NordDesign 2008
August 21 – 23, 2008
Tallinn, Estonia

Systematic Generation of Innovative Sheet Metal Profiles using Modified TRIZ

Hirsch, Nils; Mauf, Markus; Birkhofer, Herbert
Technische Universität Darmstadt
Product Development and Machine Elements
Magdalenenstrasse 4
64287 Darmstadt
GERMANY
hirsch@pmd.tu-darmstadt.de

Abstract
This paper presents an approach to the derivation of new customer requirements and applications of sheet metal products produced in an integral style by the new forming technique Linear Flow Splitting. The approach developed here, based on the TRIZ methodology [1], aims to generate new applications and requirements in a systematic way.
Technological Findings from the production processes and the evaluation of the profiles, such as structural and materials testing, have great influence on sheet metal products and their properties. In order to apply our approach, an analysis is first required, namely of particular profile properties induced by the new forming techniques, e.g. a different distribution of the micro hardness [2]. Based on this analysis, the Conflict Matrix [3] is modified by examining the interaction between the technical conflicts and the particular product properties. The resulting Conflict Matrix consists of 19 System Features and 40 Innovative Principles which are associated distinctly with the particular product properties. Furthermore, the Innovative Principles are systematically applied to the profile properties to serve as an idea generator. Both the Innovative Principles and the modified Conflict Matrix are integrated into a new method using the MindManager software to generate new applications for the sheet metal profiles. This is done in creative group sessions as a first step in the approach.

Keywords: TRIZ, Innovation, Sheet Metal Profiles, Properties.

1 Introduction
Recently, a new sheet metal forming technique, called Linear Flow Splitting, has been developed [4]. Linear Flow Splitting allows for the production of multi-chambered structures with thin-walled cross-sections and is used in combination with traditional techniques, such as roll-forming processes and joining techniques. Sheet metal profiles manufactured in integral style by this new manufacturing process are highly suitable for technology-driven development of (yet not-customer- or market demanded) new products because of various particular properties induced in the profiles during the manufacturing process, e.g. a different distribution of the micro hardness and a smooth surface finish [2]. This so-called “technology-push” approach [5] will be used especially to achieve unique selling points and

competitive advantages among manufacturers. The focus of our research is detecting the influence of Technological Findings, i.e., data and results from the evaluation of the manufacturing processes and the developed profiles, regarding the continuous manufacturing line in the design process of sheet metal profiles. The particular profile properties described by the Technological Findings provide a base, on which a methodology can be developed in order to systematically derive potentials for the fulfilment of customer- and market-expectations and also to find new fields of application [6]. Such a methodology necessitates a transformation chain from the particular properties of a sheet metal profile manufactured in integral style to new applications of these profiles. One approach for this transformation described in [7] is, based on the product model pyramid is described. In the following, this problem is addressed by using the TRIZ methodology [1] to model the transformation chain by implicating the particular profile properties and e.g. the features of the contradiction matrix.

This paper is structured as follows. The following section 2 presents the Linear Flow Splitting Process and the continuous manufacturing line. Section 3 describes the profile properties induced by the continuous manufacturing line. In section 4 the TRIZ methodology is presented with the methods relevant to this approach. Finally, section 5 concludes the paper with the modification of the methods „System Conflicts“ and „Substance Field Analysis“ and their application with some examples of innovative profiles.

2 The Principle of Linear Flow Splitting and the continuous manufacturing line

Linear Flow Splitting enables the forming of bifurcated profiles made of sheet metal in integral style without joining, laminating or heating the semi-finished part. This part is plain sheet metal, which is transformed at ambient temperature by a specific tooling system, which increases the surface of the band edge using obtuse-angled splitting rolls and supporting rolls (Figure 1). These rolls induce enormous hydrostatic compressive stresses in the local forming zone during the process [8]. Due to these compressive stresses, the formability of the material increases, which allows for the realization of large strains. The moving, semi-finished part is formed by the tool system in discrete steps into a profile with the final shape (Figure 1). The bifurcated profile consists of a web and two flanges. The surface beneath the splitting roll is defined as the upper side. According to the “DIN 8580 et sqq. classification”, Linear Flow Splitting is classified as a forming procedure under compressive stress and is assigned to the class “lengthwise roll forming of full bodies” (DIN 8583, 2003).[9] The bifurcations are caused by a surface enlargement of the sheet metal’s band edge during the forming process and form a profile containing two flanges and a web at each side of the sheet metal. The surface beneath the splitting roll is defined as the upper side of the flange (Figure 1) [10].

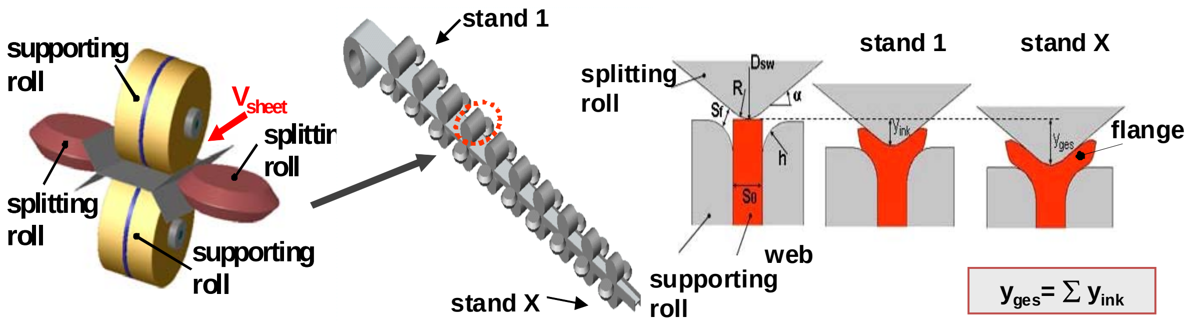

Figure 1. Principle of Linear Flow Splitting

In the future, a Linear Bend Splitting tool system for creating flanges directly out of the sheet metal (and not by enlarging the surface of the band edge) will be added. The Linear Bend splitting enables higher order bifurcations and enlarges the scope for the design of profiles. Using roll forming, following the Linear Flow Splitting Process, new multi-chambered structures can be realized with thin walled cross-sections.

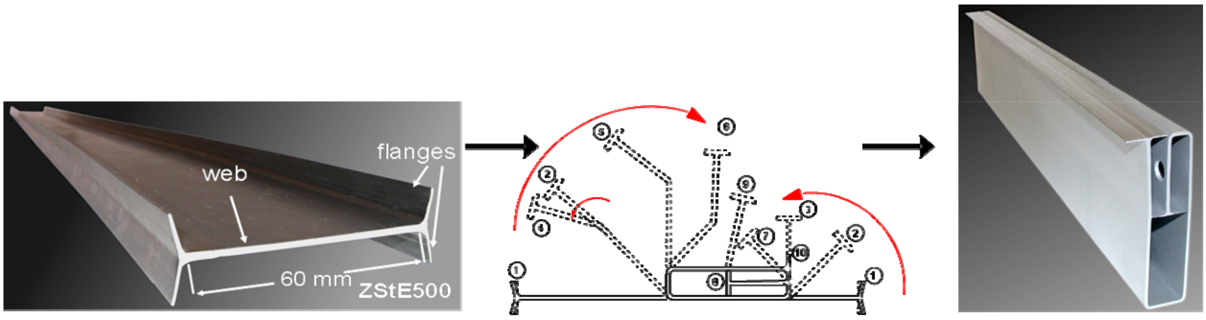

Figure 2. Sample profile

Figure 2 shows the manufacturing steps of a profile with one free flange and three chambers with integrated bore holes inside the chamber [11]. Starting with the Linear Flow Splitting Process, the bifurcated double y-profile is generated followed by bending and welding steps illustrated in a flower pattern. To produce these multi-chambered profiles, a continuous production line is established. It consists of several Linear Flow Splitting tool systems and roll forming tool systems in one production line (Figure 3). In addition to the Linear Flow Splitting for realizing bifurcations, a high speed cutting tool is integrated in the continuous manufacturing line for placing dimensional elements, like drillings and gashes, into the moving semi-finished parts [12]. A laser welding tool is used to close the profile where necessary. The different tool systems of the manufacturing line can be arranged in an arbitrary order. Thus, the possible number of different cross sections is enlarged. Besides the higher geometrical flexibility in the design of cross sections, it even becomes possible to place dimensional elements in internal walls during the manufacturing process by placing the high speed cutting tool at the front of the manufacting line.

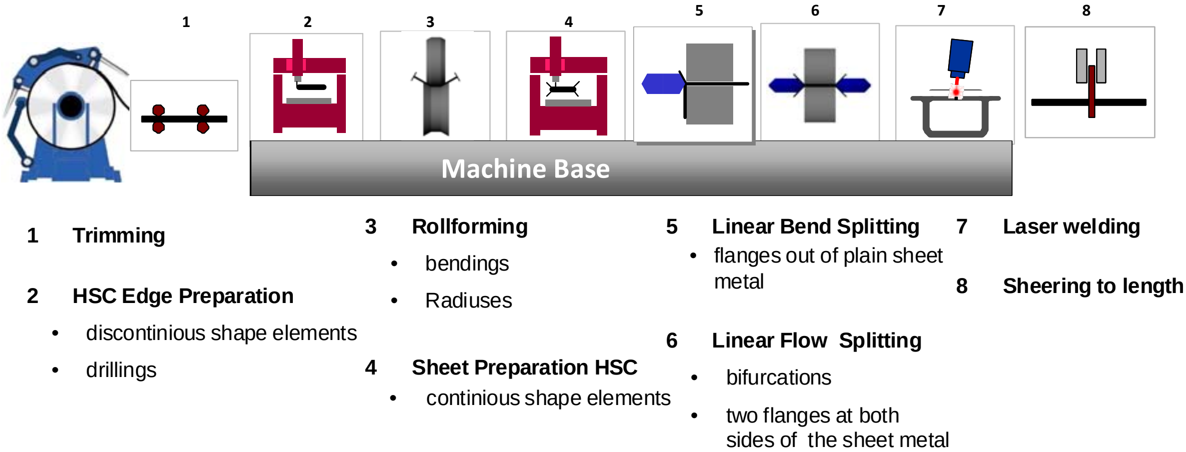

Figure 3. Continuous manufacturing line

All these manufacturing processes influence the properties of the produced profiles and lead to considerable changes in local material properties in the case of Linear Flow Splitting, as in the distribution of the micro hardness and tensile strength. In the approach described in this paper, these particular properties are the starting point for the systematic derivation of new applications for the profiles. In the following section, only the properties are described, which differ from properties of profiles manufactured in a conventional manner e.g. by bar extrusion.

3 Particular Profile Properties

In contrast to bar extrusion, the continuous manufacturing line is able to process sheet metal consisting of high-tensile steel. In addition, unlike pure roll forming, the Linear Flow Split profiles have no laminations. These two properties make the profiles suitable for light weight design. Creating flanges (Figure 1) out of the band edge (Linear Flow Splitting) or the plain sheet metal (Linear Bend Splitting) provides the opportunity to design complex cross sections with less joining. The profiles produced are characterized by increased stiffness, high surface hardness and low surface roughness on the upper side of the flanges of the bifurcated object [13]. Linear Flow Splitting leads to a smooth surface with mean roughness values Ra of about 0.1–0.2 µm at the upper side of the flanges and Ra = 0,05 – 0,1 µm in the splitting center (radius) (StW22) [10]. For high-tensile steel ZStE500, the roughness values are lower by a factor of at least 2, compared to the surface of the rolled sheet metal material [2]. The high surface quality results in a lower friction coefficient and better tribological characteristics. Furthermore the profile has a higher reflexivity at the upper side of the flanges. A closer look at the microstructure reveals a strong deformation in both the splitting centre and the split surface. The micrograph shows a banded structure along the flow lines parallel to the surface, but single grains are not distinguishable (Figure 4). These highly deformed zones that are not resolvable by light microscopy show an UFG microstructure with grain dimensions in the nm-scale [2].The microstructure of the web is non-deformed, like the as received sheet material´ s microstructure.

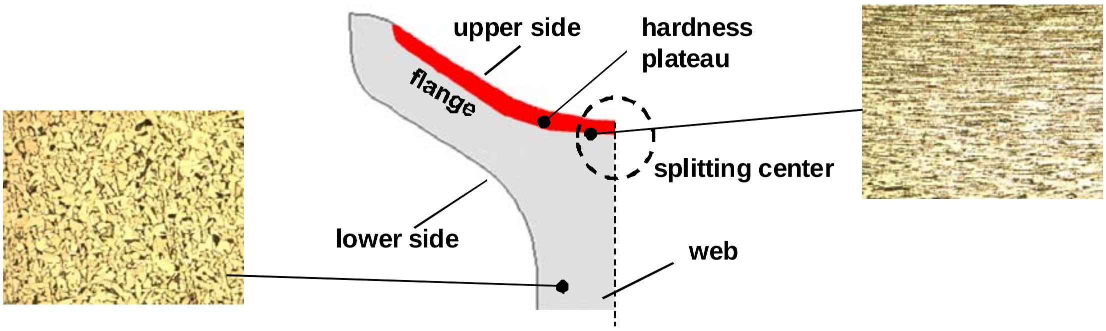

Figure 4. Microstructure of Linear Flow Split profile [8]

The hardness at the upper side of the flanges of the Linear Flow Split Profile increases up to 100 % (steel ZStE500). This corresponds to a strain hardening in the contact area of the splitting roll radius. The hardness of the non-deformed sheet material averages 196 HV0,05. At the surface the highest hardness was measured at 365 HV0,05 [2]. The hardness along the surface of the flanges is constant from the splitting centre towards the flange tips and represents a hardness plateau. The lower side of the flange as well as the contact area of the supporting rolls show non- or only slightly deformed structures. The Linear Flow Split Profile has a sharp gradient in the hardness from the splitting centre to the web. From here, a decrease of the micro hardness is recognizable in inner work piece areas, as well as in the flange end [8]. Tensile tests show that Linear Flow Splitting leads to a remarkable increase in yield strength from 476 MPa to 787 MPa [2]. The cyclic material properties differ between the strain hardened flange material and the material from non-deformed sheets. Tests with steel sheet material ZStE500 show that the cyclic yield strength R’p0.2 increases by 54%, the applicable strain amplitude in the high cycle fatigue (HCF) area increases by approx. 50%. The difference of applicable strain amplitudes in the low cycle fatigue (LCF) area is less significant [2]. These results imply that the deformation of microstructure during the forming process significantly affects cyclic material properties and the cyclic material properties vary considerably throughout the cross section of the component. The manufacturing process Linear Flow Splitting induces significant residual stresses in the profile [13]. In comparison to e.g. the bar extrusion process, a moving high speed cutting tool integrated in the continuous manufacturing line allows for placing dimensional elements like drillings, gashes and surface textures even in internal walls (section 2) in any orientation to the feed direction of the sheet metal.

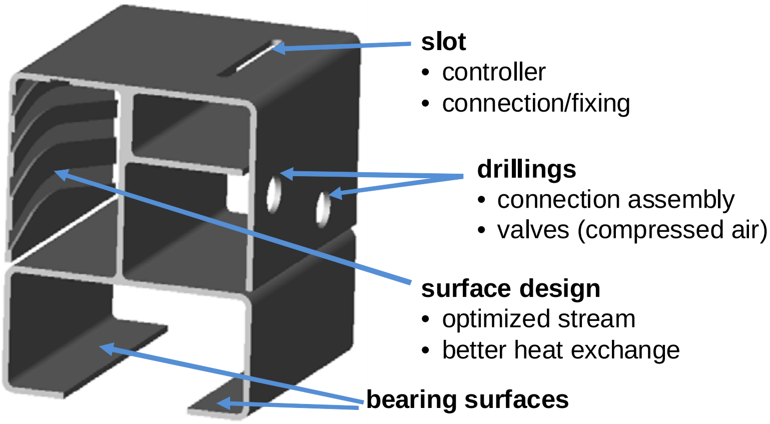

Figure 5. Profile sample with applications

Figure 5 shows a profile with three closed and one open chamber, integrated slots, drillings and milled surface texture, and conceivable applications for these dimensional elements. The objective of our approach is to derive such applications. In the following, the basis methodology TRIZ is described.

4 TRIZ

TRIZ was developed by the Russian patent expert Genrich Saulowitch Altschuler 50 years ago and has since then been continually enhanced. TRIZ is also known as TIPS "Theory of Inventive Problem Solving" [14]. TRIZ doesn't solve problems like the classic creativity techniques, but according to a system of certain rules and principles. In doing so, TRIZ combines several classic problem solving methods with the objective of solving technical and scientific conflicts. Basically, TRIZ consists of two main approaches. The first uses experiences for problem solving based on an investigation of more than 40.000 patents. From these, Altschuller derived the generally applicable 40 Inventive Principles. The second one is comprised of contradiction oriented logic. The contradiction oriented logic acts on the asumption that inconsistencies in the requirement of a system, e.g. hot and cold, are not solvable by finding an optimum, but by the full integration of the antipods in the system. For Altschuller the contradiction is the central innovation generating element.

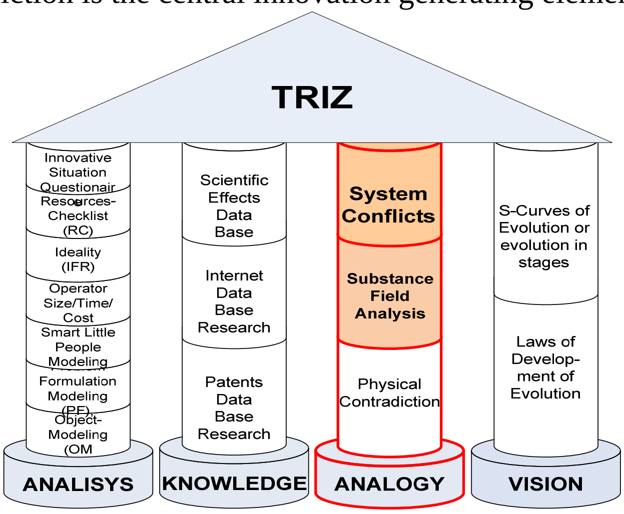

Figure 6. TRIZ tools

5 Approach of modified TRIZ

The TRIZ methodology consists of four tool groups called TRIZ-columns (Analysis, Knowledge, Analogy and Vision) (Figure 6). To derive innovations for profiles manufactured in integral style, this paper only mentions tools from the column analogy. The column “Analysis“ essentially contains tools for analyzing the present problem. In our approach, the problem needs to be found and does not exist at the starting point. The tools of the column “Knowledge” are mainly useful for the research of physical effects using sources like the Internet or databases. These methods are not suitable for reverse attainment of new applications due to the fact that they aren´t provided in a design context. It is conceivable to use these methods within the “Product Model Pyramid”, delivering the design context. The tool “S-Curve” in the column “Vision” ranks the product in its life-cycle and the tool “Laws of Evolution” could be used to confirm that sheet metal profiles manufactured in integral style have a higher grade of evolution than the common ones, but neither is useful for deriving new applications.

The column “Analogy“ is the core of the theory and contains the potent tools “System Conflicts”, “Substance Field Analysis”, and “Physical Contradiction”. All these methods are subject to the principle of analogy, since solutions of technical problems are always based on the same, persevering principles. *„Somebody someplace has already solved this problem (or one very similar to it.)“*[1] The method “Physical Contradiction” appears to be too abstract for deriving new applications from profile properties, since the detection of the physical contradiction is troublesome and the Separation Principles are even more abstract than the 40 innovation principles. The first two methods of the “Analogy“ column are suitable for generating new application but it is necessary to modify them. Our approach uses a modified version of “System Conflicts Tool” which is described in the following section. A modification of „Substance Field Analysis” is discussed at the end of this paper.

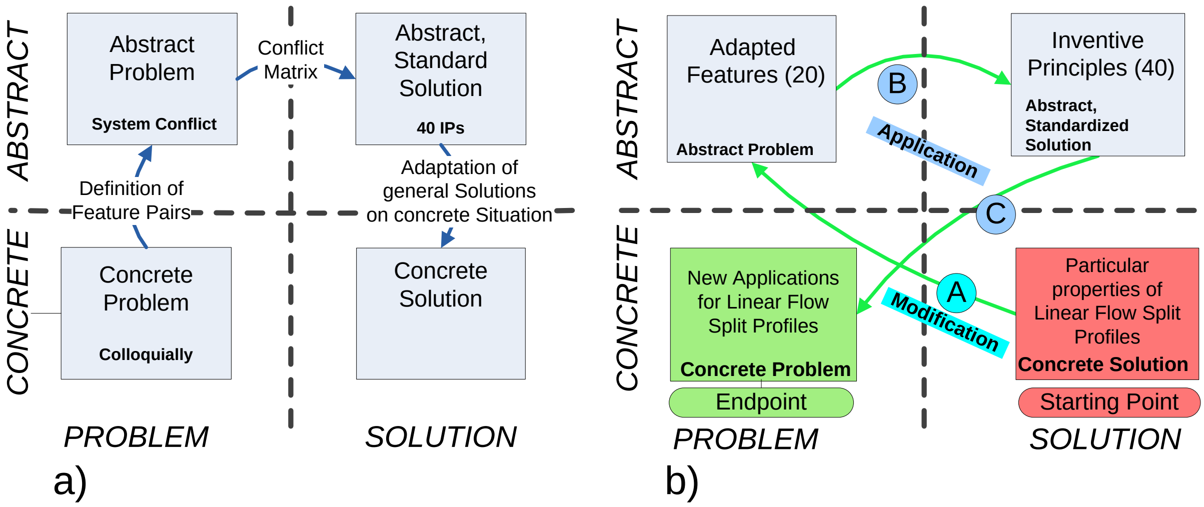

Figure 7. Common (a) and modified problem solving process based on the System Conflicts

A concrete, colloquially formulated problem, defined within the column “Analysis”, is abstracted to a conflict between two of the 39 features (Figure 7a). Nearly all technical problems can be ascribed to these 39 features developed by Altschuller based on a patent search [16]. The conflict is formulated in the basic form, in that an amelioration of one parameter causes a deterioration of the other one. Such as: “*By ameliorating feature X*

[1] http://www.mindtools.com/pages/article/newCT_92.htm last access on 20.04.2008

(desired), Parameter Y is deteriorating (unwanted)" An augmentation of the speed of a vehicle increases the risk of an accident caused by a burst tire. If the speed is increased (feature no. 9), the reliability (feature no. 27) decreases. For further information see [17,18]. The problem described in such a manner is now solved by a set of Inventive Principles defined by the conflict matrix. The rows contain the features to be improved, the columns contain the deteriorating ones. The intersection cell shows four most frequently Inventive Principles used in the past for solving the same conflict. In the last step, the solutions derived are adapted to the original problem. As mentioned before, the procedure of the analogy tools is not applicable for deriving new applications for sheet metal profiles without modifications. The problems to be solved are unknown, but the solution must contain sheet metal profiles. So the main task is to detect problems having the solution: a profile. The starting point of this search is the set of particular properties described in section 2.

The first modification of the TRIZ tool System Conflicts is to invert the starting and the ending point of the procedure (Figure 7b). The endpoint of the common problem solving process, the sheet metal profiles with their particular properties, become the starting point. In short: **Problems and Conflicts solvable with integral sheet metal profiles are sought. These conflicts serve to provoke ideas for new applications.**

Figure 7b illustrates the procedure proposed with our approach. In the first step, a choice of the suitable features is carried out (step A). Here suitable means the ones "influenced by the particular properties of the profiles". The use of all features would generate new applications for any technical system (according to the intention of TRIZ) and not only for profiles. The adaption was carried out by checking the influence of each profile property (section 2) with each of the 39 features of the conflict matrix. The resulting conflict matrix consists of 20 features. Table 1 shows an example of the connection between the particular profile properties and the features defined by Altschuller.

Table 1: Example of the feature 12 "Form"

Feature 12 Form
Sheet metal profiles manufactured in integral style differ from conventional manufactured profiles concerning **bifurcations (flexible design of cross sections)** and **dimensional features** generated by HSC.

The features are (as in conventional TRIZ) linked with the 40 Inventive Principles by the New Conflict Matrix (B) containing only the suitable features of step A described in Figure 7. An adaptation of the Inventive Principles isn´t reasonable, since testing in creative sessions has shown that all inventive principles are able to generate innovative ideas concerning the profiles. As a result a database with more than 100 application ideas for all the 40 Inventive Principles is integrated in the new approach as an idea generator at step C of Figure 7. Table 2 illustrates the Inventive Principle "Local quality":

Table 2: Example for the Inventive Principle "Local Quality"

• not the hole flange is strain hardened, gradient of micro hardness; distribution of micro hardness
• ductile web has other function as the hard flange, tribological differences, different reflection properties; different material thickness, different stiffness, form defines function.
• generating micro turbulences by surface structure
• function: to reinforce, to conduct
• coatings (powder, varnish) adheres better/worse on upper side of the flanges
• chemical reactions commence with different speeds in different profile sections

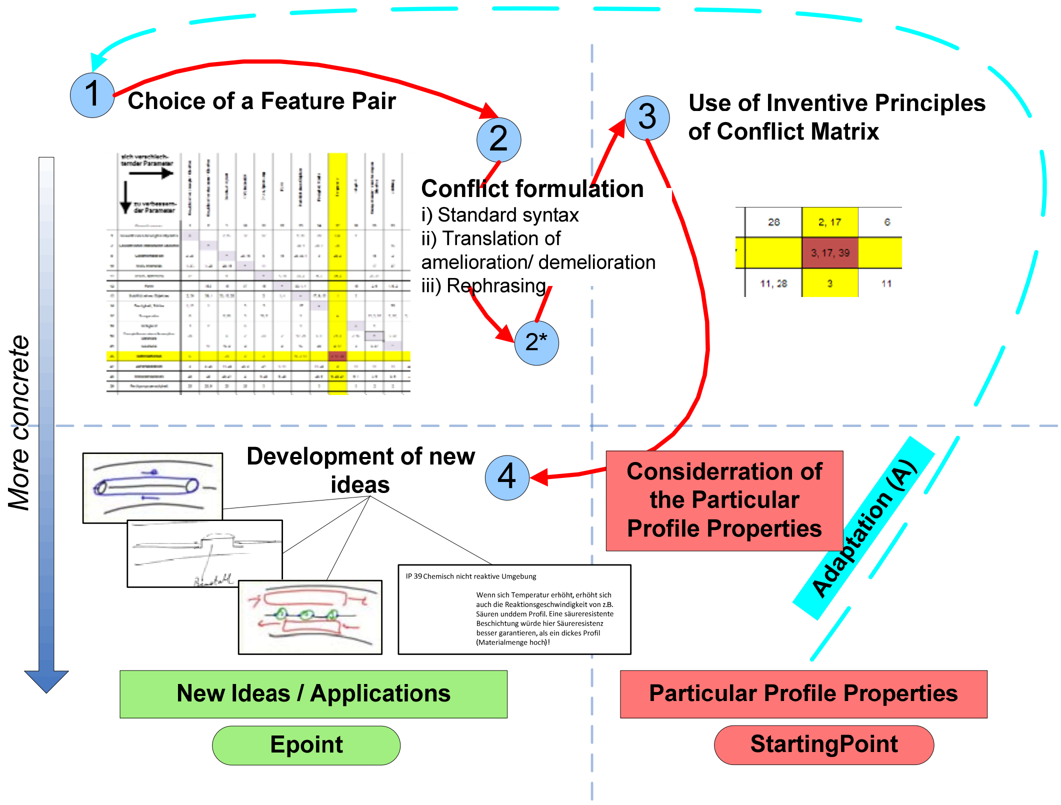

Figure 8. Procedure of application of the modified System Conflicts´ method

Figure 8 shows the application procedure of the modified System Conflicts´ method (step B and C in Figure 7) to generate new applications. In the first step, two adapted features are chosen. In the second step, the conflict is formulated gradually, starting with the standard syntax (if feature X ameliorates, feature Y becomes worse). Finding a suitable formulation is significant for the next steps. First, the user can decide which feature is the ameliorating and which the deteriorating one. Often the standard syntax is too abstract to permit a clear comprehension of the conflict. This understanding, though, is essential for applying the Inventive Principles to derive new applications. Therefore, it is recommendable to substitute the adjectives of the standard syntax by others, e.g. “ameliorate the weight” can mean “enhance the weight”. The final formulated conflict is then solved by application of the 40 Inventive Principles, considering the particular properties of the profiles. This process is supported by sample solutions for each of the 40 Inventive Principles. The solutions are new types of profiles with respective new applications.

Figure 9 shows an example of the modified TRIZ method, applied in a creative group session for one conflict pair (temperature and weight), using the software MindManager 7.0 from Mindjet. The session presented here results in over 30 ideas for new applications of differing quality for this conflict pair. The System Conflict in standard syntax is “if the weight of an moving/stationary object ameliorates, the temperature becomes worse” and after rephrasing: ”By reducing the weight/mass(desired), the temperature of the object raises for a given heat quantity(undesired)” (step 1 and 2 described in both Figure 8 and 9).

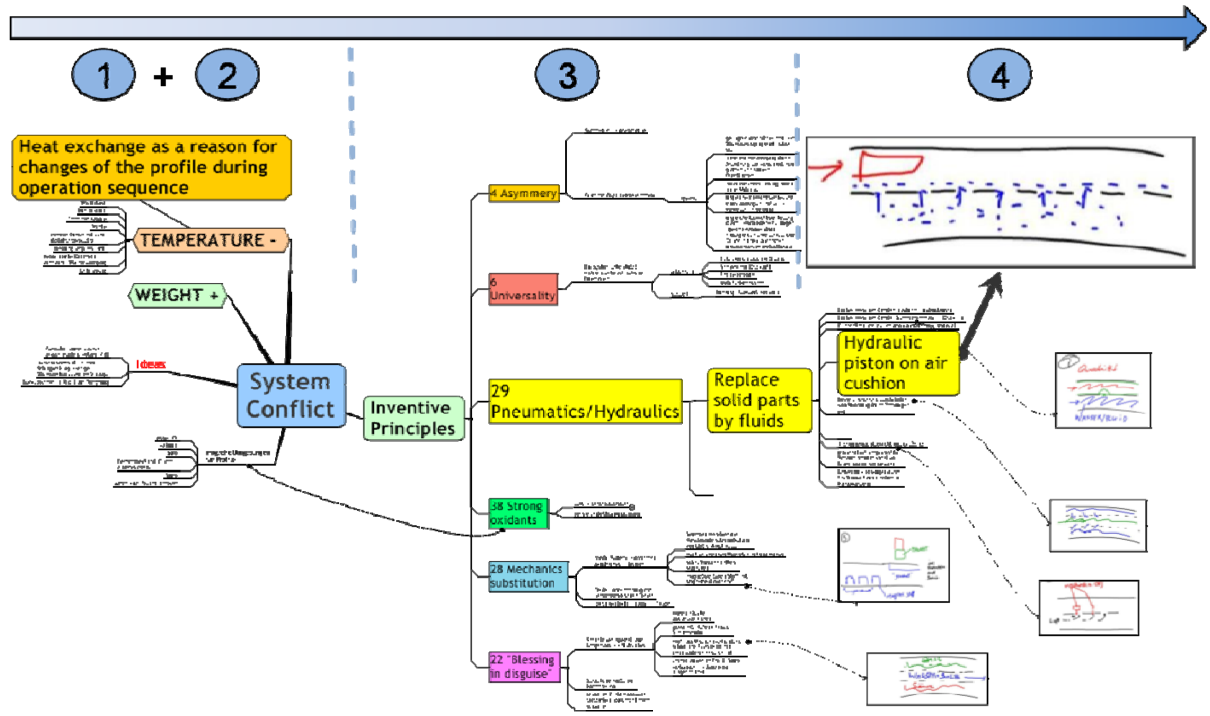

Figure 9. Example in MindManager

The modified contradiction matrix leads to a set of Innovative Principles located in the intersection cell of the feature weight (row) and temperature (column) e.g. Pneumatics and Hydraulics (step 3 of Figure 8 and Figure 9). This principle suggests to replace solid parts by fluids. In conjunction with the idea generator database for each Innovative Principle, one solution is to realize a profile with at least two chambers (step 4 of Figure 8 and Figure 9). One filled with compressed air and another to guide a piston. The wall between these two channels is perforated by High Speed Cutting. The compressed air passes through the holes and the piston is sliding on an air cushion with strongly reduced friction. The profile can be used for pneumatic delivery for example. This example shows how the modified System Conflict Tool guides the members of the creative session groups to a great number of new applications for the profiles. The tool was applied to a couple of promising conflict pairs.

6 Conclusion and Future Work

The developed method, based on the System Conflict tool of the methodology TRIZ, derives new applications for sheet metal profiles manufactured in integral style. The approach presented leads to interesting profiles using the special features of the continuous manufacturing line. The method demands an intensive preparation of the users in order to grasp the knowledge concerning the manufacturing process, the profiles and their properties, before starting the creative session.

The next step toward a powerful method requires a systematic application of all conflict pairs by experienced users. The generated solutions can serve as a demonstrative introduction for newcomers. Furthermore, the method should be implemented in software in order to save the solutions and to optimize the procedure. Substance Field Analysis is a suitable TRIZ tool for generating innovative applications for Linear Flow Split Profiles. Within this tool a normalized system is modeled, consisting of substances, fields and their relations, and this so called “Substance Field Model” is then solved by application of 76 Standard Solutions [14]. In future the Substance Field Analysis will be modifiable by using the particular profile properties as starting point and the “Seven Generalized Standard Solutions“ [19].

References

[1] Rantanen, K., Domb, E., “Simplified TRIZ“, Auerbach Publications, Boca Raton, 2002.

[2] Müller, C., Bohn, T., Bruder, E., Bruder, T., Landersheim, V., el Dsoki, C., Groche, P., Veleva, D. „Severe Plastic Deformation by Linear Flow Splitting“, Materialwissenschaft und Werkstofftechnik, 38(10), 2007, pp. 842-854.

[3] Bläsing, J., Brunner, W., „*Workbook TRIZ“*. TQU Verlag, Ulm, 2000.

[4] Groche, P., v. Breitenbach, G., Jöckel, M., Zettler, A., "New Tooling Concepts for the Future Roll Forming Applications", ICIT Conference, Bled, 2003.

[5] Specht, G., Beckmann, C., „F&E-Management“, Schäffer-Poeschel Verlag, Stuttgart, 1996.

[6] Birkhofer, H., Martin, A., Ulbrich, S., Wäldele, M. et Al., "Topology- and Shape-optimization of Branched Sheet Metal Products", In print in: H. Kopfer (Ed.), Operations Research Proceedings 2006, Springer-Verlag, Berlin, 2006, pp. 327 – 336.

[7] Hirsch, N., Birkhofer, H., “Technologische Erkenntnisse als Grundlage für Produktoptimierung und Ableitung von Innovationspotentialen“ In: Sonder-forschungsbereich 666: Integrale Blechbauweisen höherer Verzweigungsordnung - Entwicklung, Fertigung, Bewertung, P. Groche (Ed.), Meisenbach Verlag, Bamberg, 2007, pp. 119 - 124.

[8] Groche, P., Vucic, D, “Multi-chambered Profiles made from High-strength Sheets”, Production Engineering, Annals of the WGP, Vol. XIII/1, Hannover, 2006, pp. 67-70.

[9] Hirsch, N, Birkhofer, H, Landersheim, V., Hanselka, H., Günther, U., Martin, A., “Ontology-Based Approach to Transform Fatigue Properties of Branched Sheet Metal Products for Use in Algorithm-Based Product Development””, Proceedings of the ASME 2008 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Brooklyn, New York, August 3-6, 2008.

[10] Groche, P., Vucic, D., Jöckel, M., , “Basics of Linear Flow Splitting”, Journal of Materials Processing Technology, 183(2-3), 2007, pp. 249-255.

[11] Wäldele, M., Vucic, D., Birkhofer, H., “A New Manufacturing Process as the Seed for an Algorithm-based Product Design in the Early Phases”, NordDesign2006, Reykjavik, 2006.

[12] Wäldele, M., Hirsch, N., Birkhofer, H.,“ Providing Properties for the Optimization of Branched Sheet Metal Products“, ICED07, Paris, 2007.

[13] Veleva, D., Landersheim, V., Groche, P., Bruder, T., Hanselka, “Rechnerunterstützte Prozesskettenanalyse zur Herstellung von Spaltprofilen und numerischen Bewertung ihrer Schwingfestigkeit“ In: Sonderforschungsbereich 666: Integrale Blechbauweisen höherer Verzweigungsordnung - Entwicklung, Fertigung, Bewertung, P. Groche (Ed.), Meisenbach Verlag, Bamberg, 2007, pp. 109 - 118.

[14] Herb, R., Herb, T., Kohnhauser, V. „TRIZ - der systematische Weg zur Innovation : Werkzeuge, Praxisbeispiele, Schritt-für-Schritt“, Verlag Moderne Industrie, Landsberg/Lech, 2000.

[16] Bläsing, J. P., Brunner, W. „Workbook TRIZ. Theory of Inventive Problemsolving. Von der Theorie zur Praxis“ TQU Verlag, Ulm, 2000.

[17] Klein, B., „TRIZ/TIPS. Methodik des erfinderischen Problemlösens“ Oldenbourg Wissenschaftsverlag, München, 2007.

[18] Orloff, M. „Grundlagen der klassischen TRIZ. Ein praktisches Lehrbuch des erfinderischen Denkens für Ingenieure“, Springer, Berlin, Heidelberg, 2006.

[19] Mao, X., Zhang, X., AbouRizk, S., „Generalized Solutions for Su-Field Analysis“. In: The TRIZ-Journal, 08/2007.