Digitalization in roll forming manufacturing

A Sedlmaier, T Dietl and P Ferreira

data M Sheet Metal Solutions, Am Marschallfeld 17, 83626 Valley, Germany

a.sedlmaier@datam.de

Abstract. Roll formed profiles are used in automotive chassis production as building blocks for the body-in-white. The ability to produce profiles with discontinuous cross sections, both in width and in depth, allows weight savings in the final automotive chassis through the use of load optimized cross sections. This has been the target of the 3D Roll Forming process.

A machine concept is presented where a new forming concept for roll formed parts in combination with advanced robotics allowing freely positioned roll forming tooling in 3D space enables the production of complex shapes by roll forming. This is a step forward into the digitalization of roll forming manufacturing by making the process flexible and capable of rapid prototyping and production of small series of parts. Moreover, data collection in a large scale through the control system and integrated sensors lead to an increased understanding of the process and provide the basis to develop self-optimizing roll forming machines, increasing the productivity, quality and predictability of the roll-forming process. The first parts successfully manufactured with this new forming concept are presented.

1. Introduction

The weight of a car or aircraft structure is the predominant factor in terms of the reduction of emissions and fuel consumption [1]. Around 75% of the weight of a motor vehicle is divided between body, powertrain and suspension and chassis components. Reducing the weight of the body-in-white means smaller engines can be employed and smaller suspension systems are needed, so reducing the total weight of the body is crucial towards achieving lighter vehicles [2].

The application of load optimization algorithms to the components of the body-in-white can lead to significant weight savings [3], but yields complex part geometries. Traditional roll forming is only capable of producing profiles with constant cross sections, and so is unable to produce such complex geometries, while deep drawing lacks the flexibility to produce low series of parts or prototypes due to the high initial costs of the dies, with each die limited to a single part geometry and dimensions.

The 3D Roll Forming process has been developed during the last 10 years as a response to the industry’s demands for this kind of complex geometries; however, it has been limited to profiles with variable width. The forming concept presented aims to widen the range of applications of 3D Roll Forming by allowing the production of profiles with discontinuous cross-sections in both width and height. Furthermore, current profile production techniques are inefficient for small-batch production.
The presented forming and tooling concepts enable small production runs and rapid prototyping of profiles in a cost effective way [4].

The machine concept presented is also a step into digitalized roll forming due to the application of an advanced control system with possibilities to monitor machine data in real time, tooling stands capable of moving freely in 3D space, application of sensors to monitor the part geometry as it is being formed, possibilities to optimize the process in real time by changing the forming strategy and the tooling paths, and the implementation of control algorithms that limit the power consumption of the machine and avoid excessive torques or forces to prevent damage.

The real time monitoring of standard roll forming lines is also explored, especially the potential applications of this sort of data monitoring and collection in the setup process and in the prevention of machine failures. By analyzing manufacturing data together with simulated results, a better understanding of the process can be gained, a crucial step into digitalizing the roll forming process in an industrial setting. A data acquisition system developed at data M is presented, where relevant machine parameters are collected in the industrial site and transmitted to a remote location for storage and analysis.

2. A new forming concept based on roll forming

In order to manufacture profiles with cross sections variable in both width and height, a new forming concept was developed at the authors’ company. The goal was to design as flexible a process as possible, in order to be able to manufacture a variety of parts ranging from conventional profile shapes with constant cross sections to profiles varying in width and in height with minimal changes to the tooling or the machine. This is a crucial step to achieve a digitalized manufacturing process, as flexibility in production and capability to produce small series of parts are two key aspects of digital manufacturing.

A simple die with the desired shape holds a pre-cut sheet in position, defining the shape of the profile’s base. At this stage no plastic deformation has yet occurred. The roll forming tools then move along defined trajectories to form the profile’s flanges step by step. To this end the flanges are bent around the top die, until the final profile shape is reached. By employing rolls with simple geometries and freely movable tooling, the forming angle at each step can be defined by the operator in the control software, allowing for real time optimization of the process, whereas in standard roll forming changing the bending sequence requires a new set of tools.

![Figure 1](image-url)  
**Figure 1.** A pre-cut sheet is placed in a die, taking the shape of the profile’s web. Roll forming tools move along the die.

In order to achieve process flexibility with minimal tool changes, a modular tooling system has been developed. It consists of a set of angled plates and forming tools (Figure 2) that can be combined with each other to realize the desired forming strategy. A quick change pallet system is used in order to speed up the roll changes while keeping high accuracy in the positioning of the rolls.
Figure 2. The modular tooling system consisting of angle plates and adjustable roll forming tools

During the development of this new forming and tool concept, numerical simulations were carried out with the commercial finite element software package COPRA® FEA RF. The simulation uses 3D hex-elements along with an implicit solver. In order to model the new 3D forming concept, the software package had to be extended by adding kinematic modules, thus allowing roll tool movement in 3D space. The roll tool curves (trajectories) are derived from the 3D part geometry and transferred to the simulation program – for each single forming tool. Finite element analysis was a central element of the process development, providing insight into profile quality and process stability, while also providing the data to optimize the initial sheet trimming. The data from the simulations also provided a major input in the mechanical and electrical design of the machine, in the dimensioning of the actuators and of the machine base.

3. Machine concept for advanced roll forming

This new forming and tooling concept was translated into a new roll forming machine – the 3D Roll forming Center® - which can be conceived as 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 rolls are mounted on robots which position them according to the information from the control system. They must be positioned freely in space with a high degree of precision (translation and rotation) while applying high forming forces, therefore requiring high stiffness of the system. To fulfil these requirements a hexapod system was developed, employing parallel kinematics. Some components of this design have been previously applied in a 3D roll forming machine for truck long members [7].

Figure 3. 3D Roll forming Center® with Hexapod Robot and Roll Tooling.

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 performed with the same set of rolls.
During the forming of a 3D Profile, the robots move and rotate the rolls whilst the linear slide is moving from left to right (or vice versa). The operator can react instantly to defects by programming additional intermediate forming steps or changing the trajectories slightly. The flexibility of the process also opens the possibility of programming self-optimizing steps in the control software, using the data from the control system and from sensors implemented in the machine.

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 [4].

4. Real time monitoring of the roll forming process

Closing the digitalization gap in roll forming is not feasible without collecting manufacturing data in a systematic way. Furthermore, the benefits of data collection and analysis in roll forming could be enormous. Possible data streams which are being analyzed at the authors’ company are:

- Torque applied to roll forming tools via servomotors
- Force exerted by the sheet on the forming rolls using load cells
- Speed and position of the sheet using encoder wheels
- Geometry of the formed part using laser triangulation sensors

The setup of roll forming machines is a target for improvement. Currently, experienced operators adjust the roll gap and roll alignment in each station using feeler gauges and a straight edge. Material is fed into the machine and adjustments are made based on the quality of the profiles being produced. No direct information is available to the operator; he must determine, based on his experience, where the adjustments must be made. This is also the case if the machine starts producing defective parts during a production run. By implementing torque monitoring in each forming stand through the use of servo-motors and advanced control units, the operator gets a direct feedback on the work being done by each pair of rolls. By comparing the real-time values with simulated results, as well as historical data from previous runs, the setup can be verified and problematic stations can easily be identified and corrected.

Figure 4. Real time monitoring of the current (mA) being delivered to the selected servomotor, displayed on a mobile device. The dashed lines represent machine limits that must not be exceeded.
Another improvement could be fault prevention through real-time monitoring of production facilities: by comparing torques or forces in each roll forming stand with the respective simulation results extreme values can be detected, and the production can be automatically stopped to prevent machine damage (Figure 4). Production planning can be improved through analysis of historical manufacturing data: by keeping track of the length of profile a set of rolls produced before needing replacement, tool set remanufacture and exchange can be done in advance, reducing waste and downtime. By monitoring force and torque on machine stands and sheet speed and position, high-wear events such as force and torque peaks or sliding between rolls and sheet can be recorded for a better prediction of tooling lifetime.

The integration of data acquisition systems, sensors and computer controlled power units is the first step towards digitalization of the roll forming process. By creating a robust data archive, data trends can be analyzed and compared with simulation results, and control strategies can be readily implemented to mitigate problems. The end goal of this digitalization process is to achieve increasingly autonomous roll forming stands and machines, and a flexible and robust manufacturing process.

5. Results

First tests have been successfully performed on the 3D Roll forming Center®. The target was to manufacture profiles that were only previously possible with deep drawing, therefore proving the suitability of roll forming as a replacement. The following geometries have been examined:

1. A symmetrical U - shaped profile with a straight hat section along the rolling direction and a changing height of the flanges (Figure 5a).
2. A curved top hat section (with changing height of the flanges) (Figure 5b)
3. A non-symmetrical part with varying width and having a top hat section only on one side (Figure 5c)

Figure 5. (a) Roll formed long member of a light commercial vehicle; (b) Roll formed variable in height bumper section; (c) Non-symmetrical variable in width automotive part.

The part geometries in Figure 5a and Figure 5b belong to the category of height variable profiles, the one in Figure 5c to the width variable profiles. The material used was St37 mild steel. Sheets with thicknesses up to 3mm were successfully formed. The maximum forming speed was set to 8m/min.

During the tests, optimizations regarding the tool setup were achieved. The number of forming steps with the same tool setup was increased from 2 to 6 for the first bending steps of the top hat long
member geometry. The reduction of necessary tool changes (rolls and angle plates) improves the performance of the process. The ability to change the forming strategy in real time also allowed the production of profiles in aluminum (AlMg3) and stainless steel using the same basic process and without any significant tool changes, where in roll forming three different tool sets would most likely be necessary.

A laser triangulation sensor system was developed at the authors’ company in order to monitor the profile shape in real time (Figure 6). The results from this monitoring were then used for understanding the material behavior compared to prior simulations of the process, and then changing the forming steps in case there were deviations.

Figure 6. A new inline sensor for the real-time monitoring of profile geometry using laser triangulation

During the experimental roll forming trials, data collection using Open Platform Communications Unified Architecture (OPC UA) was tested. OPC UA implements a binary protocol directly on the TCP layer. Thus, the handling overhead in the transmission of a given data volume is minimized. Furthermore, in every clock cycle OPC UA only transmits real changes to parameters. Testing was performed through the implementation of a OPC UA server in the control unit. For each axis four individual parameters were traced (position, force, torque and following error), plus some general data on the status of the line. In total, data on 394 individual parameters was transmitted and stored with a clock cycle of 5ms. Despite encrypting and streaming this data between locations physically separated by several hundred kilometers through a conventional DSL line, data collection was limited by the speed of storing the data in a database rather than the data transmission itself. For a control unit with a reasonable specification this demonstrated that data collection is feasible using OPC UA and there is no need for any special, additional data interface.

The test described above did not employ any specific sensors or other measuring equipment. Data on the position, velocity and torque of each axis was generated by the control unit for controlling the servo motors. This demonstrates that even without sophisticated measuring equipment informative data may be collected for subsequent analysis.

In further tests, a real-time monitoring system was implemented, warning the operator in case of violation of tolerance limits. Again the relevant data was streamed from the control unit to the monitoring server using OPC UA. The analysis of the stored data also allowed the development of a
power control algorithm that limits the power consumption of the machine by reducing the forming speed, further enhancing the environmental friendliness of the process.

6. Conclusion

A new forming and tool concept for flexible roll forming is presented. To apply this new concept a new advanced machine with hexapod robots was developed and studied. It allows the manufacturing of complex 3D profiles variable in width and in height. First parts with different materials and thicknesses have been successfully manufactured, proving that 3D roll forming is a viable replacement for deep drawing.

The well-established virtual design chain based on the implicit finite element solver COPRA® FEA RF was extended with capabilities for simulating general 3D roll forming problems. Thus, the manufacturing process and design can be defined, modelled and verified before it is actually implemented.

Due to the digitalization of the roll form tooling, rapid prototyping of roll formed parts is now accessible. Profile prototypes can be manufactured in a fast and cost efficient way. Optimization loops are short as the tools are simple and highly flexible, design flaws are minimized. The actual part is produced in the same process as later in the industrial roll forming line.

New software tools, sensors and data acquisition systems have been developed for the monitoring of manufacturing processes. In a next step, industrial lines will be equipped with this technology. These represent a step forward in understanding the data streams coming from roll forming and their application. Further improvements of the data collection process, enhanced monitoring strategies and feedback for improved simulations as well as machine and product designs will follow.

References

[1] Fontaras G, Franco V, Dilara P, Martini G and Manfredi U 2014 Development and review of Euro 5 passenger car emission factors based on experimental results over various driving cycles Science of the total environment 468 1034-42.
[2] Eckstein L, Göbbelsist R, Goede M, Laue T and Wohlecker R 2011 Analyse sekundärer Gewichtseinsparpotenziale in Kraftfahrzeugen ATZ - Automobiltechnische Zeitschrift 113 68-76
[3] Sedlmaier A, Hennig R and Abee A 2011 Fabrication of Load Optimized Truck Members with Variable Cross Sections by Flexible Roll Forming Proc. Int. Conf. on Steels in Cars and Trucks (Salzburg)
[4] Abeyrathna B, Abvabi A, Rolfe B, Taube R and Weiss M 2016 Numerical analysis of the flexible roll forming of an automotive component from high strength steel IOP Conf. Series: Materials Science and Engineering 159(2016)012005
[5] Sedlmaier A and Dietl T 2015 Recent Advances in the Industrial Application of Flexible (3D) Roll Forming for Automotive Parts by the Use of Modern CAE Tools Proc. IDDRG 2015 Conference (Shanghai)
[6] Abee A, Sedlmaier A and Stephenson C 2010 Development of new 3D roll forming applications by means of numerical analysis as a part of a quality control methodology CBM Metal Matters 18 21-23.
[7] Dietl T, Sedlmaier A and Schneider T 2016 Multiachs Steuerungstechnik im Einsatz für die Herstellung von Walzprofilen (mit 3D Konturen) Proc. 36. EFB Kolloquium (Fellbach)