PARAMETERIZATION OF THE TOOL GEOMETRY AS A PREREQUISITE FOR THE SHAPE OPTIMIZATION OF TOOL SURFACES

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ABSTRACT

The requirements to parametric design methods in car body construction are changing by the increasing application of high strength materials and in addition by the subsequently ongoing development of CAD- and PLM-Systems. The optimization of geometry elements and mainly the adjustment of all depending geometry objects refers today no longer only to one forming process and its tools. The optimization rather refers to a complex chain of forming stages and all involved tools. The presented paper analyses the changes and the resulting new boundary conditions for CAD applications used in production planning and construction to support the tool making process. The development of single associative-parametric solutions, named features, within the given base PLM system is needed. Thus also new stable mathematical algorithms for surface and solid design are required.

Parts made of high-strength steel show more spring back effects than ordinary steel. The compensation of these effects by adjusting tool geometry will be necessary, in order to manufacture accurate parts for car body assembly. The compensated tool surfaces are computed and optimized today by means of FE simulation. This leads to a mesh based description of the compensated surfaces. To initialize the processes of solid tool design and tool machining one needs a CAD format thereof. The effort of converting this mesh based surfaces coming from production planning into a form which is applicable in solid tool design and machining is becoming more and more a global bottle neck in the work flow of virtual tool making.

Three new CAD applications are presented, which accelerates the tool design and at least the machining of tools substantially. The first solution describes a method to automatically convert the optimized spring back compensated surface given in discrete mesh data to continuous NURBS face data. It serves as bridge between FE simulation and further design steps, done in CAD- or PLM-environment. The second solution covers the “quick” die design, which is requested in production planning. The method available today is to discretely design die addendums which are automatically augmented to a continuous NURBS face format. The production planner then receives a surface model consisting of so called “active faces”, which prepares the solid tool design and tool machining without any need of rework. The third solution describes a parametric method for the automatic computation of the bases bodies and active faces which are required to design and manufacture trimming steels.

Keywords: spring back compensation, die design, trimming steels, restrike tools, tool making, parametrical design, solid modelling, PLM, PLE

1. INTRODUCTION

Since the second half of the 90's one works intensively on the associative-parametric representation of surfaces for die design in car body construction. The first goal was to develop a parametric model for the die addendum which corresponds to practical proceeding /2/. With this approach the second step was to create a complete solution for die design by coupling the known features as tipping, design of binder and die opening line. Software tools e.g. METHOPLAN (iCapp, Zurich) and also VIKING (Inpro, Berlin) and DIEDESIGNER (Autoform, Zurich) have been developed. Now, 10 years later, the production planner is able to provide lots of different die designs in shortest time.
systems for further process steps like surface- and solid modeling need NURBS faces. Groups of designers are used to convert the data, coming from the production planning, which were present mostly as pure meshes to continuous NURBS faces. A problem occurs: All associations and parametric for the die design, which were provided before in mesh based system, get lost. An integrated optimization which covers both, die design and solid tool design is not possible using two different systems with two different data bases.

Mr. Mbang of DaimlerChrysler /7/ spoke in this context at tool maker forum in Sinsheim (07/02/07) about the 2-nd paradigm change. The first one was the replacement of the drawing-table by 3d CAD-systems. The 2-nd change now is the transition of the different single solutions in CAE/CAD (e.g. Mr. Griesbach /4/ gave in 2001 an overview of the workflow at AUDI, fig. 1) to the holistic treatment of the whole process chain of tool making, the so called Product Lifecycle Engineering (PLE).

Spring back compensation means to modify tool surfaces in order to compensate spring back effects of the sheet metal due to the forming process. Today the compensation calculation is done automatically by the use of FEA simulation (e.g. OUTIFO, MASHAL, AUTOFORM, LS-DYNA...). But an effective adjustment of tool geometry can only be done, if the whole chain of forming operations will be taken into account.

In order to compensate the spring back effects that appear e.g. after the trimming operation partially within the deep drawing stage, both operations has to be considered in the optimization loop. If the tool maker will not be able to virtually do the compensation, he has to use "Trial and Error" method. This means not only a critical delay but also high costs. Mr. Roll from DaimlerChrysler estimated in /9/ that one correction loop for the compensation of all tools (OP 20 – OP 60) e.g. for a hood inner needs 10 weeks and causes costs of 150.000 €.

Geometry optimization in the future has to refer the whole operation sequence (fig. 3). Apart from the well-known requirements of stability, computation speed and lean data structures above all a constant update methodology for the geometry objects -the features- is required. This is provided today within CATIA V5.

Since the iterative optimization of the die is mesh based -due to the discrete formulation of the FEA method- the transfer of these data becomes necessary into a continuous description with NURBS surfaces. The active faces are
needed for the following design steps. One also can observe, that active faces are requested more and more by the production planning departments in order to set up more accurate simulations of the whole forming sequence. The need for continuous surfaces is moving forward related to the process chain. In former times one had only about 30% of all active faces in production planning, today one has about 60% (Fig. 4).

The design of active faces, which builds the link between production planning and further design steps, could not really be parameterized so far. This bottleneck in the process chain became ever closer.

2. SPRINGBACK COMPENSATION - AUTOMATIC SURFACE RECONSTRUCTION

The following approach has been developed to automatically transform given NURBS face data, describing the original shape to the deformed, i.e. spring back compensated, shape of the die.

The input data to the automatic compensation consists of the original and compensated mesh, and of the CAD data of the tool in question. The two meshes code a non-uniform movement field for the CAD surfaces. This means that each surface must be morphed to a new shape, which in general is no longer of the same surface type, i.e. planar surfaces will not stay planar, cylindrical surfaces will not stay cylindrical and so on.

The obvious data model for the surfaces is the NURBS basis, because it allows to increase the flexibility of a surface by inserting knots. A second ingredient is a powerful NURBS approximation scheme as given in /10/. So the main loop for each surface is: check accuracy, approximate, check, locally insert knots, until the desired tolerance is met everywhere within the range of definition of the surface. This process produces surface patches with a maximal gap of two times the given tolerance. To end up with compensated surfaces that still form a solid within tolerance, the latter has to be chosen accordingly. In order to handle trimmed surfaces correctly we have to establish a globally defined field of movements. We use the notations in /8/ to describe our approach. We solve for the unknown vector valued parameters \( \lambda \),

\[
M(p) = \sum_{i=1}^{n} \lambda_i \Phi(||p - p_i||)
\]

with \( \Phi(r) = c_i \chi_i = \text{harmonic radial basis function} \)

Where \( n \) is the number of movement vectors. This allows us to specify a movement everywhere in 3D space, which is needed to morph the basis surfaces of trimmed faces. The procedure has been realized within the software PANELSHOP (iCapp).

Figure 5 shows the work flow with view of the data. The geometry modification outside the PLM stream is necessary to adapt the NURBS surface data to the compensated die shape.

The evaluation and compensation is done by software OUTIFO and PAM STAMP 2G (ESI Group, Paris) /6/. Because the transformation of the faces runs fully automatically, the compensated surface data could be handed over automatically from the simulation system to the PLM system. Figure 6 and 7 show the CAD data of the die before

\[
M(p) = \sum_{i=1}^{n} \lambda_i \Phi(||p - p_i||)
\]

\[
M(p) = c_i \chi_i = \text{harmonic radial basis function}
\]
and after the compensation. The vector field is represented colored.

**Figure 7:** Spring back compensation, detail of Fig.6

### 3. DIE DESIGN – AUTOMATIC COMPUTATION OF HIGH QUALITY ADDENDUM FACES

The use of parametric profile curves to define a parametric addendum surface as proposed in /2/ is nowadays used commonly /6/ /12/. The market leading software packages DIEDESIGNER (Autoform) uses a mesh strategy while DIEMAKER (ESI Group) is based on a hybrid formulation. The global shape of the addendum can be well described, but the problem to ensure continuous transitions of a NURBS based addendum surface to the part boundary was still not solved thereby.

If linear triangle elements are used to connect to the part boundary, it is sufficient to adjust a C0-continuity. But if the designer works with NURBS surfaces and his intention is to use the resulting faces afterwards for solid modeling and machining, then the transitions have to be C1 continuous at least. The calculation of the addendum surface should further be done by the use of a low number of supporting profile curves in order to avoid small undulations in the resulting NURBS surfaces introduced by the local generation scheme for profiles.

If sweeping or lofting functions are used for surface calculation, self intersection problems emerge (They will be illustrated later in chapter 4). In addition to this it remains unclear at which spine curve the sweep should be oriented: The part boundary or the die opening curve? If Coons-patches will be used to span surfaces between the profiles, the wall angle can not stay constant, if the rail (die opening curve or the part boundary) is strongly curved.

A special algorithm has to be developed: The different sections of the profiles must also get different boundary conditions. In this way it could be managed to transport the process relevant characters along the part boundary and the die opening curve despite the use of a low number of profile curves. At the same time the transition to the part boundary has to be ensured as C0 and C1. The variable or constant blending to the binder face is then computed afterwards easily by any standard blending function of the PLM or CAD-System.

**Figure 8:** Use of less profiles for die design: four different profiles define the addendum for the symmetrical back hood inner

**Figure 9:** Smooth surface creation along the part boundary and the die opening curve at the same time while keeping the wall angle constant

The algorithm works as follows: The main task after each patch surface of the addendum has been computed, is to make the surface network overall C1. Because the patch construction uses only local information one can not compute C1 a priori. The necessary conditions to archive C1 continuity between two arbitrary NURBS surfaces are given in /1/. Unfortunately the problem is more involved because it has to be assure C1 at vertices where more than two surfaces meet. An approximate solution will be computed by searching for a solution to the unconstrained minimization problem:
where \( N_k(u,v) \) is the normal of surface \( k \) evaluated at \((u,v)\), and the set of \( u_{ki} \) are corresponding points along the seam of the two surfaces in question. If no solution could be located, some knots are inserted into the 'failing' surface seams and the iteration starts again. On successful termination the normal deviations of neighboring surfaces are less than \( \text{tol} \). In the application DIEMAKER this is solved with \( \text{tol} = 0.1 \) deg, which is sufficient for today’s solid modeler. The procedure has been realized within the software DIEMAKER for PAM-STAMP 2G and DIEMAKER for CATIA V5 (ESI Group).

Figure 10: Continuous transitions between addendum patches and part boundary are ensured

4. TRIMMING STEELS – AUTOMATIC DESIGN OF CASTING BODIES AND ACTIVE FACES

For the manufacturing of a fender today mostly two or three trimming operations are used. For the 3d construction of the trimming steels a workload of more than 100 hours incures. The trimming steels together with the restrike tools become time critical, because of their large number of different parts. In order to design them efficiently the active faces are needed as input data. But designing active faces is complicated and time consuming: They can not be easily derived from the die face model. Because they are running along the 3d trimming curve within the complex 3d shape of the die surface, they also can not be constructed following any predefined process relevant parametric. This means later changes of the product faces can not be used for any automated geometrical update of the mentioned tools.

Efficient design processes must include the update management of changes and reduce the manual effort to the conceptual and creative activities. The level of detail should be optimally adapted to the needs of further process steps. The assigned calculation methods must also be robust and should follow a process relevant associative-parametric approach. In addition the internal linkage of the geometrical objects should enable any exchange of product data.

When using conventional CAD-functions -like sweeping or lofting- to design trimming steels a substantial problem occurs: Internal overlaps arise, if the radii of the 3d trimming curve are smaller than the expansion of the cross section profile (Fig. 12, 13). To solve this problem a robust algorithm sweeping a profile along a spine curve and simultaneously eliminating all possible self-intersections of the resulting solid was developed.

The main ingredient is an algorithm that is capable of offsetting a 3d-curve under the constraint that one axis of the moving local coordinate system is fixed. The general offset condition for a curve in 3d states: A point of the offset-curve is considered valid, if there is no point on the original curve with a distance smaller than the desired offset \( O \). The fixed axis \( n \) is used to decompose the offset direction into a normal and an 'outer' compound. The offset direction \( o(t) \) is

\[
o(t) = n \ast o'(t) \quad \text{leading to curve} \quad c_o(t) \\
c_o(t) = c(t) + O \ast o(t)/||o(t)||.
\]

All of points of \( c_o(t) \) are tested against the offset criterion, and only remaining points are used to construct the final curve.

Figure 11: Base bodies of trimming steels for a side panel of Porsche

To compute the active surfaces one has to consider several constraints. First of all for each point on the trimming curve one has to determine a collision free outer direction which does not lead to self intersections. If possible this direction must be perpendicular to the working direction, otherwise it must be perpendicular to the local surface normal. Then one has to assure that while the tool moves towards the part, the first point of contact of the active surface is always on the trimming line, therefore avoiding possible global collisions with other parts of the sheet metal. Next one applies offsets or shear to the active surface to generate a smooth cut, i.e. one assures that not all of the trimming curve is at once in contact with the part.

Figure 11 shows the bases solids of the trimming steel – created with the new algorithm- which are needed for the production of a Porsche side panel. The designers workload could be reduced from approx. 40 to 2 hours.
Figure 12: typical 3d trimming curve (left) with conventional designed trimming steel (right)

Figure 12 and 13 illustrate the problem: Along a given 3d-curve on a 3d-surface model a cross section profile is to be moved, in order to describe thereby a body.

Figure 13: Part, trim curve range and profile

Figure 14: Sweeping a profile along a 3d trimming curve mostly results in an invalid body with self intersections

Figure 14 shows the occurring self intersection when using conventional sweeping or lofting functions. Figure 15 shows the body computed with the described new algorithm. The automatic design of active faces is shown in figure 16. Additional to the self intersection problem the requirement to prevent collision and backdraft has also been solved. The procedure has been realized within the software PANELSHOP (iCapp) and also TSE (CATIA V5 CAA, Cenit, Stuttgart).

Figure 15: Result of the new algorithm, all self intersection could be removed

Figure 16: All active faces could be calculated automatically. A backdraft correction was as well implemented as a collision correction

5. CONCLUSION

In the introduction the changing conditions of the virtual process chain for car body tool construction have been described. The control of the total process chain is needed especially for using high strength steels with huge spring back behavior. Additional to the today’s management decision in most automotive companies the mentioned process control calls for the integration of CAE and CAD activities for the purpose of production planning and 3d tool design in one PLM system.

The optimization of individual geometry elements has to be handled ever more under consideration of several or even all forming operations. As a condition for optimization loops parametric solutions for all used 3d tools and other geometry objects must be present. By the use of purely native general purpose CAD functions stable parametrical approaches can not be find due to the complex 3D die surfaces.

The presented paper shows three process relevant new mathematical solutions to substantially improve today's process chain: A fully automatic algorithm transforms the NURBS surfaces of a die on its spring back compensated surface, which is represented by mesh data. This approach builds the bridge between mesh-based FE optimization and
the required NURBS based surface generation. (PANELSHOP, iCapp, Zürich). The second presented solution, which was integrated into software DIEMAKER for CATIA V5 (ESI Group, Paris), is to create continuous and smooth NURBS faces for die design. The third solution is to completely automated design casting bodies and all needed active faces for trimming steels (TSE, CAA V5, Cenit, Stuttgart).

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