# Realization of Design Features for Linear Flow Splitting in NX 6

Anselm L. Schüle, Thomas Rollmann and Reiner Anderl

*Abstract*—Within the collaborative research center 666 a new product development approach and the innovative manufacturing method of linear flow splitting are being developed. So far the design process is supported by 3D-CAD models utilizing User Defined Features in standard CAD-Systems. This paper now presents new functions for generating 3D-models of integral sheet metal products with bifurcations using Siemens PLM NX 6. The emphasis is placed on design and semi-automated insertion of User Defined Features. Therefore User Defined Features for both, linear flow splitting and its derivative linear bend splitting, were developed. In order to facilitate the modeling process, an application was developed that guides through the insertion process. Its usability and dialog layout adapt known standard features. The work presented here has significant implications on the quality, accurateness and efficiency of the product generation process of sheet metal products with higher order bifurcations.

*Keywords*—Linear Flow Splitting, CRC 666, User Defined Features.

## I. INTRODUCTION

THe new manufacturing method of linear flow splitting is researched by the Collaborative Research Center (CRC) 666 since 2005. Focus is set on the creation of a product development process for bifurcated sheet metal products [1], [2]. Linear flow splitting [3] facilitates the manufacturing of integral sheet metal products with higher order bifurcations without material doubling or joining. The key technology of linear flow splitting (Fig. 1, left) and its derivative linear bend splitting (Fig. 1, right) allow the cleaving of sheet metal by plastic deformation. In linear flow splitting the sheet metal is progressively formed by multiple sets of tools, each consisting of a splitting roller and two supporting rollers. In linear bend splitting the edge where the deformation takes place is firstly created by creasing the sheet metal at the desired position [4].

Linear flow splitting and linear bend splitting, combined with cutting, welding and roll forming operations render it possible to define new product categories of sheet metal profiles with specific new features and geometrical properties. In the current state of development of the linear flow splitting technology and the surrounding process chain, it is possible to create complex sheet metal profiles in an appealing quality. To enable designers and engineers to use this new methods standardized features and tools need to be developed to create detailed 3D-models of the desired branched products. These models are required for subsequent product development processes like simulation or production planing.

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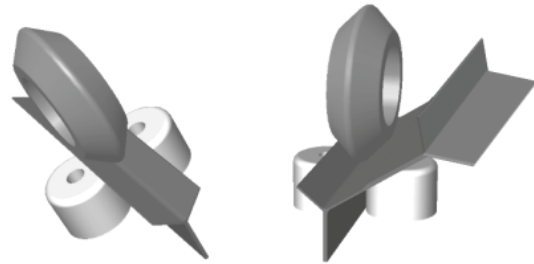
Fig.1 Linear flow splitting and linear bend splitting technology

## II. STATE OF THE ART

### Feature based modeling

A feature is an aggregation of product properties. The definition contains all relevant properties, the specific values as well as their relations and constraints. Design features are characteristic features for product modeling. They contain geometrical information, constraints and dimensions. Design features can be used to built a product model. This approach is known as design by features or feature-based modeling. Modeling can be started either with a more or less complete geometric model and the application of form or detail features, or by starting from scratch by combining form features from a standard library. In modern CAD-Systems, standard (design) features can be combined and wrapped to so called User Defined Features. These UDFs can hold geometry from standard features and detail features and can be used to set specific constraints or to ensure company standards. User Defined Features are organized in libraries [5].

### Modeling Bifurcated Sheet Metal Structures

At present, modeling functionalities for bifurcated sheet metal structures in common 3D-CAD systems like NX, Catia V5 or ProEngineer do not suffice to provide efficient and user-friendly design of integral sheet metal products [6]. Sheet metal environments for example can not handle varying sheet thickness as seen in linear flow splitting. Modeling bifurcated sheet metal profiles by splitting the body and applying bend features leads to problems in terms of parametric design and model consistency as soon as the product gets more complex and higher order bifurcations are modeled. Sketching the geometry and extruding the new flanges is the only way that leads to satisfying results. This method however has significant disadvantages in terms of modeling time and usability.

In order to compensate these issues, User Defined Features can help to establish standardized feature sets for the linear flow splitting and linear bend splitting techniques [7], [8]. Applying linear flow splitting features to CAD models then reduces to only one step - the insertion of the UDF - which can easily be repeated instead of sketching and extruding the whole geometry. UDFs can furthermore be associated with geometrical and mathematical constraints to ensure quality and manufacturing objectives [9].

In [10] a modeling method is introduced that utilizes a set of User Defined Features to generate 3D-models of sheet metal products. This method, realized in the CAD System PRO/Engineer Wildfire, enables the user to easily generate profiles by manually combining UDF for bends, flanges and bifurcations. This approach is called Direct Modeling Approach.

In addition to manually combining the UDFs, an algorithm enables the designer to automatically create 3D-models. This is called the algorithm-based product development process, which is one of the new paradigms of the CRC 666. The algorithm-based modeling processes the solution tree of the desired sheet metal product. This solution tree often is the outcome of a mathematical optimization process. The algorithm based modeling approach was deployed using C++ to address the application programming interface (API) Pro/TOOLKIT of the Pro/ENGINEER CAD system [6].

Both approaches enable the designer to quickly generate CAD models of different topologies to compare and evaluate the respective designs. The generated models are standard PRO/Engineer models and can be further detailed by adding design features, e. g. bores or notches.

The usage of User Defined Features for the creation of bifurcated sheet metal structures holds several disadvantages: During the modeling process the intermediate stages do not comply with the respective shapes of the real product during the production process. Furthermore, none of the UDF-based approaches can satisfy the scientific desire to model branched structures with topological manipulations of the Boundary Representation structure. Thus the identity of edges and faces from the base model and the bifurcated model is not given and references of formerly created features might be corrupted. In addition, the existing UDFs always add geometry to the models that does not match the character of linear flow splitting and linear bend splitting being manufacturing methods based on plastic deformation.

Hence a new approach using Parasolid 3D-CAD geometric modeling Kernel is introduced in [11]. The developed application enables the user to create bifurcated sheet metal parts using linear flow splitting, linear bend splitting and standard bending operations. The created parts can be saved in an open file format that is supported by several established 3D-CAD systems.

In addition to this new approach, this paper introduces an improved way to create and insert UDFs for linear flow splitting and linear bend splitting. Unlike the formerly introduced UDFs these newly developed do not change the volume of the target model which adapts the real manufacturing process when applying the linear flow splitting and linear
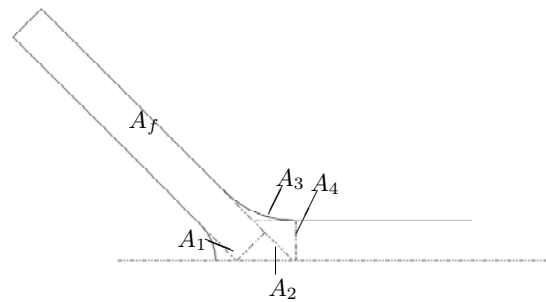


Fig. 2. Geometry of linear flow splitting

bend splitting technique. Furthermore a tool is introduced that allows the semi-automated insertion of the created UDFs into 3D-models and thus deals with usability and time issues during the modeling process.

### III. Special Properties Of Linear Flow Splitting And Linear Bend Splitting Features

TABLE I
MATH SYMBOLS AND DESCRIPTIONS

| Symbol | Unit | Description |
|--------|------|-------------|
| $l_f$ | $mm$ | flange length |
| $y_{ges}$ | $mm$ | total splitting depth |
| $s_0$ | $mm$ | sheet metal thickness |
| $s_f$ | $mm$ | flange thickness |
| $R$ | $mm$ | splitting roller radius |
| $\alpha$ | ° | splitting roller flank angle |
| $h$ | $mm$ | support roller radius |
| $\gamma$ | ° | auxiliary angle |
| $A_f$ | $mm^2$ | total flange area |
| $A_i$ | $mm^2$ | area of flange section $i$ |
| $\widehat{[]}$ | | angle in radians |

For modeling of linear flow splitting and linear bend splitting features several geometrical and mathematical restrictions apply. In this section geometrical and mathematical backgrounds for the determination of the model's properties are presented. Unlike former solutions the focus is set on the preservation of volume consistency when inserting the UDFs into existing models.

Linear flow splitting profiles can be modeled in a Y-formed shape as shown in Fig. 2. Linear bend splitting is quite alike but has a slightly different geometry in its notch base which can be disregarded. As seen in Fig. the flange can be divided into several subareas. For each of them equations can be found to determine their respective expanse. Due to the character of linear flow splitting, which is plastic deformation, volume consistency can be assumed. Thus the flange length of the created bifurcation can be determined by equating the total area of the original cross section $A_0$ with the sum of the areas $A_f$ and $A_i$:

$$A_0 = y_0\, s_f \qquad (1)$$

$$A_0 = A_f + A_1 + A_2 + A_3 + A_4 \qquad (2)$$

The respective dimensions can be calculated using trigonometrical functions:

$$A_1 = \frac{R^2 \tan \alpha - \widehat{\alpha}}{2} \qquad (3)$$

$$A_2 = \frac{s_f^2}{2 \cos \alpha} \sin \alpha \qquad (4)$$

$$A_3 = h^2 \left( \tan \frac{\gamma}{2} - \frac{\widehat{\gamma}}{2} \right) \qquad (5)$$

$$A_4 = \frac{s^2}{2} \tan \alpha \qquad (6)$$

The flange length $l_f$ can be determined by solving

$$A_f = A_0 - A_1 - A_2 - A_3 - A_4 \qquad (7)$$

with

$$l_f = A_f\, s_f \qquad (8)$$

It can now be used to create the geometry in a User Defined Feature.



Fig. 6. Fiolog boxes

## IV. SYSTEM DESIGN

A feature-based modeling tool for bifurcated sheet metal products should have the following functionality to support direct modeling of bifurcated sheet metal profiles in a user friendly and efficient way:

- Design features for both, linear flow splitting and linear bend splitting.
- Model volume consistency for all operations.
- A user friendly dialog that adapts common design feature dialogs.
- Convertibility of parameters after the feature is applied to the model.
- Easy deletion of wrong or misplaced geometry.

Siemens PLM NX 6 was used for implementation. NX has a very good support of feature based modeling and User Defined Features. The NX Open API, the application programming interface, supports various programming languages and enables customization and remote access to NX functions. Anyhow, the concept introduced with this paper can be transposed in almost any CAD System with UDF and API support.

For each manufacturing method, linear flow splitting and linear bend splitting, a specific UDF was designed. Therefore geometry and expressions were created. The first step of modeling linear flow splitting is to define a work plane. This work plane is parallel to the target face and its offset corresponds to the total split depth. To preserve volume consistency, a rectangle of length and width of the target face is extruded and subtracted from the target body. The direction of the extrude is the inverse normal vector of the target face; extrusion length is the split depth. The work plane is the new base of the bifurcation. Here the flange geometry is drawn in a sketch quite similar to Fig. 2. The sketch is parametric, the parameters itself a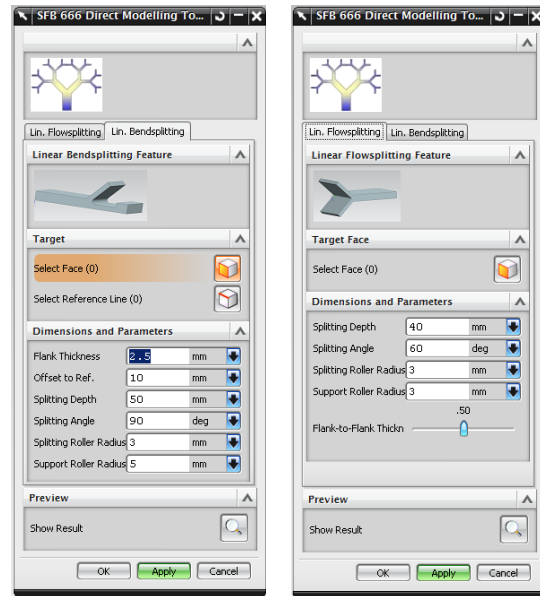re direct inputs or calculations from the expressions shown above. The User Defined Feature for linear bend splitting is very similar to the one for linear flow splitting. Major difference is the additional reference which defines the offset of the created pocket and flange. Furthermore, only one flange is drawn in the sketch.

For quick and easy insertion of the created User Defined Feature a tool is developed that guides through the process. The developed tool utilizes the NX Open API for Java which allows to remotely use and call NX functions and manipulate NX Objects. The created tool consists of three modules: The core application, the created UDFs and the graphical user interface. Fig. 3 shows a scheme how the tool operates and how the modules interact.

The designer who wants to use linear flow splitting or linear bend splitting features starts the toolbox from the NX menu. A dialog opens that asks for parameters and references for the User Defined Features. When a feature is applied, the dialog starts a Java callback function that processes the given parameters and references and creates a Knowledge Fusion[1] rule in the opened NX part file. This rules contain the name of the inserted UDF and the respective parameters and references for its insertion.

## V. IMPLEMENTATION AND VALIDATION

### Core Application - Direct Modeling Toolbox

The core application consists of five different classes. The main class, which is starting point of the application controls the tool and the user dialog. In a simplified UML diagram of the application (Fig. 5) the main class can be found in the middle of the diagram. Each feature, linear flow splitting and

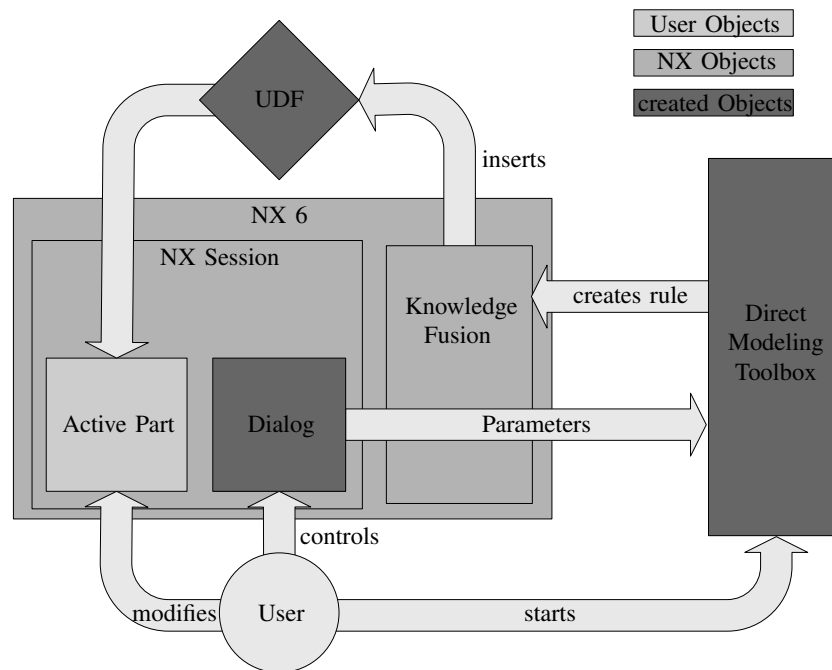[1]Knowledge Fusion is the knowledge based engineering environment of NX

Fig.3. Application scheme

linear bend splitting, has its own builder object that accumulates information and provides functions for the insertion of the respective User Defined Features into the CAD model. The builder classes can be seen on the left and on the right of the main class in Fig. 5. Parameters and references are stored in data classes as shown in the upper left and upper right corner of the UML diagram. Insertion itself is realized by adding Knowledge Fusion (KF) rules to the NX part. Using KF rules is the only way to remotely apply UDFs to existing parts. Each builder object has a data object that contains all references and parameters used for the UDF. The selected faces and edges coming from the user dialog introduced in the next section can be processed to determine all required references for the UDF.

*Dialog Design*

The dialog (Fig. 4) adapts the user dialogs of common standard features like block, hole or chamfer. NX Block Styler is used for dialog design. It provides native NX dialog elements. Dialog appearance and step by step insertion give a huge benefit on usability.

The dialog consists of two tabs, one for each feature. On each tab, a small preview of the selected feature is shown. Beneath the references can be set. For linear flow splitting the target face has to be selected, for linear bend splitting the target face and a reference line have to be selected. The reference is used to define the direction of the flange. An additional offset defines the position of the feature on the sheet metal surface. Beneath the references there are the parameter input boxes. For linear flow splitting these are splitting depth, splitting angle,

split- and support radius. In addition flank-to-flank thickness can be set by a slider bar that can be moved between $0.1$ and $0.9$ (with $0.5$ for equal thickness).

The application was tested by modeling different sheet metal profiles with bifurcations. Step by step insertion can be seen in Fig. 6. In the upper picture the raw model is shown. This can be a simple sheet metal or a free flange of a more complex product. In the next picture, the linear flow splitting feature dialog is shown. The user varies the parameters and selects a target face. When applying the feature the linear flow splitting feature is shown instantly in the model.

*Parametric Design*

In order to enable the iterative design of branched sheet metal products the linear flow splitting and linear bend splitting features appear as specific objects in the model history that can be edited like standard features. Starting rollback editing in the model history tree, the user has the opportunity to edit the linear flow splitting and linear bend splitting parameters in a user friendly dialog box.

*Linear Flow Splitting Feature*

To apply a linear flow splitting feature to a NX Model, the user needs to define a target face. The toolbox automatically detects the face's long and short edges and sets the splitting direction parallel to the long edges. After editing the parameters like split depth, split angle and flank-to-flank thickness the feature can be applied directly or in a preview mode.
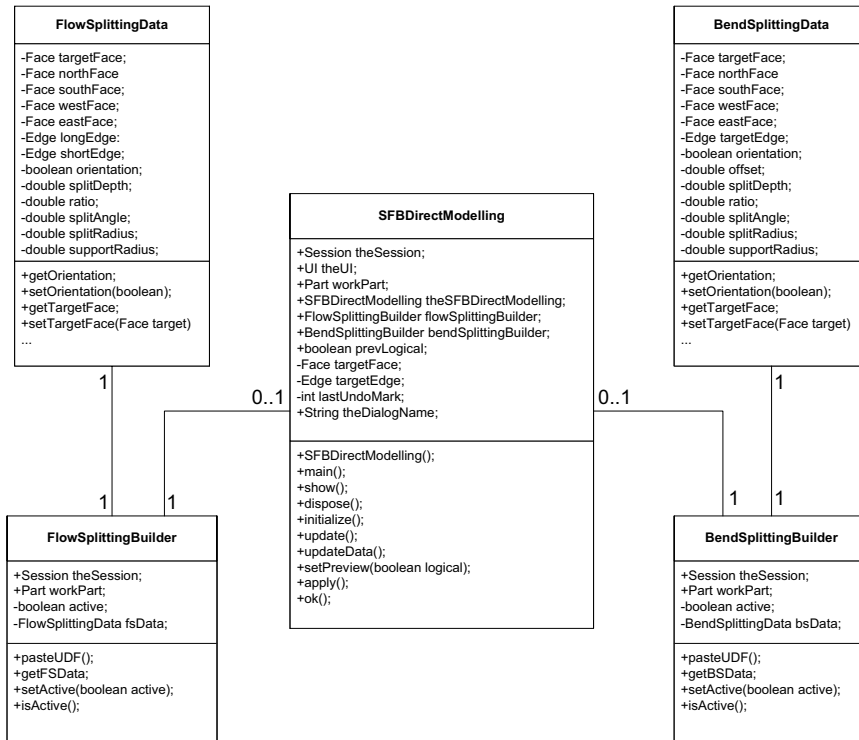
**FlowSplittingData**

-Face targetFace;
-Face northFace
-Face southFace;
-Face westFace;
-Face eastFace;
-Edge longEdge:
-Edge shortEdge;
-boolean orientation;
-double splitDepth;
-double ratio;
-double splitAngle;
-double splitRadius;
-double supportRadius;

+getOrientation;
+setOrientation(boolean);
+getTargetFace;
+setTargetFace(Face target)
...

**SFBDirectModelling**

+Session theSession;
+UI theUI;
+Part workPart;
+SFBDirectModelling theSFBDirectModelling;
+FlowSplittingBuilder flowSplittingBuilder;
+BendSplittingBuilder bendSplittingBuilder;
+boolean prevLogical;
-Face targetFace;
-Edge targetEdge;
-int lastUndoMark;
+String theDialogName;

+SFBDirectModelling();
+main();
+show();
+dispose();
+initialize();
+update();
+updateData();
+setPreview(boolean logical);
+apply();
+ok();

**BendSplittingData**

-Face targetFace;
-Face northFace
-Face southFace;
-Face westFace;
-Face eastFace;
-Edge targetEdge;
-boolean orientation;
-double offset;
-double splitDepth;
-double ratio;
-double splitAngle;
-double splitRadius;
-double supportRadius;

+getOrientation;
+setOrientation(boolean);
+getTargetFace;
+setTargetFace(Face target)
...

**FlowSplittingBuilder**

+Session theSession;
+Part workPart;
-boolean active;
-FlowSplittingData fsData;

+pasteUDF();
+getFSData;
+setActive(boolean active);
+isActive();

**BendSplittingBuilder**

+Session theSession;
+Part workPart;
-boolean active;
-BendSplittingData bsData;

+pasteUDF();
+getBSData;
+setActive(boolean active);
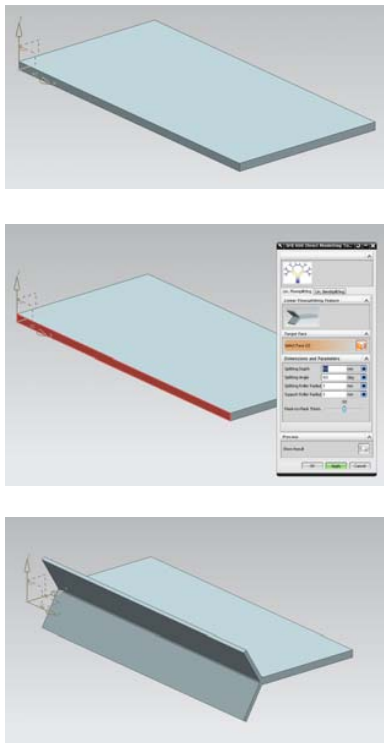+isActive();

Fig. 5. Simplified UML diagramm







Fig. 6. Modeling example

*Linear Bend Splitting Feature*

The linear bend splitting feature works in almost the same manor as the linear flow splitting feature. In order to define the position of the cleavage an additional edge (or line) has to be defined. This edge is the reference for the offset of the bend splitting feature and defines the opening direction of the cleavage.

*Model History*

Whenever one of the created features is applied to a model, the feature appears as a new entry in the model history. Each entry has a unique name, consisting of the feature name and a number added by NX. The model history allows direct access of the created features for parameter variation or feature deletion.

## VI. CONCLUSION

In this paper the development of design features for integral sheet metal design with higher order bifurcations in NX 6 is introduced. User Defined Features are used for geometry and required calculations. Unlike former UDF-based methods, the presented method does not change the overall volume of the modified part. Hence intermediate steps of the production process can be modeled. Furthermore modeling with the presented tool and UDFs is similar to the production process of linear flow splitting itself, where the bifurcated profile is formed incremental from the raw metal strip. Usability and modeling

time aspects were covered by introducing a way of semi-automatic insertion of the developed UDFs with a toolbox based on the NX Open Programming Interface. NX Block Styler is used to create a GUI that provides NX characteristic look-and-feel. The application supports direct modeling of branched sheet metal structures and enables the designer to add bifurcations to existing models as well as modeling bifurcated sheet metal structures from the scratch. Thus designers can apply the new manufacturing methods within their common modeling environment of NX 6.

In order to support the upcoming technology of deep drawn bifurcated sheet metal parts and curved sheet metal structures, which are topics of the second phase of the CRC 666, new modeling methods will be developed. Research will focus on both, the UDF-approach and direct manipulation of Boundary Representation structures.

### ACKNOWLEDGMENT

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