming Technology.

6 CONCLUSION

With TRIZ Reverse an approach has been created to determine the potential of the Tailored Forming Technology. It can be applied to determine for which combinations of contradictions Tailored Forming provides a solution and which properties can be optimized in an already existing component.

The favourable use of the TRIZ Reverse approach is in the beginning of the product development process, since the general potential can be determined and the modified contradiction matrix can be used in the classical approach afterwards.

Possible further steps would include to check whether TRIZ Reverse can also be applied to other new or existing technologies. One example would be the work of Lippert and Lachmayer (2016), in which different bionic inspired infill structures for components made by selective laser melting are analysed. In such a manner it is possible to decrease the weight of components and simultaneously keep their strength. Thus, the technology has the ability to solve contradictions and the application of TRIZ Reverse is conceivable. For which inventive principles a solution is provided is subject of further investigation.

REFERENCES

Albers, A., Wagner, D., Kern, L. and Höfler, T. (2014), "Adaption of the TRIZ method to the development of electric energy storage systems", *24th CIRP Design Conference Mass Customization and Personalization*, Milan, April 14th-16th, Elsevier, Amsterdam, pp. 509-514. http://dx.doi.org/10.1016/j.procir.2014.02.060

Altschuller, G.S. (1986), *Erfinden - Wege zur Lösung technischer Probleme*, VEB Verlag Technik, Berlin.

Behrens, B.-A., Bouguecha, A., Frischkorn, C., Huskic, A., Stakhieva, A. and Duran, D. (2016), "Tailored Forming Technology for Three Dimensional Components: Approaches to Heating and Forming", *5th Conference on Thermomechanical Processing*, Milan, Italy, October 26th-28th.

Brauckmann, O. (2015), *Smart Production - Wertschöpfung durch Geschäftsmodelle*, Springer Verlag, Berlin Heidelberg.

Bullinger, H.-J. (2008), *Fokus Technologie - Chancen erkennen Leistungen entwickeln*, Carl Hanser Verlag, Munich.

Gembarski, P.C., Sauthoff, B., Brockmöller, T. and Lachmayer, R. (2016), "Operationalization of Manufacturing Restrictions for CAD and KBE-Systems", *14th International Design Conference - Design 2016*, Dubrovnik, Croatia, May 16th-19th, The Design Society, In: Proceedings of the Design 2016 - Vol.2: Design Support Tools, pp. 621-630.

Glaser, M. and Miecznik, B. (2009), " TRIZ for Reverse Inventing in Market Research: A Case Study from WITTENSTEIN AG, Identifying New Areas of Application of a Core Technology", *Creativity and Innovation Management*, Vol. 18, No. 2, pp. 90-100. http://doi.org/ 10.1111/j.1467-8691.2009.00516.x
Herb, R., Herb, T. and Kohnhauser, V. (2000), *TRIZ - Der systematische Weg zur Innovation*, Verlag Moderne Industrie, Landsberg am Lech.
Hipple, J. (2005)," The Integration of TRIZ with other Ideation Tools and Process as well as with Psychological Assessment Tools", *Creativity and Innovation Management*, Vol. 14, No. 1, pp. 22-33.
Koltze, K. and Souchkov, V. (2011), *Systematische Innovation - TRIZ-Anwendung in der Produkt- und Prozessentwicklung*, Carl Hanser Verlag, Munich.
Lippert, R.B. and Lachmayer, R. (2016), "Bionic inspired infill Structures for a light-weight Design by using SLM", *DS 84: Proceedings of the Design 2016 14th International Design Conference*, May 16th-19th, Dubrovnik, Croatia.
Mann, D. and Dewulf, S. (2003), "Updating the contradiction matrix", TRIZCON 2003, Philadelphia.
Mann, D., Nähler, H.T. (Ed.), Gronauer, B. (Ed.) and Gundlach, C. (Ed.) (2013), "Matrix 2010 - Re-Update der TRIZ Widerspruchsmatrix", c4pi - Center for Product-Innovation, Wennigsen, Deister.
Möhrle, M.G. (2008), "TRIZ-basiertes Technologie-Roadmapping", In: Möhrle, M.G. and Isenmann, R. (Ed.), *Technologie-Roadmapping*, Springer-Verlag, Berlin, Heidelberg, pp.189-207, http://doi.org/ 10.1007/978-3-540-74755-0
Pokhrel, C., Cruz, C., Ramirez, Y. and Kraslawski, A. (2015), "Adaption of TRIZ contradiction matrix for solving problems in process engineering", *Chemical Engineering Research and Design*, Vol. 103, pp. 3-10, http://dx.doi.org/10.1016/j.cherd.2015.10.012
Sauthoff, B., Gembarski, P.C., Lachmayer, R. (2014), "Der "Generative Design Approach" im Kontext von technischer Konfiguration", *DfX 2014: Proceedings of the 24th Symposium Design for X*, October 1st-2nd, Bamberg, Germany.
VDI 4521 (2016), *Inventive problem solving with TRIZ - Fundamentals, terms and definitions*, Beuth Verlag, Berlin.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support from the Collaborative Research Centre (CRC) 1153 “Process Chain for Manufacturing Hybrid High Performance Components by Tailored Forming”, funded by the German Research Foundation (DFG). The authors would further like to thank all participants of the CRC for their support, encouragement and implementation of various ideas.