Die Surface Designer System

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***Abstract*—This paper defines Die Surface Designer (DSD) System for fast draw die in the product development feasibility phase on surfaces coming from styling. We propose a CAD integration, for better support the design process in industry, particularly on the development of new products in automotive sector. The DSD system intends to reduce the lead time by providing and integrating flexible and efficient capabilities for testing early concepts from surface analysis points of view in automotive product development.**

I. Introduction: Background and Motivation

The creation of a new product (e.g. new vehicle, new airplane, etc) is a complex task, characterized by uncertainty and variability. It requires the cooperation of experts in different fields and the analysis of the several aspects involved - both general and specific ones, such as brand positioning, target market, customer requirements, costs, style and performance attributes, specific company target cascades and naturally homologation rules [1,2,3]. Research has shown that upwards of 70% of a product's manufacturing cost is dictated by decisions made during the product design phase [4].

Much research has been undertaken in this area in an attempt to enhance the product innovation process in organizations [5,6,7]. Despite considerable progress there is still significant room for improvement. In particular Product Development (PD) in automobile industry is a complex task, starting on the Kick Off gateway where basic programme viability is established by means of, the requirements for the new vehicle, the early stages of the design take care both of the styling and the performance. While stylists attend to the aesthetics through drawings or virtual sketches, engineers prepare the basic vehicle organization through specific digital models. The key elements of the exterior and interior package dimensions and preliminary locations of major modules and components are selected to verify ergonomics and homologation rules. Then, virtual simulations are performed to check if the conceived design would work under various intended usage situations, thus satisfying customers and feasibility constraints. This implies interactions among the different actors and design loops until the basic checks are satisfied before starting the detailed product design. Moreover, not only one proposal but some alternatives are created whose feasibility aspects have to be evaluated.

High and strong competition in the automotive sector forces companies to minimize changes and then to produce new vehicle models based on the previous ones without major changes in order to reduce costs. Both styling and analysts strongly rely on past experience: it often happens that a collection of past solutions, possibly coming from different projects is put together with newly conceived parts to have a first version of the new vehicle on which they refine the specifications to be considered in the detailed design. To speed up the evaluation process at this stage different kinds of data and digital representations (such as surfaces, simplified components volumes, 2D sections, and ergonomic rules) are simultaneously used. This pre-design activity generally requires 3-6 weeks or even more due to the time required to retrieve and adapt existing data to the needs of the different software tools which are used independently. In fact, existing automotive feasibility analysis packages (mechanical, ergonomics, regulations, benchmark databases, and so on) are usually not defined in a unique environment and not fully integrated into CAD systems.

We would like to fix our attention upon two steps of the automotive engineering process: the body elements design and the production feasibility check of these elements. Although these steps belong to different knowledge areas, the efficiency investigation of the entire production process brings them together for sharing skills and tools; it's here that the use of a particularly designed tool can help to reach the goal of enhancing the productivity.

The main goal of the feasibility check is to prevent future troubles during industrial production of the CAD designed model. Using forming simulation algorithms it tries to predict the sheet metal behavior during the stamping phase, allowing the die designer to correct unwanted effects and to succeed in realizing elements of good quality and of best fit with the designed models. At the same time this check can provide, to the element designer, a useful feedback on how the details and the limits of the industrial manufacturing process interfere with the style creation process, giving a guide for designing elements of good industrial quality with limited production costs.

Furthermore the requirements for the readiness and the speed of the production feasibility check are always more stringent, opting today for the just-in-time, especially during the design of those external elements that contributes to the style of the vehicle, always more creative, and at the same time to its overall perceived quality.

One of the main automotive industry goal today is to decrease, or ideally avoid, aesthetic defects as well as style reworking due to impractical manufacturing design.

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The industrial product must conform with quality standards expressed in mathematical form as surfaces of class A or class B.
To reach this point there is an urgent need of renewing the product feasibility check step, in terms of precision and speed; these are influenced by: (1) sheet metal die technicians experience; (2) precision and realization speed of blank holder and addendum surfaces to pass as input to the forming simulator; and (3) precision and computation speed of the forming simulation software.
The goal of this investigation project is to develop a software tool which can help sheet metal die technicians to realize blank holder and addendum surfaces faster and better, making them more responsive during the evolutionary design phases. We are speaking about a CAD module that will make the overall process as automatic and precise as possible.

II. STATE-OF-THE-ART

The production feasibility check, normally today starts working by importing an element's CAD model into the forming simulator, which transforms the CAD quality level surfaces in a triangular (or more generally polygonal) mesh; this is necessary to ease the complex computations needed (mainly integration functions).
At the time of writing, the great part of forming simulation software's owns a module for the automatic parametric generation of the blank holder and addendum surfaces for an imported model. Using this module and proper operator input, the simulator extends its internal element's mesh model to reach the size of a real sheet metal; the simulation is then performed on this complete sheet metal model.
The main industrial importance of this automatic generation, in comparison with the manual creation of the corresponding geometry in a CAD environment, becomes clear when this step must be repeated several times. This is due to the fact that the starting element's CAD model keeps changing, as a result of the evolution in its design; this can both be because of style needs or for changes required as a result of previous simulation steps. When the design process has completed, and the production feasibility check has been passed, the real final blank holder and addendum surfaces must be manually generated into a CAD environment and added to the element's CAD model for subsequent die production by a CAM factory. The blank holder and addendum surfaces automatically generated by the forming simulation modules are in practice discarded and manually recreated into the CAD environment.
This happens also in several cases when the sheet metal die technicians need to modify the blank holder or the addendum surfaces automatically generated by the forming simulator. Sometimes more complex shapes are needed to correct unwanted effects not taken into account by the simulator itself; in those cases the die technicians have no choice but to leave apart the simulator add-in and turn back to manually modifying the original element's model in a CAD environment; then they use this modified model as the starting point of the forming simulation.
The main limit of this approach clearly resides in the simple mathematical internal representation of the surfaces needed by the forming simulator, as opposed to the complex one normally used by CAD systems, which is usually made of NURBS surfaces. The complexity difference creates a gap between the two systems, CAD and simulator, which are forced to work separately each other, often doubling the work to be done.
Polygonal meshes are too poor, from a mathematic point of view, to grant the desired industry class A or even class B quality required today. And when further changes to the model are needed, polygonal meshes lack the desired pliability, so that the only practical way to obtain industrial quality results is to leave behind the simulator module and to manually recreate its results in a CAD environment.
Our proposal to overcome this limit is to develop a CAD module for the automatic generation of quality blank holder and addendum surfaces, which means, as explained, that they will be created with NURBS. With a tool like this the CAD element's model on which the simulation should be performed will always be the model of a complete real sheet metal.
The quality of the starting models would grant a higher precision output from the forming simulation than that available today, giving a higher degree of acceptance to the following recycle steps.
It will save time, and obviously money, in all the cases where automatically generated blank holder and addendum surfaces do not meet sheet metal die technician's needs. Even if the automatic generation process should not be smarter than the one actually used by the forming simulation model, its output would be at least immediately usable and/or modifiable, which is not in current state of the art.
Furthermore, nowadays the blank holder and addendum surfaces must be manually created at least one time when the feasibility check has been passed and the die must be produced; this task will be automated (at least partially) by the DSD System.

III. DSD SYSTEM

Although CAD Systems have improved dramatically in the last years, and its use is nowadays widespread in the automotive industry, there is no product on the market which offers any structured help to the sheet metal die technicians in designing the blank holder and the addendum surfaces needed for sheet metal dies production. This task is in fact regarded today more as artisan than industrial.
Maybe CAD Systems designers have held for too long their focus on how the user can create models and surfaces, not regarding why these models and surfaces were been created. The DSD System would help to shift this focus on everyday industry needs, and would be the first proposals to assist sheet metal die technicians in doing a bulk part of their work. The DSD system could also be a better quality replacement for the previously described add-in module of the forming simulators, in every situation where it is needed. As such, there are several reasons why we think that this tool would be strategic for the automotive production

process: (1) it would bring improvements in the forming simulation field, creating results with higher precision and of better industrial quality which must not be discarded at the end of the phase, but that can be re-used and enhanced in the following industrial production steps; (2) it would shorten the time needed for the generation of the final blank holder and addendum surfaces, achieving shorter new product development cycles; (3) it would give to the CAD model designer the opportunity to commit a remarkable part of the work with the warranty that the results obtained would be already validated by a forming simulator and would comprise only real die-grindable surfaces, increasing the role of SMEs in projects with OEMs; and (4) it would be applicable to every transport enterprise project, not only automotive.

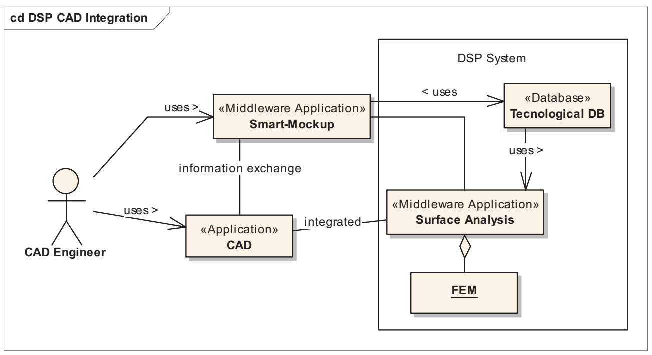

Figure 1: CAD integration of DSD system.

DSD system can be integrated into a CAD system through ´~available and appropriated plug-ins. Figure 1, shows DSD integration in CAD system and its usage. A detailed description can be found at [8]. Users can access directly DSD system or can access through CAD tool or Smart-Mockup application. DSD system has a: (1) technological data and (2) surface analysis module based on FEM (finite element method).

The **Smart Mock-Up** software tool consists on a fast modeling and assembling framework to support users in building fast and smart virtual mock-ups, during the entire semi-automatic translation phase of the briefing requirements into ergonomic and engineering constraints. The Smart Mock-Up application will process all the data collected and interpreted by the Knowledge Repository and integrate it into a 3D modeling and visualization environment. In other words, the application will assist the users involved during all the process stages, starting from the brainstorming phase, through the concept creation, to the earliest steps of specific analysis and simulation tasks to design a vehicle prototype.

Figure 2, shows the working process with DSP system. The automatic updating of the draw die shapes during the development steps of A and B class surfaces, according a knowledge technological library, for a fast evaluation of possible zones of aesthetic defects for avoiding reworking in the manufacturing phase or penalty point from the OEM quality department, is of paramount importance. In detail, the Die Design and Technology Department needs to process mathematical models (even B-Class quality), with the aim of auto-generating parametrical outshape 3D models, to bring into FEM and simulation software.

This feature leads to a dramatic improvement in terms of time reduction. Starting from the extraction of important parameters from the components ready of stamping in an historical library of technological feasibility, (e.g maximum curvature shape, size, material, thickness, among others), this module alerts for possible future manufacturing problems and designer from begin will try to solve this problems

In order to comply with such needs, the styling output rising from the Smart Mock-Up environment would be filtered through one more ontological inquiry step.

The ontology design phase, in fact, would care to create a knowledge base, interpreting and translating the skilled expertise's of Die Design component matter into parameters, to be stored into the database. Such parameters will be operated as a Boolean Sum ("And" operation) with the output results arising from any inquiry concerning the style (packaging, ergonomic and homologation rules).

In this vehicle product development phase is strategic to predict the results that can arise in product industrialization by means of the preliminary evaluation of the risks of

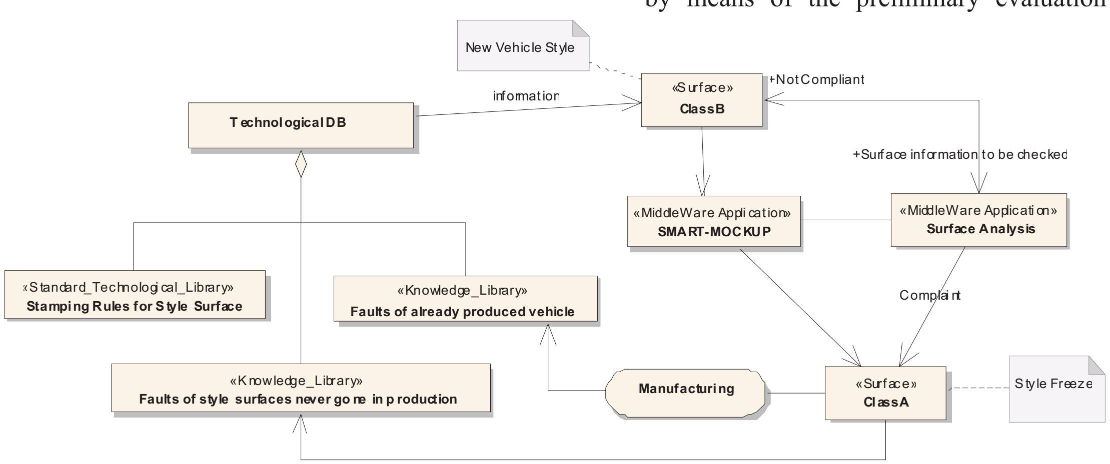

Fig 2: DSP system.

products for not technological compliance or low quality surfaces, or also perceived customer craftsmanship.

This process doesn't impact with the creativity and sensibility of the stylists, but can significantly increase and help the style efforts towards feasible products through some technological warnings that avoid these quality risks since the first style proposals.

Besides, a revision zero objective in manufacturing phase of a vehicle is a must that allows high costs saving and right first time products.

The 3D model resulting after the styling operations, can be further operated with the "stamping parameters" and will be ready to get the correct out-shape template from an out-shape library.

Of course the entire process will mime and affect all the peculiar phases, created to solve the styling issues: from the ontology creation, through its interrogation, to the output consisting in the visual 3D model (conveniently picked among all the 3D templates). The challenge is, therefore, to create a correspondence between any outshape 3D model and each visual 3D model, obtained from the output of the styling inquiries.

In other words, the ontology would be enriched of appropriate parameters, coming from the translation of the Die Design and Technology Department expertises. Then, the styling result (the visual 3D model) will be operated with all the opportune parameters, which will be subsequently embedded into the 3D model, to manage further edits. Afterwards, the export phase would close the model, freezing the parameters into the final mathematic model to be exported into FEM code for the mould simulation.

IV. Working Methodology

DSD can be used on PD integrated with a CAD tool and we suggest five steps as illustrated in Figure 3.

Figure 3: Five steps working methodology proposed.

A. Step 1:Model balancing

The operator starts by opening an element's CAD model. The system then automatically computes the most convenient spatial orientation for the model in order to remove (or at worst to minimize) any undercut zone.

If there is a removal that cannot to be handled by the system, the operator will be warned and can then take control and give subsequent input to the system. In this case the removal of the remaining undercut zones will be manually completed using a specific designed tool to develop flanges. In Figure 4 you can see in yellow the original model and in purple a developed flange.

Figure 4: A developed flange created manually.

B. Step 2: Addendum preparation

After balancing the element into the most suitable view, the operator is asked to create a curve which encloses all its external profile; let's define this curve logically as the model enclosing curve. The DSD System then automatically fills any hole in the model and creates the connection surfaces between the given model enclosing curve and the external profile of the model. Every surface automatically created will be in curvature continuity, which assures smooth surfaces. In Figure 5 you can see the DSD System resulting calculation of connection surfaces (orange), which were achieved after the creation of the model enclosing curve (black). The element that was imported into the DSD System is also visible in the figure, visualized slightly brighter than the connection surfaces.

C. Step 3: Blank holder creation

When the system has achieved a correct selected area, the next step is to achieve a 3D surface model. The surfaces that are modelling the blank holder will be automatically generated, by the input from the previous step and the external profile of the CAD element together with an operator defined smoothing parameter. In Figure 6 you can see the expected results (in yellow the starting model). As in the case of 2D, if the automatic generated results aren't suitable for a particular element's model, the operator will be able to modify the model manually by using traditional CAD tools.

Figure 5: Addendum preparation. The resulting connection surfaces after definition of the element's surrounding "model enclosing curve".

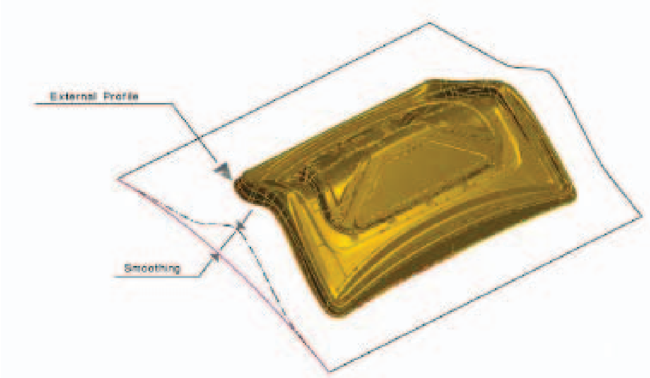

Figure 6: The expected surfaces of the blank holder, with indicated dimension affected by the smoothing parameter.

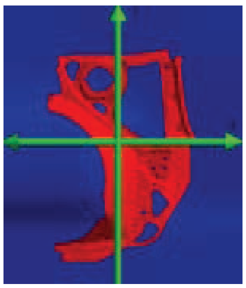

Figure 7: Blank holder dimensions, X and Y axis.

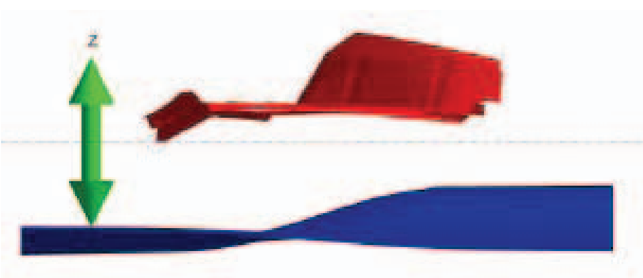

Figure 8: Blank holder relative height, Z axis.

There are certain dimensional key parameter inputs that give the operator an oppurtunity to control the automatically generated surfaces, which are defined according the X,Y and Z axis (see Figure 7 and 8) .

D. Step 4: Addendum creation

In this step any header of the model must be closed using specific automated designed tools (Figure 8 shows an example in purple of the expected results).

Then the operator creates a set of sections each starting from the model enclosing curve created in step 1 and ending on the blank holder. Those sections can be given in the form of 2D splines that the system will convert in arcs and lines, or directly in this latter form; furthermore at every point where a section starts, the operator will have the opportunity to put geometrical constraints (such as tangent and curvature continuity).

The system will then automatically generate the addendum surfaces starting from the input sections given by the operator. In Figure 10 you can see an example of the first method explained; in yellow the starting model, in grey the blank holder, and in green the expected results obtained from the light green hatched section starting from point A.

In Figure 11 a hint of the second method available; the user constructs the desired profile using arcs and lines.

E. Step 5: Model changes management

If any changes should be applied to the starting element's model, two chances arise: since the whole CAD system is parametric, the changes may be confined to parameters' values or not. In the first case the CAD system should be able to apply the same actions taken in steps 1 through 4 to the new geometry, ending up in new blank holder and addendum surfaces in an entirely automated process. In the second case the changes involve the model's geometry, and the system is not sure it can apply the same actions taken before. The only possible solution is to compare the changed element's model with the original one, identify a geometrical transformation which brings from the original model to the new one, and then apply this transformation to the final result of the original model. Exceptions may arise in case the parameters' changes cause substantial geometry modifications; consequently the automated process could stop at an intermediate step, and the case should be treated as the second one.

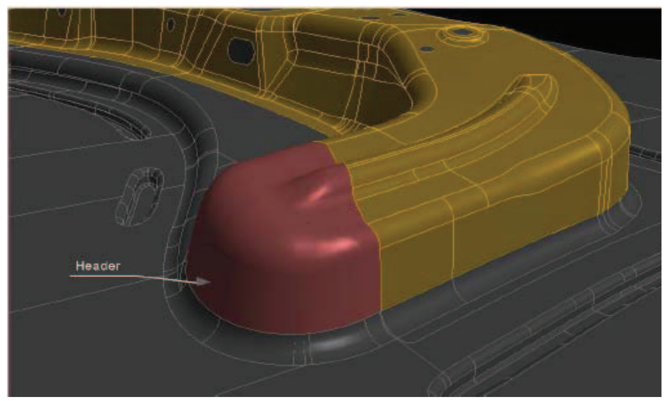

Figure 9: Expected results in header closing.

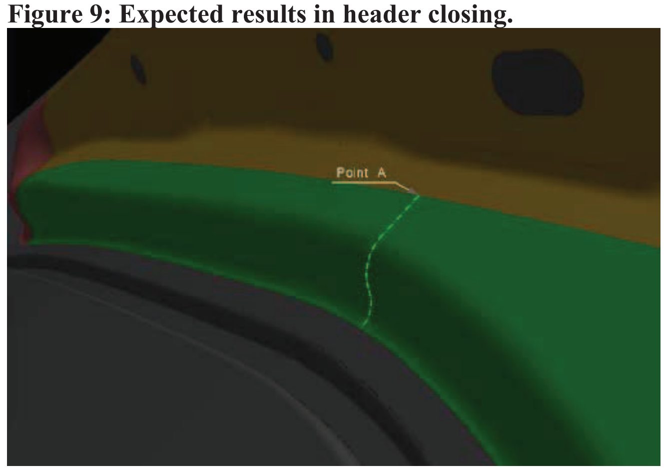

Figure 10: Expected addendum surface starting from one 2D spline section.

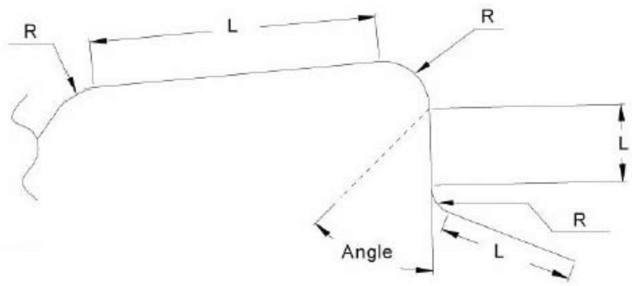

Figure 11: Section creation with arcs and lines.

V. CASE STUDY

The ideas presented in this paper are the basis for what is needed for vehicle development — knowledge of system interdependencies, time frames, cost, supplier information, and so on, is known since the beginning. Changes can still be made but their consequences are quickly understood though user-friendly computer environment, similar of all day use. A top-down, requirements driven development process that leverages the knowledge of the past programs and lesson learned, is the best way for automakers to rapidly develop the variety of new vehicle models they'll need in the future. The focus of the research program is the feasibility phase strongly related to the kick off of the new product and to the first styling surfaces sketches. We perform a case study in an Italian designer Pininfarina <www.pininfarina.it>. Output of this case study is been used to improve CAD and it is important in the training of end-users. Due to information confidential, we present case study in a generic form. Pininfarina test was full one-shot vehicle model frame, applying all of their checking procedures on surfaces in ergonomics, stamping and normative issues.

Let's consider the production of a niche vehicle, which is going to be produced in 70000 vehicles during 3 years. Typical "customer concern weighting and in plant actions" are related to stamping problems of outer panels, for instance, where it could happen to occur in the under rocker zone and in the rear quarter panel as scratches, reduced thickness, dings or slip style radius.

Keeping into account that it's considered normal to have about 5 small problems for each rear quarter side, the time necessary for solving these problems is summed to 22 minutes. This is giving an average cost around 14€ for each rear quarter side.

Similar problems can occur in the tailgate, the hood, the inner and outer segments of the doors, the roof and also the fender. These areas, in addition to the two rear quarter sides for each car, give a total waste of 6,86M€ for the full production of 70000 vehicles.

The mentioned defects could be reduced or eliminated by rigorous actions and the DSD System implemented in the feasibility phase of the product development. DSD System will provide software that allows Right First Time approach, high quality improvement and concurrent engineering, not quantified on "a-priori base".

VI. CONCLUSIONS

In this paper the authors propose a software framework aimed at supporting the validation and set up of the initial surface analysis process related with manufacturing stamping physical limitations on die.

The proposed system will save considerable amount of time in product bringing to early stage stamping feasibility checks. Reducing working time will conduct to cost reduction. This CAD environment is complemented with other validation based on past experience, ergonomics and homologation rules. Central and flexible data base will give the opportunity of accessing and sharing information among different development and production phases.

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