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A CONCEPT FOR INTERFACES TO GENERATE 3D CAD-MODEL FROM CUSTOMER REQUIREMENTS

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1. Introduction

The Collaborative Research Centre (CRC) 666, founded in July 2005, aims to exploit the enormous prospective potential of the new technique of linear flow splitting. This procedure makes it possible to create integral sheet metal products with higher order bifurcations. The key hereto is a newly developed linear flow splitting technique for cleaving sheet metal, as can be seen in Figure 1. This technology, in combination with metal-cutting and welding processes, opens the ability to define new product categories with completely new features and geometrical properties.

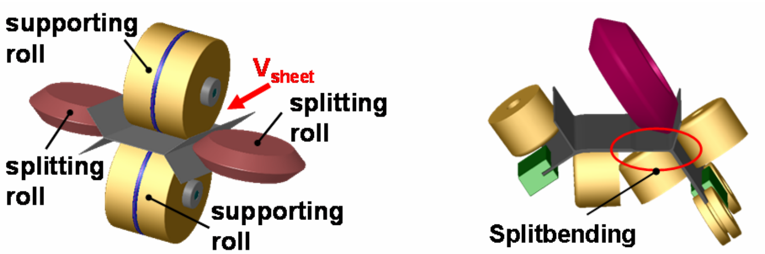

Figure 1. Sheet metal linear flow splitting

This paper pays particular attention to the methodical inventions in the early product development stage and the information data model intended to perform the overall data management. Interactions and interfaces between the different science disciplines will be paramount to realize a continuous product development process.

In particular, after the requirements have been extracted and specified from the customer wishes, an algorithmic approach is being applied to generate concrete 3D CAD models of possible solutions of bifurcated sheet metal parts. The data exchange, interfaces and the data management shall be presented here.

2. Data Exchange in CRC 666 information model

2.1 Virtual product creation in CRC666

For the data exchange between the subprojects during the virtual product creation an integration approach for integral sheet metal is realized. The virtual product creation process reaches from the standardized description of the requirements over product development (solution finding, shape generation, detailed design, calculation and simulation) up to production planning (shown in Figure 2).

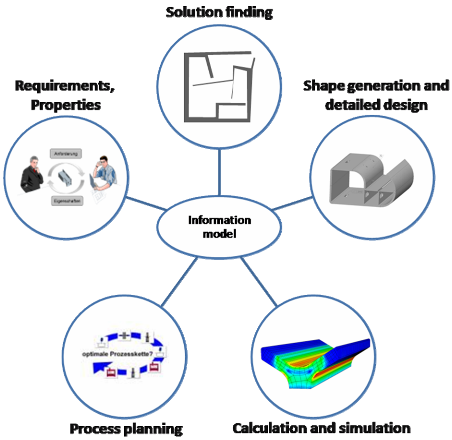

Figure 2. Product creation process, supported by an information model

The product creation process in CRC666 begins with the analysis and standardization of the customer requirements of a sheet metal product. Each anticipated value of any possible requirement has to be classified to a concept scheme of outer properties, the so called taxonomy for sheet metal products. This is necessary to set up an algorithm based process to transform the fuzzy requirements into quantifiable values for the inner properties of the desired sheet metal product.

Based on the quantifiable values for the inner properties, a solution for the design of the desired sheet metal product will be found. All exact inner properties for the desired sheet metal product regarding the appearance are passed on to a two-pass mathematical optimization procedure.

- The first step of this optimization process determines the mathematically optimal geometric shape and topology (in this paper, the way and order of operations the sheet metal part is bent and spitted) of the sheet metal product.
- The second step especially defines a valid unrolling for the sheet metal component taking into account the various production restrictions. Usually there is a vast amount of possible unrolling, i.e. the sequence of flow splitting and bending processes, for a single product.

The result of the mathematical optimization procedure is a solution tree, which is composed of solution nodes representing the manufacturing operations.

In the next step detailed design will be made. Based on the solution tree, the shape in a 3D-CAD model will be generated by means of feature generation from the solution nodes. On the generated 3D-CAD model, the engineer can manually add cutting and milling features like holes, chamfers etc., which represent the result of the integrated HSC-processes in the bending and splitting processes. The result of the 3D designing instance is a fully detailed 3D-model of the sheet metal component.

The detailed design will be in the next step optimized with the aid of calculation and simulation. 3D geometry and optimizing parameters will be transferred between the design and calculation and simulation.

After optimizing the design, the optimized detailed design will be needed to generate information for production planning, like unrolling etc. The challenge in the production planning in CRC666 is the continuous production by integration of splitting processes and cold forming of sections by bending sheet metal in combination with HSC-processes. Important information for this planning is the determined geometry of the part, the chosen unrolling of the product, technology constraints, known machining limitations and constraints as well as cost and cycle time data. This given information can be used to set up a virtual simulation for the entire production process to ensure the operational reliability of the facility.

3. Determination of Customer Requirements

In order to optimize the process of creating a customer defined requirement specification, it should be performed machine-aided in the future. Today the customer specifies their requirements for a product in a written language request which is supposed to aid the developer to understand the properties of the desired product. Frequently though, the data in those written request is insufficient to create a requirement specification which should serve as a base for the further creation of a product development process. A refinement und a time-saver in the creation of a requirement specification would be achieved, if the developer could guess correctly, which exact wishes and requirements the customer had in mind, while creating the request. By means of analyzing the association and relationship strength between the used terms in such a request and also the terms associated with the required product itself, it should be possible to simplify the creation of a requirement specification for the developer.

XML (Extensible Markup Language) would be used for the integration of the requirements in an information model. To achieve that a XML Schema with a set of all standard requirements would be defined according to which the desired product would also be described.

3.1 Standardization of Customer Requirements

"Standardised requirements are requirements that can be understood and interpreted in the same way, either by the developers or by the customers. For this reason, they are called unambiguous.

Designers know exactly what customers expect when customers exclusively employ terms of the standardised requirements in their descriptions of the desired product."[Chahadi 2007]

To be used, standardised requirements have to be defined for the real, manufacturable product. The larger the collection, the more the standardised requirements and the easier it is to create i.e. generate new products.

An automatic generation of the product requirement lists from the developed splitting sheet metal profiles is aimed by the gathering of standardised requirements. A further aim is to simplify the discovering of the relations between the actual product properties and the terms applied in the customer requirements. The next step for allowing the growth of the set of predefined standardised customer requirements is to analyse all possible and available customer requirement lists for splitting sheet metal structures.

Table 1. Different Possibilities for Matching Common Requirements

Requirement Number (Possibilities)	Assembly 1	Assembly 2	Assembly 3	Assembly 4	Found Common Requirements Between The Assembly's
1	o	o	o	o	-
2	x	x	o	o	1;2
3	x	o	x	o	1;3
4	x	o	o	x	1;4
5	o	x	x	o	2;3
6	o	x	o	x	2;4
7	o	o	x	x	3;4
8	x	x	x	o	1;2;3
9	x	x	o	x	1;2;4
10	x	o	x	x	1;3;4
11	o	x	x	x	2;3;4
12	x	x	x	x	1;2;3;4;

In a research four customer requirement lists for splitting sheet metal products were used and combined, each for the four building blocks of the product. The aim was to discover the common features of the product requirements for the different assembly's of the same sheet metal category. Table 1 shows a part of the results from the research on the different assembly of the same product and their relation in a constellation of common requirements. Marked with an "x" are the common requirements that are met at least in two requirement specifications of the four assemblies. Marked with an "o" are the requirements that are met only in the requirement specification of a particular assembly and not by the rest. The numbers of the assembly's that share common specifications are put in the right column. Those common requirements are to be added to the list of common standard requirements.

In the case, of the four researched assembly's 12 different constellations were found. In the case of 5 the constellations were 27. This research model could be expanded to a random number of assembly's. It is expected that the set of standardised requirements would grow on a diminishing scale when more assembly's requirements are added to the model due to the fact that such common requirements that aren't yet part of the standardised once, those that already have been met by at least 2 assembly's, are met ever more rarely and the number of unique once grows.

The dependence between the number of common requirements and the number of researched building block is depicted by the graph of a root function shown Figure 3. This leads to the conclusion that the requirement specifications of future sheet metal products will behave in the same way and the number of common requirements could be determined from researching a narrow set.

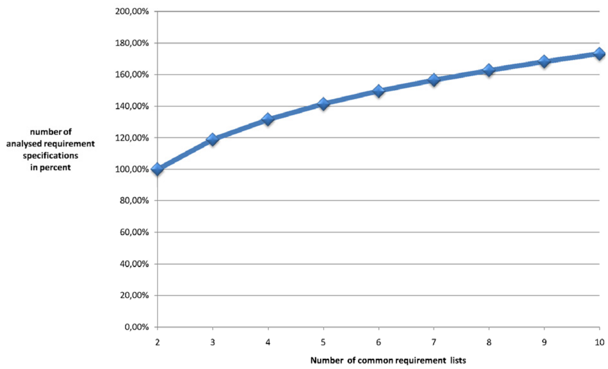

Figure 3. Relationship between the quantity of analysed requirement specifications and the number of common requirement lists

The standardized common requirement specifications were put in a System of concepts and characteristics, considering the real product properties.

3.2 Standardised Requirements and the system of concepts

Figure 4 shows a simplified concept for the determination of customer requirements from the written customer request and the way these are integrated in the central information systems. First, the customer requests are led to the requirement determination system. The algorithm in the determination system scans the requirement terms from the customer request and then these are arranged according to their importance. In order to determine the requirement terms from the customer request, the semantic grid, the pragmatic and the syntax play a very important role, particularly in order to find the relations between terms in the context. After the determination of the requirement terms these are compared with our system of terms, to check, whether these are available in our standardized requirement system. If these terms are present in system, then they are prepared for the desired product directly. The properties related to the terms could possibly require an adaptation. If the requirement term is not available in the system of terms, the task of the developer is to define, if possible, a relationship between the new term and the next term in the system of terms, otherwise the new term should be inserted into the system of terms and its properties be specified, adhering to the manufacturing restrictions, so that it is ready for use in the next run. When all requirement terms from the customer query are processed, then a requirement specification is generated from them. This requirement specification must be still intelligible for the customer. If the developer should get an approval from the customer, they generate then from the requirement specification an XML-File. The central information system reads this XML-File and makes this available for other product developers in CRC 666.

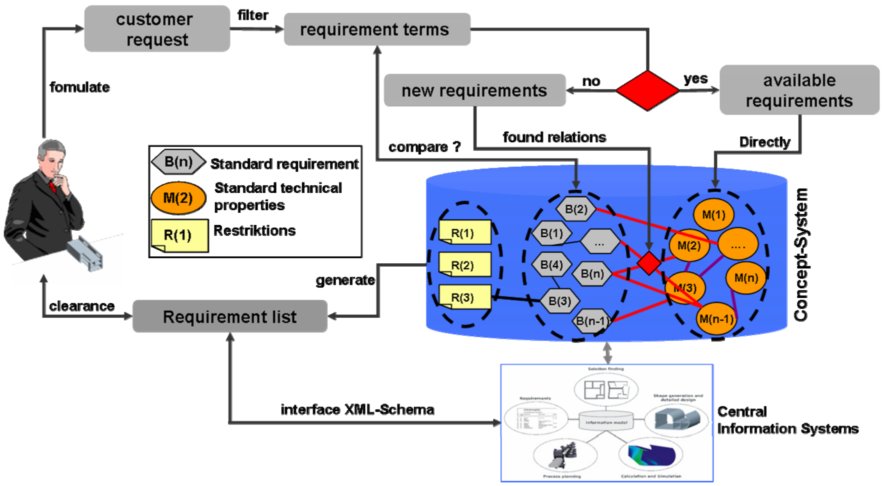

Figure 4. Customer determination, interface to the central system

3.3 Relations between requirement terms in the requirement Concept-System

For the creation of the Concept-System, an analyse of the associations and the closeness of the relation between the terms was exclusively performed. The thus associated terms and requirements could help the developer on the one hand and precise the requirements specification and on the other hand help the customer to express his wishes and requirements in the most exact way. A network of terms with determined relations could be extremely helpful in order to create a requirement specification together with the customer.

To measure the relation between these terms in a quantifiable way and the closeness of their relation, the distance mass a.k.a Euclid distance is computed. This method for cluster analysis is used to order different objects (in our case terms) in groups according to some given criteria [Bock 1974].

$$d_{ij}^{(r)} = \sqrt[r]{\sum_{m_x \in M} \left| a_{ix} - a_{jx} \right|^r} \quad (1)$$

Whereas d_{ij} is the distance between object i and object j, a_{ix} is the value of the x-th feature of the i-th object, a_{jx} is the value of the x-th feature of the j-th object, m_x is the number of features in the set M and $r > 1$ is the Minkowski constant.

The Euclid distance mass is used to determine the similarity between two objects based upon their internal features. If the features happen to be all identical then the distance mass is zero which is to say the objects are the same. The bigger the values and the distance are the bigger the difference between the terms would be. For the determination of the Euclid distance and the strength (weight) of the relation between the terms, the following is taken into account:

- The closeness of the relation between two different terms
- The closeness of the relation between the two and the rest of the terms in the set of terms with common sense

For example, the customer could require a metal sheet profile for some specific use. In our case the profile contains the requirement “The product should not be bend for the deployment in the area of X”. The developer puts into the system the term “bend” with the Priority 1 and the closest terms in the sense of requirement specifications that also have the strongest relation are shown. In this case it’s the term” Bending→deflection” (shown in Figure 5).

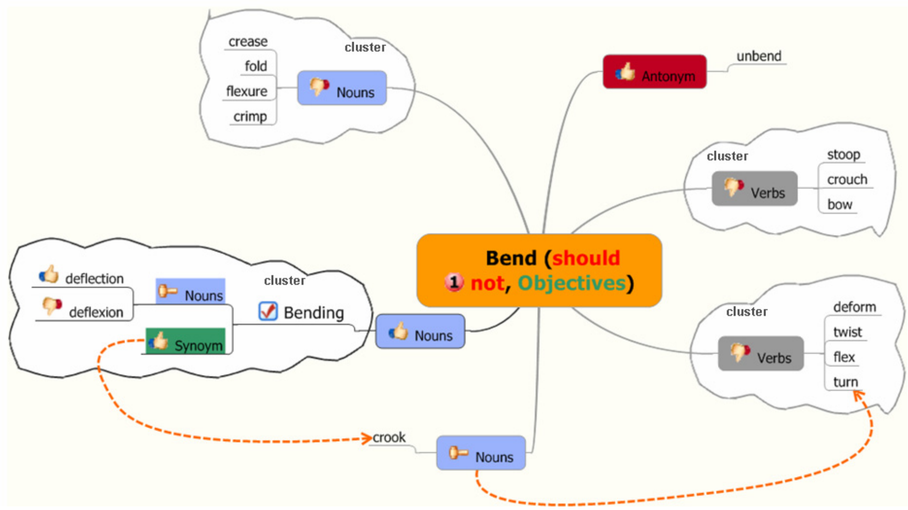

Figure 5. Relations from the term “Bend” in the Concept-System

3.4 Customer Requirements and Data Exchange with the Information System

Some steps from the process like the weighing of the requirements and the transformation of the customer requirement to product proprieties are omitted in the framework of this document, but still available in other work from me [Chahadi , 2007 SFB66, 2007 ICED’07].

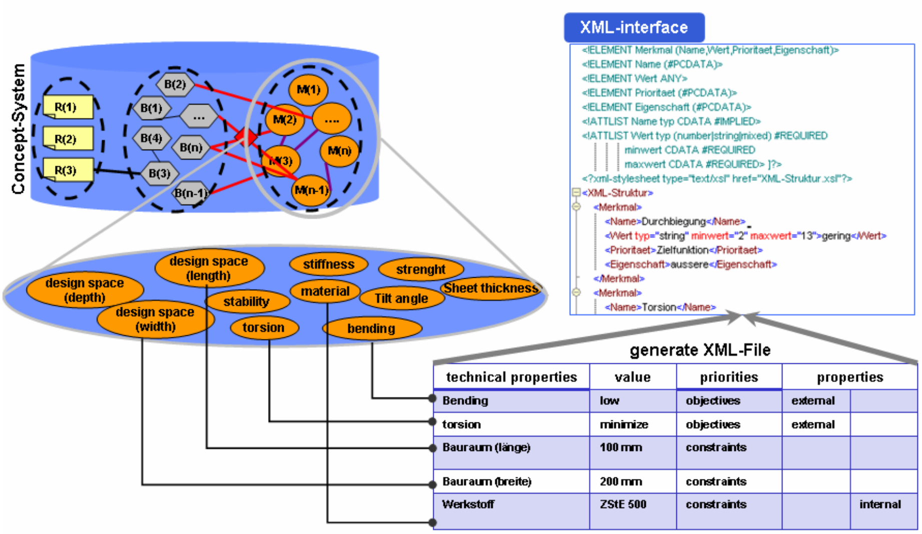

Figure 6. Relationship between requirements and product properties, XML-Data exchange.

The system of terms is based on XML data exchange. For that purpose, one standard XML Schema would be created containing all possible and available requirements. It should set the grammar for the used XML data and also the gateway to the central information system, so that, the exchange of data between the different projects of the CRC 666 would be standardized.
In this particular case, for example, all requirement terms from the customer inquiry are processed by the developer and from these a requirement specification is built, provided that it could be integrated in the prepared structure. Figure 6 shows a part of the requirement structure. The next step is for the customer to approve the requirement specification. If that happens the developer creates an XML file containing the specification and it is uploaded in the central information system for the actual processed product. By means of Xquery, each part of the project could be accessed and inquired for some necessary data. The access to the data from the requirement specification would be impossible, if it is not built in a standardised way. We at CRC 666 aim to automate the whole product development cycle and for that to be achieved we'd like to have the possibility to automatically create CAD Models with as few in-between steps as possible. The next part shows how that could be done.

4. Generation of the CAD-Model

The term topology in the sense of this paper describes the way and order of operations the sheet metal part is bent and spitted. It must not be misconceived as actual location of e.g. vertices and edges in the sense of the geometrical representation. The Figure 7 presents two different topologies for a single geometrical shape.
In this first phase of the project the complexity of the sheet metal structures is limited to extruded shapes. Thus, the mathematical representation of the topology is being recorded in form of a binary tree structure [Groche 2005].

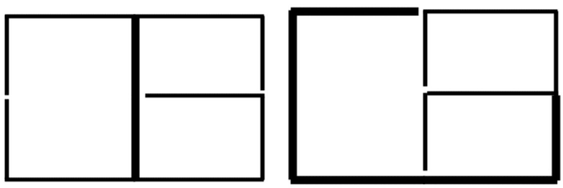

Figure 7. Two different topologies representing the same geometrical properties

As the number of conceivable topologies for one part shape is huge and would not be manageable, a mathematical optimization process of the solution set takes place. By this, the number of usable topologies is in a first step reduced based on the set of customer requirements. These remaining topology solutions are then recorded in a textual form describing each solution's specific shape.
It needs to be noted that not all specific parameters and requirements to the product can be handled by the mathematical optimization. Thus, after the first – mathematical – solution set reduction, another benefit of the remaining solutions has to be accomplished, based on these requirements that cannot be filtered or evaluated by mathematical parameters (e.g. design space restrictions).
Since this last step has to be done manually by the engineer, a maximum of computer support needs to be established to enable a profound remaining solution analysis and to ease the engineer's decision making process.
The core component for supporting this approach is generating the 3D-CAD model of the geometry of each remaining solution part. Apart from enabling the product developer to access the "look and feel" of a solution's geometry, the 3D representation is of paramount importance to evaluate the design for connecting points or further detailing with machining operations or PMI (product manufacturing information). Furthermore, the CAD model is a core element for any following geometry-based operations, e.g. FEM simulations or production planning, which boosts the importance of the generation of the 3D model a fundamental step in the overall algorithm-based product design process.
The first step in generating the 3D-CAD model is getting and processing the mathematically generated topology structure. As transport layer, a data model has been developed that comprehensively and

non-ambiguously describes the geometry of the optimized integral sheet metal part with higher order bifurcations. The foundation of this data model is the XML language, which proved most suitable for representing the structure of the relevant data as well as processing it.
As one can see Figure 8, the geometry data model structures and lists the geometry elements needed to form the part's topology and geometry including all their attributes necessary according to their appearance in the model. This representation contains all information necessary for the unique representation of any conceivable bifurcated sheet metal geometry.

```
<sheet thickness="2" depth="100">
  <flank0 id="0" length="27" thickness="2">
    <bend id="2" distance="5" radius="1" angle="270" />
    <lfsplit id="3" distance="15" radiusleft="1" angleleft="90"
      radiusright="1" angleright="270" splitradius="0.5">
      <flank0 id="4" length="5" thickness="1" />
      <flank1 id="5" length="8" thickness="1" />
    </lfsplit>
  </flank0>
  <flank1 id="1" length="16" thickness="2">
    <lfbend id="6" distance="3" radius="1" angle="90"
      splitradius="0.5" length="3">
      <flank0 id="8" length="8.5" thickness="2" />
    </lfbend>
    <lfbendend id="7" distance="16" augmentation="1"
      length="2" refid="6" />
  </flank1>
</sheet>
```

Figure 8. Exemplary XML-based data structure

Despite the complexity of the possible geometries, the data model could be kept as small as six different XML-elements which altogether compose the geometry of the model.
The root element *sheet* defines the global attributes of the part, which are e.g. the thickness of the original sheet metal or the overall extrusion depth of the part.
The origin of every geometry is a basic, plane sheet metal flank, upon which the different operations that have to be performed to form the local part geometry are applied. In the data model this fact is accommodated by defining *flank*-elements as base elements that represent the operations upon them as child elements in the data structure. These operations that can be applied to flanks are e.g. *bends*, *splits* or *splitbends* and these form the final geometry of the flank. The characteristic of split and splitbend-elements is the fact that they split their base flank into two continuing flanks of smaller thickness. Therefore the child-elements of split and splitbend-elements can only be flank-elements, which itself are the base-elements for the following operations.
The challenge to be able to represent sheet metal parts with bifurcations in a CAD system, which is not supported natively in any state-of-the-art 3D-CAD system, was solved with a new method of generating and describing such geometries. The algorithmic generation of the part geometry is based on a systematic combination of user defined features, which can be seen as a modular construction kit. A user defined feature (UDF) can be understood as distinct, self defined knowledge-based geometry unit. [Bronsvoort 2001] In combination with other such UDFs the complete part geometry can be composed, including multiple bifurcations. The arrangement of the UDFs is automated by supplementing information as parameters to the surfaces of every UDF-module, to specify where on the part further elements can be attached. The elements that follow in the geometry generation process look for this information and place itself on exactly that location. Internally the UDFs are representing an interlinked list that itself is formed from the individual content of the XML data model.
For parsing and processing the part topology data, an API extension to a parametric 3D-CAD system has been developed that automatically generates the corresponding 3D-model in the CAD system's native geometry format.

The benefit of this approach is that any geometry can be generated automatically and in no time. That way, it is possible for the designer to quickly generate multiple CAD models to compare and evaluate.
Another benefit of this generation and representation approach is that any further detailing or extensions to the CAD geometry model, e.g. bores or notches, can be applied by the designer in his familiar CAD environment. The geometry created from the XML-data presented before is shown in Figure 9.

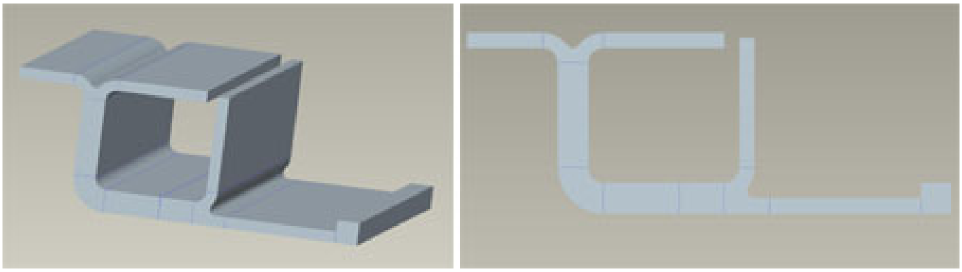

Figure 9. Final part geometry based on the data structure of Figure 8

The final part then bears the optimum geometry and all further details added by the designer to be included in the product development process. The CAD model is then available for the following geometry-based product development processes that rely on 3D-data [VDI 2003].
In the future, another purpose of use for this way of describing and building bifurcated sheet metal parts is composing and displaying the different intermediate steps of the originally flat sheet metal to the finished bifurcated part. These steps are due to production constraints, and displaying them can help the production planner in archiving the best order of operations.
The methodology described for generating the complete 3D CAD-Model of bifurcated sheet metal parts, based on a textual data model, has been implemented and tested using the software Pro/Engineer Wildfire. The definition of parametric user-defined features as well as their application in a solid model to create the complete part geometry is possible in Pro/Engineer. Further detailing of the 3D CAD model can be done using well-known features or product manufacturing information as already state of the art in most CAD systems. Using these techniques, the algorithmically optimized bifurcated sheet metal part can be detailed with e.g. bores, notches or tolerance information and surface roughness information, as shown in Figure 10.

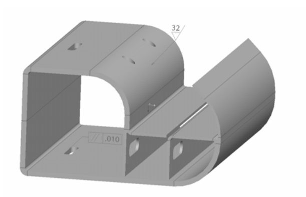

Figure 10. Algorithmically optimized bifurcated sheet metal part with manufacturing information's

In order to support the idea of an algorithmic product design process, the automated geometry generation of the specified bifurcated sheet metal part has to be established. The CAD-system Pro/Engineer supplies the API (Application Programming Interface) Pro/Toolkit, which is based on the language "C" and provides functions to get access to many Pro/Engineer objects and their specific information, as well as functions for the creation of geometry. The automatic generation of user defined features, which are topologically fixed (respecting vertex-edge-face relationship) but geometrically flexible (respecting parametric), can also be established by Pro/Toolkit. For this process, the software needs specific information about feature parameters, neighbour relationships and other semantic data. By processing this data, the geometry of each single instance of a user defined feature

can be created and furthermore by considering parent features can be correctly placed in the complete part's context.
The data of the final part is then handed over to the data management as neutral geometry, which makes it possible to support follow up processes, e.g. FEM analysis.

5. Summary

Based on a definition of interface and information model, an integration approach for the virtual product creation for integral sheet metal products is realized. Beginning with the standardized representation of customer requirements, over the algorithmically generation of topology and 3D-geometry in feature-based parametric 3D-CAD-System, and supporting the down streaming processes like, calculation, simulation and process planning on the basis of the detailed 3D-CAD model, the novel algorithm-based virtual product creation process has been well represented in the uniform definition of interface and information model.

Acknowledgement

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References

Chahadi, Y., Wäldele, M., Birkhofer, H., „Von der Kundenanfrage zur standardisierten Produkteigenschaft", Sonderforschungsbereich 666 (SFB 666) – Integrale Blechbauweisen höheren Verzweigungen - Tagunsband 1. Zwischenkolloquium, PP 27- 36, Darmstadt 2007.
Chahadi, Y., Wäldele, M., Birkhofer, H., "QFD - a link from customer requirements to product properties", International conference on engineering design, ICED'07, PP 711 - 712 August 28 – 31, 2007.
Bock, H., „Automatische Klassifikation, Theoretische und praktische Methoden zur Gruppierung und Strukturierung von Daten". PP 26, Göttingen, 1974.
Groche P., "Integral sheet metal design with higher order bifurcations development, Development, Production, Evaluation", application by DFG (German Research Foundation), Darmstadt, 2005.
Bronsvoort W., van den Berg E., Bidarra R, Noort A., "Essential Developments in Feature Modelling", CAD/Graphics'2001, August 22-24, Kunning, International Academic Publishers, 2001.
Verein Deutscher Ingenieure, „VDI-Richtlinie 2218", Informationsverarbeitung in der Produktentwicklung - Feature-Technologie, März 2003.

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