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3D Roll Forming in Automotive Industry

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Summary

We present a new concept for the production of conventional and load optimized roll formed profiles. Due to the consistent application of the most advanced finite element simulation software and CAE planning tools a very first 3D roll forming center was developed completely virtually.
First parts have already been produced successfully. The production of profiles varying both in width as well as in height prove the flexibility of this new concept.

Key Words: Roll Forming, Rapid Prototyping, 3D Roll Forming, Hybrid Material

1. Introduction

Over recent years the automotive industry has been focusing heavily on the subject of weight reduction in order to meet legal requirements for CO_2 emission and fuel consumption. A weight-optimum body in white can be achieved by using topological optimization algorithms. However, this leads in many cases to complex part geometries which cannot be manufactured by the known and common roll forming processes. Even with production-oriented design this kind of parts is still not accessible for the classic sheet metal roll forming process due to their variable geometries. Only profile shapes with a constant cross section over their longitudinal axis can be roll formed with the current technology. However, due to the fact that roll forming is a progressive sheet metal forming process with a high energy efficiency and characterized by its ability to form high tensile steels there has been a concentration on the improvement of the roll forming technology.
These developments resulted in the 3D roll forming technology, which has extended the limits of this process drastically: it now allows the production of profiles with variable cross sections. Its advantages like high productivity and energy efficiency remain unchanged.
The advancement of a proven process chain of CAE tools in combination with the digitization of the production process made this progress in 3D roll forming possible. In this context the rapid development of non-linear finite element simulation and control technology must be highlighted.

2. Efficient Planning Tools

In traditional roll forming of geometries with constant cross sections proven design-process-chains are being used. Starting point for the process design is a CAD system. The CAD model of the desired profile is the basis for the development of forming tools and a suitable forming machine, respectively.
In the first steps, a so-called flower pattern is developed, defining the subsequent incremental bending steps from a flat strip to the final profile. The cross sections in each bending step are the basis for the following design of the required roll tooling.
Tooling and machine parameters (distance of forming stands, distance of roll axes, stiffness of forming stands) are, in the next step, essentially the input to build a finite element model. The effort to build the finite element model is reduced to a minimum as highly specialized pre-processors are doing this job automatically directly from the CAD system. The simulation using special FEA-solvers allows for a quick validation of the modelled forming process. The tool engineers can thus easily investigate and benchmark different variants of forming strategies. Due to the fact that the (normally) time consuming and error-prone FEA modelling job has been eliminated, product development is accelerated substantially and product quality becomes predictable.
The roll forming tooling can be optimized in iteration loops, considering factors such as product quality, the quality of the forming process itself (dimensional stability, surface finish, process stability…) as well as cost for tooling and cost for the whole production process (roll tool dimensions, number of forming steps required…). data M's software package COPRA® is already providing a highly efficient workflow in the design and simulation process for classic roll forming.

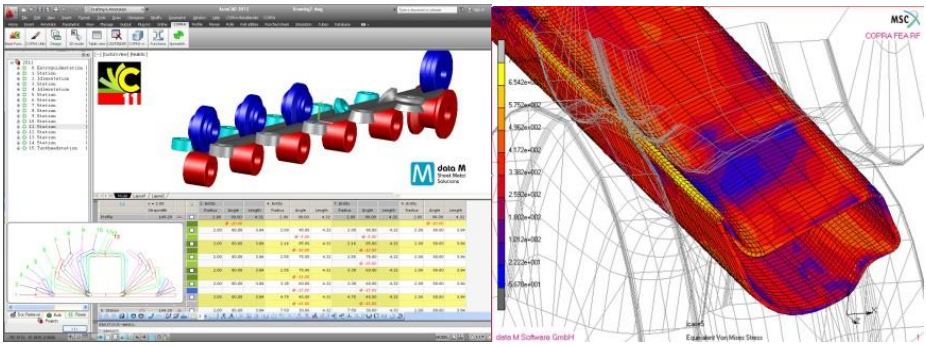

Figure 1: COPRA® - Leading Roll Tool Design and Simulation Software

2.1 3D Roll Forming

Compared to “classic roll forming” the so-called “3D roll forming” widens the range of application by profile shapes having a variable cross section over its longitudinal axis. This necessitates also further development of the proven planning workflow and requires new tooling concepts.
A single flower pattern for all subsequent forming steps is no longer sufficient to describe a 3D roll forming process. Instead it is necessary to develop individual flower patterns for every single cross sectional geometry occurring in the 3D profile have to be developed. This directly leads to the question of the correct sheet metal pre-cut for profiles with variable cross sections. The various profile flower patterns take us to a first draft of the required pre-cut. The real size of sheet metal pre-cut has to be determined by some finite element simulation. This is because the forming strategy used has a decisive influence on the strip edges and thus on the contour of the incoming sheet strip.
Subsequently multiple challenges are to follow regarding the roll forming line and its roll tooling concept. For instance - every single forming roll has to fit into different profile cross sections. The rolls are moving along the variably changing profile geometry in order to ensure a continuous forming. For a width-variable profile this means for instance a combination of rotational and translational movements within the profile’s flanges. This may lead to collisions between roll and profile or even between the rolls itself, if the tooling was not optimized in advance. Other challenges to be taken into account are the kinematic and dynamic behavior of the forming machine.

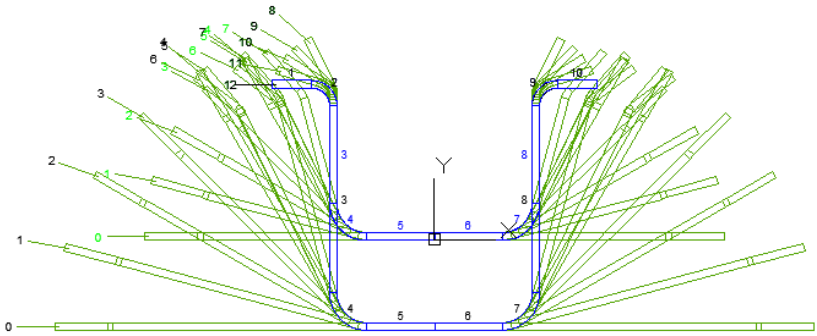

Figure 2: Flower Pattern of a load-optimized Profile

Depending on the shape of the load matching profile to be produced the work space of all the roll forming stations should be determined. The maximum roll forming speed is limited by the dynamic behavior of the forming stand’s actuators. All these calculations are, for example, incorporated in the evaluation of economic efficiency and the dimensioning of electric drives or mechanical parts.

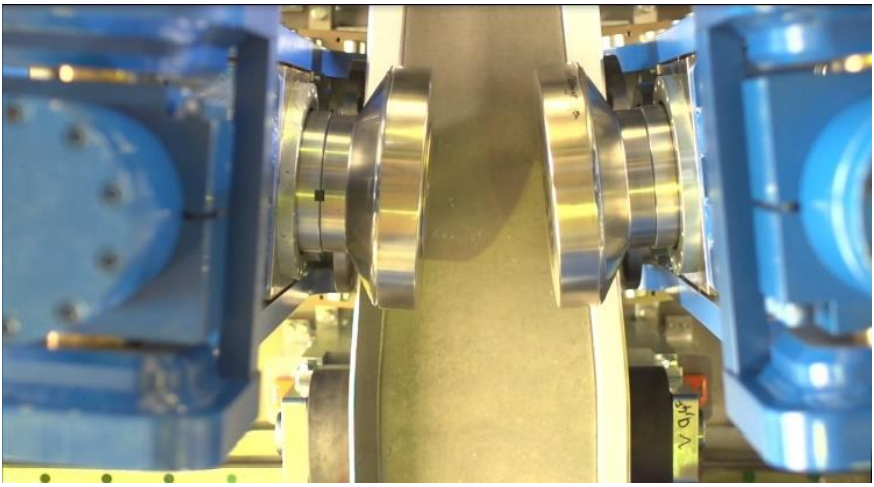

Figure 3: Top view of a load-matching U-Profile in a 3D roll forming line – rotation and translation of stands in one roll forming station

2.2 Process Planning Tools for 3D Roll Forming

The process planning tools for 3D roll forming are based on the already established design-process-chain of COPRA®. The software module COPRA® RF assists in the design of profile flowers and forming rolls – also for load matching 3D profiles. A software interface offers the possibility to export the complete roll tooling to the 3D CAD system Autodesk® Inventor in order to conduct collision checks or fit into an existing machine design.

The central point in the virtual process development is at this stage the finite element simulation software COPRA® FEA RF. This high-end simulation uses 3D hex-elements along with an implicit solver; which due to contact, material models and friction becomes highly non-linear. This software package has been extended (within the development of 3D roll forming) by adding kinematic modules allowing the 3D roll tool movement. The roll tool curves (trajectories) are derived from the 3D part geometry and transferred to the simulation program – for each single forming tool.

The results of these simulations are providing detailed information about the feasibility of a 3D profile, for instance:

- Expected profile quality with regard to geometrical issues (Flatness, warping, bending angles of flanges in transitional areas, deviations etc.)
- Is it advisable to modify the design of the required profile to better suit the roll form process? Often related to the transition zones between different cross sectional areas.
- Range of expected forming forces, driving torques or rotational speeds.
- Does this process fit into an already existing 3D roll forming line (with regard to roll diameter, distance of axes, forming forces, working space of flexible forming stands) or is it required to design a new mill?

The following figure shows the process-planning workflow for 3D profiles at the author's company. It is being used for both – feasibility studies as well as application on already existing 3D roll forming mills.

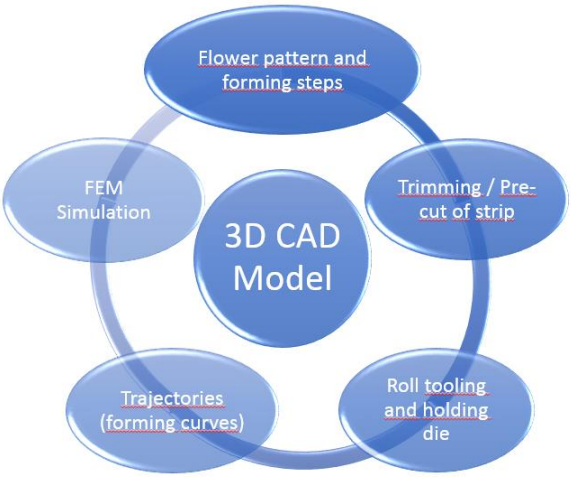

Figure 4: 3D rollform process-Planning for a new load matching profile

For the conception of a new 3D rollforming mill the same planning instruments are used. However, due to the fact that the forming tools in a 3D RF mill are being moved through complex parallel kinematics, some classic engineering instruments cannot be applied immediately. Depending on the roll tool position in 3D space, loads on the actuators can change drastically. The feedback of forming forces on the behavior of the machine's structure is thus of great importance.
The solution for this challenge is the co-simulation between COPRA® FEA RF (a nonlinear FE software) and a multibody dynamics simulation software like MSC Adams®. This allows the engineer to study the dynamics of moving parts and loads and how loads and forces are distributed throughout the complex movement of rolling tools, resulting in drastic improvement of the quality of the machine design. At the same time, for the dimensioning of the actuators, data M's engineers use control technology which has been developed specifically for roll forming lines: COPRA® Adaptive Motion Control.
This software package is in its "virtual mode" assisting in the planning and dimensioning process for roll forming of 3D load matching profiles. In a first stage the kinematic devices of each forming station are parametrized in the control. The engineer inputs the trajectories of each station and starts some simulation run on the control. The control helps (for instance for a given roll forming speed) to determine the maximum axial or revolution speed of the motor drives. During the virtual forming process, the control records the changes of velocity in each forming stand. As the dynamic of each actuator and their maximum speed are limited, this method allows (considering all controlled axes) the determination of the maximum possible speed of the whole forming process. In other words: what will be the maximum roll forming speed. Based on this principle the motor drives of such a 3D roll forming line are being optimized which in turn leads to the final mechanical dimension of the machine and the electrical cabinets as well. Clearly these

thoughts are taken into consideration in the commercial viability of the whole system.

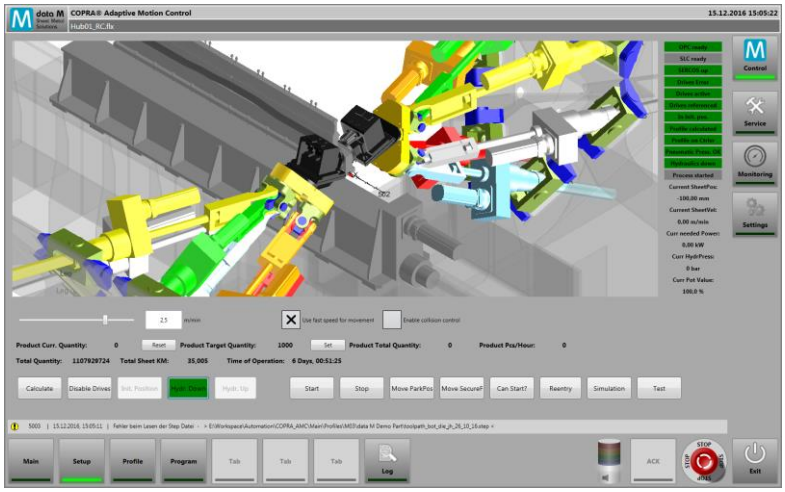

Figure 5: User Interface of COPRA® Adaptive Motion Control

3 Load Optimized Parts for Commercial Vehicles (Trucks)

Similarly to car manufacturers, producers of commercial vehicles also have an interest in light weight- and especially in load-optimized designs of their chassis frames. There is also interest in an increased number of possible variants in consequence of requirements for transportation, driving systems, special purpose vehicle bodies.

Recently the author's company has presented a 3D roll forming line for the production of chassis long members for trucks [1]. This mill allows for the production of a family of more than 50 long members with different profile geometries using only a single tool set. The high level of digitization reduces set-up time to almost zero. Simply the recipe- or program change, operated by the MES (Manufacturing Execution System) or locally by the operator, is required.

The presented machine concept is highly flexible. Therefore the smallest or largest of batches can be produced at the minimum cost and utmost energy efficiency.

Due to the use of the most advanced control technology along with specially developed parallel kinematic mechanics both geometrical and/or material changes can be compensated quickly.

Another advantage of this method is the simple compensation of spring back by adaptation of only a few forming rolls, therefore allowing high tensile steels to be roll formed reliably. The open and flexible control concept with soft- and hardware-interfaces allows for an easy integration in existing production lines. Data transfer to or from ERP- or MES systems can be realized using OPC UA.

Figure 6 (right): Example of a Chassis Frame with load optimized Long Members
Figure 7: 3D roll forming line for truck beams developed by data M

Process- and machine data can be stored in local or cloud-based data bases in real-time. Thus allowing (based on this data) the future possibility to predict machine maintenance and availability periods as well as process robustness and product quality.

4 The 3D Roll Forming Center®

Traditional Roll Forming is usually not suitable for small lot sizes. However, these are common in the production of high-class products like sports cars, SUVs or aircrafts, meaning roll forming has been “locked out” from complex geometries with variable cross sections being used in the automotive industry. This is the reason for presenting a new machine- and forming concept. Using advanced robotics, roll forming tools can be positioned freely in space. The combination of modern control technology and simulation technology has led to digitization of the production process allowing for the production of smallest lot sizes of load-optimized and also classic profiles. Alternatively this concept can be used for rapid prototyping in roll forming as well as process development and -optimization. There is also room for applications in material research – especially with regard to hybrid/ multi materials or high tensile materials. Furthermore, one of the positive advantages with this machine concept, are very low tooling costs, compared to other forming methods..

4.1 Description of Forming Method and Machine

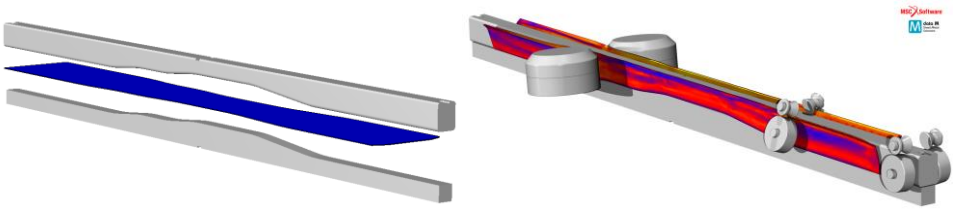

Figure 8: A flat raw sheet is placed in a die taking the shape of the profile's web. Roll forming tools move along the die (trajectories)

Like in an oversized bench vice with a prefabricated shape, the flat raw sheet strip is placed in a die, where the sheet already takes the shape of the profile's web. The roll forming tools themselves then move along trajectories in order to form the profile's flanges step by step around the top die – until the final profile shape is reached.

4.2 Concept of Machine

The 3D Rollforming Center® could be likened to a roll form simulator – consisting of a single pair of forming stands. The sheet, clamped in a die and mounted on a linear slide, passes the roll forming stands in alternating direction. The roll forming stands (one on each side) are mounted on a robot which aligns the forming rolls into the correct forming position. Given a straight profile with constant cross section, the robot would not move during one forming process – it would just keep the rolls in their position. Just before the second forming cycle the rolls will be brought into their new bending position. Several bending operations can be done with one and the same rolls. The robots have a tool changing system for fast and precise tool changes during production.
The 3D Rollforming Center® consists of a machine bed with a linear slide, hydraulically holding the driven upper and lower dies. Perpendicular to this slide are a pair of hexapod robots (left and right) each with moveable platforms holding the roll forming stands. The control system synchronizes the movements of the linear slide with the hexapods.

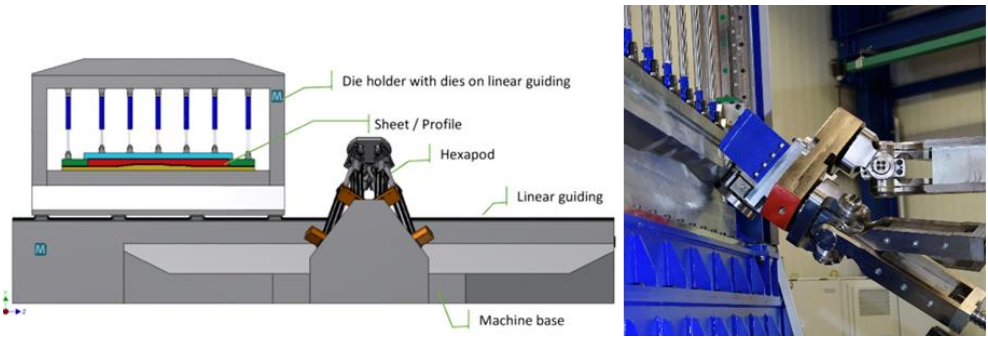

Figure 9: 3D Rollforming Center® with Hexapod Robot and Roll Tooling

Forming a 3D Profile, the robots are changing their position while the linear slide is moving from left to right (or vice versa). The hexapod mechanism is able to follow every combination of translational or rotatory movements. The greatest advantage of this machine is its high flexibility due to the digitization of the roll forming tooling. The system can react instantly to changes in material behavior, for instance, by programming additional intermediate forming steps. By using this procedure, the forming of a width-variable profile was successfully optimized – without the need of changing the rolls or making new ones, instead just by reprogramming the robot's bending angle.
Several trials to form load matching parts on the 3D Rollforming Center® have been successfully carried out investigating two categories of profiles: firstly being variable in width and secondly with variation in height.

Figure 10: Parts already roll formed on 3D Rollforming Center®

4.3 Concept of an industrial line

With the 3D RF Center® it is now possible to investigate and validate new concepts for industrial lines at a very early development stage. Profile quality, feasibility as well as prototype parts can be investigated in the forefront of any subsequent planning steps, both cost efficient and quickly. Concerning tooling, only the holding die (manufactured from simple material) and the usually very simple and small forming rolls have to be manufactured. At the author's company a concept for high volume industrial production has been developed. In a first step, the part has been formed on the 3D RF Center® and the whole forming process optimized. Additionally, by analyzing the profiles trajectories, the number of forming tools and the number of required degrees of freedom (controlled axis) could be reduced significantly in any future, proposed or planned 3D RF machine.

5 Outlook

The 3D Rollforming Center® has been shipped to a large material research institute. The target of their investigation is of course new materials such as high tensile steels and their forming behavior. The concept of this prototyping machine

is also suitable for the cost effective and flexible production, of small batches of profiles. Due to this highest flexible machine concept, both conventional as well as 3D geometries can be produced in a “rapid prototyping” manner. Further areas of interest are the development of innovative sensor technology for roll forming. At the author’s company a prototype of a new 3D laser triangulation sensor was developed. This is able to scan the full profile length in the machine. Along with respective control technology and integrated sensors the subject “big data” for roll forming 4.0 can get pushed forward.

6 References

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[2] https://youtu.be/7I1EMPflBAw YouTube: Flexible roll forming of Truck Chassis Long Members

[3] https://youtu.be/-ExYY8LfU9A YouTube: 3D Rollforming Center