Development of new 3D roll forming applications by means of numerical analysis as a part of a quality control methodology

By André ABEE*, Albert SEDLMAIER*, Carl Stephenson**
* data M Sheet Metal Solutions GmbH, Am Marschallfeld 17, 83626 Valley, Germany
** data M (UK) Sheet Metal Solutions Ltd, Hilton Hall Business Centre, Hilton Lane, Essington, Wolverhampton, Staffordshire WV11 2BQ

Abstract
Quality management in roll forming became more and more important over the recent years. Besides the stimulated demand for good material, tight machine and tooling tolerances, this has been boosted by the introduction of conducting Finite Element (FE) simulations over the last 5 years, in the design departments of material suppliers, machine makers and custom roll formers. This has resulted in a positive increase of know-how and understanding of the roll forming process and thus roll forming is now well on its way from the “Black Art/Book” experience level to that of a more scientific approach.

The acceptance and benefits, drawn from performing such FE simulations, in daily roll form design practise as a part of the total quality management are presented in this report.

This evolution of conventional roll forming can be seen as the base for the development of discontinuous “flexible” roll forming. For this purpose alone it has appeared that more than ever, it is important to understand the behaviour of roll forming processes. The complex interrelations between hardness, control and design and their impact on the process and the profile's quality are topic of scientifically substantiated practical orientated investigations including numerical analysis. The requirement for fundamental investigation in the field of flexible roll forming is also presented in this report.

Whereas flexible roll formed profiles with a variation in width has been the main talking point in process development up until now, the increasing pressure from the automotive industry stimulates the development of strategies to produce profiles with a variation in depth and height. Important issues are the understanding of the process and the machine realisation at minimum cost in order to be competitive with press operations. This report details these investigations and objectives of today's studies.

1. Introduction
Text books tell us, roll forming is a bending technology with rotating tool motion used to manufacture open and closed profiles. In order to obtain the desired profile several stages are used, feeding a cut strip of metal through successive pairs of stands.

As we are all aware, compared with other forming processes, classic roll forming offers a number of technical, economical and ecological advantages e.g. high productivity at low tool costs.

The restriction of producing profiles with a constant cross sectional shape in longitudinal direction has now been overcome by the development of the so-called “flexible” roll forming process. [1] Approximately 10 years ago, the roll forming know-how was merely on an on-site expertise base between the machine operator and the tool-designer, with the foundation of years of practical experience. Several possible effects were known, and in most cases the machine operator and tool-designer knew how to react. From day to day new phenomena would appear and a solution had to be developed. All that counted was the fact that the manufacturing process continued. Understanding why or what they were doing was – if at all – only second or third priority. It can be noted now, that the roll forming process is far too complex to understand and describe all interrelations on a practical base only.

Nowadays, the tool designer has access to FE simulation in order to investigate and optimise the roll forming process. This has boosted the possibilities of and the need for understanding of roll forming processes dramatically. Now the Tool Designer, Machine Operator and colleagues of the R&D department can increase the company specific in-house know-how of their roll forming process and make it accessible to all. [2]

2. FEA and quality management in roll forming companies
Serious concerns about quality management in roll forming process were increased further by the possible increase in “company specific” know-how of the roll forming process. By means of the application of finite element software to simulate the roll forming process, the closeness of this numerical tool to the designer of the roll-tooling and machine operator appears to be very important. In typical roll forming companies, no Finite Element specialists are available and even if so, the understanding and communication between the Tools design department and research department are quite often very difficult and fragmented.

2.1 Simulation as a part of quality management in daily roll forming business
Typically, a roll formed profile will pass through the development stages as presented in Figure 1 on the route from conception to a produced part.

Figure 1. Roll forming experience and FE simulation in daily roll forming practise

Quality Management has to cover all stages in this development process, and can be carried out by different standards in the design work, roll production, tool quality approval and machine setup; through to the monitoring of quality during production. [3],[4] A further quality control can also be obtained by a serious implementation of FE simulation software, as a standard tool in the design phase, in order to optimize the design prior to tooling manufacture. This can now be observed in many roll forming related companies such as machine makers, tool makers, custom roll formers, and in some cases the steel supplier. Another typical company related quality aspect can be found in the learning process of simulating processes that are in operation. Weak points in the production can be detected and optimized. The above figure clearly illustrates that company internal experience in roll forming is essential to success. It can be observed in modern roll forming companies that the available roll forming experience is being logged by applying FE simulation, in order to guarantee success, and then access to this knowledge base is shared amongst all employees. This is the basis for the possibility to further increase the level of Roll Forming experience within the organisation.

2.2 Goals for finite element simulation in roll forming
The main goal for companies applying finite element simulation of roll forming is to increase the process stability. A typical first application can be found to increase the understanding of the roll forming process, and aids to learn about more about the in-house processes. Furthermore, finite element simulations are performed in the design departments of roll forming tooling nowadays, in order to predict achievable geometrical tolerances. Additionally the process can be optimized to run at reduced forces, reduced roll tool wear, minimum material load, and minimum energy consumption and so on.
Several other parameter studies can also be applied in order to investigate the influence of deviations in the material properties, sheet thickness or other imperfections like tool wear, machine deviations or different machine settings. With respect to roll forming of high strength and ultra high strength steels, it can be considered that the deflection of the machine shafts is a serious phenomenon, which influences the process and profile quality significantly. [5]

3. Discontinuous roll forming

Typical phenomena in discontinuous - flexible - roll forming are caused by necessary geometrical elongation and compression of the material in longitudinal direction in the transition zones. [6] This is the major difference between flexible and conventional roll forming, as traditionally no remaining longitudinal elongation or compression is required or desired in the finished profile.

The contact between the roll tooling and the material is situated in a small bending area directly in the forming stations only. Thus, compensations for the described necessary deformation in the transition zones, reflect in geometrical deviations of the finished profile dimensions, therefore the goal for well designed flexible roll form tooling is not to compensate, but to avoid these detrimental effects. [6]

A high level of roll forming experience is required, but alone this will not be enough to develop an appropriate design for a specific family of flexible roll formed parts. Consequently, an understanding of the working principles of flexible roll forming tooling, and the ability to performing "high-end" finite element analysis is required.

3.1 Discontinuous in width direction

The manner in which the necessary elongations and compressions react in the profile is determined on many parameters such as cross sectional shape, forming step, roll design, material properties, sheet thickness, etc.

For the convex transition zone (area A in figure 2) the length \( L_{out} \) is larger than the length \( L_{in} \) in the flat sheet. In the final part one can see that \( L_{out} = L_{in} \) with \( L_{in} \) unchanged; therefore a compression of \( L_{out} \) is necessary. The opposite is required for the concave transition zone (area B in figure 2), which can be can be found as: \( L_{out} < L_{in} \) in the flat sheet, \( L_{out} = L_{in} \) in the final profile with \( L_{in} \) unchanged, thus an elongation of \( L_{out} \) is necessary.

It should be noted that it is not only a compression or elongation of the strip edge (indicated with \( L_{out} \)), but it is a compression and elongation of the complete areas A and B respectively.

Furthermore it can be derived that this geometrical compression and elongation is only depending on the flexible radius and the instantaneous normal distance between a point in area A or B and the profile web during forming. This distance can be described by the "leg-length-radius" in typical flexible in width profiles (figure 3).

3.2 Flexible in depth direction

Whilst flexible roll formed profiles with a variation in width is the main subject matter until now, the increasing pressure from the automotive industry forces the development of strategies to produce profiles with a variation in depth, thus development of suitable forming strategies, necessary kinematics and special tooling are the main topics within the newly formed R&D department within data M Sheet Metal Solutions right now.

Typical profiles [8] are presented in figure 4.

Figure 4. Typical profiles flexible in depth.

Finite element simulations have confirmed the possibility of forming profiles which have flexibility in depth, and have also proved that the geometrical elongation and compression of the material in rolling direction depends only on the flexible radius and the "flexible leg length". However, contrary to profiles flexible in width, this distance is not constant, but typically dependent to the flexible angle as well.

Figure 5. Top view, side view and unfolded pre-cut sheet of a flexible in depth profile.

The necessary geometrical elongation and compression is indicated in figure 5 by the hatched areas and can be clearly recognized. The distance between the flexible radius and the strip edge is dependant to the current flexible angle for typical automotive parts where the mounting ear of the top-hat shaped profile in one plane. Because of this, the kinematic forming path is not equidistant related to the pre-cut sheet.

Another interesting issue is the fact that the kinematic path is not strictly a real existing path in the pre-cut sheet, depending on the chosen forming strategy. This is related to the difference between the profile length and the respective length of the pre-cut sheet as indicated with \( DL \) in figure 5.

This requires an additional control parameter to guarantee a well coordinated material feed in the rolling direction which is not constant anymore. In this case it is advantageous to have an integrated control system for the complete line.

The first feasibility studies of such flexible in depth profiles have been performed at data M, figure 6 shows a result of a study in FEA for a typical automotive top-hat part.

The mounting ear of the profile is in one flat plane whereas the height of the profile varies through the length of the profile. Such profiles can be found in for example in the structural side members of a car or light trucks.

Typical dimensions are \((85-110) \times 180 \times 2.2 \text{ mm} (H \times W \times T)\) and are typically produced in high strength steel.

continued on page 23
The previously mentioned essential geometrical elongations and compressions can be clearly recognized in figure 7. This figure shows the longitudinal strain in the final part. A compression is evident in the side flanges and the top-hat mounting ears caused by the forming of the convex flexible radius, in the bottom of the top-hat profile. A further elongation can also be found in the side flanges which is also evident in the top-hat mounting ears, caused by the forming of the concave flexible radius, in the bottom of the top-hat profile. The longitudinal strain is higher in the areas with a larger distance between the flexible radius and the strip edge. That is in the deepest parts.

Some typical difficulties appear in dealing with all different process parameters, one basic issue is the definition of the shape of the pre-cut sheet, as this influences the behavior during the forming. The machine control therefore needs to take into account the kinematics in each forming station as a function of time, rather than sheet movement, since this is not necessarily constant in flexible roll forming in depth. The complex movement of the tools to fulfill the desired tool paths as prescribed by the control needed a further development of typical flexible roll forming stations. The machine concept must fit for this advanced tooling system.

4. Flexible roll forming in a productive environment

Quality management of both design and machine operation is very important to achieve a stable roll forming process, in which a wide variety of roll formed profiles at tight tolerances can be produced. Small deviations and their influence to the process must be known and must be under control, and thus data M have found through significant research and development, that with the use of finite element analysis, they are able to understand the flexible forming process in more detail and pre-empt difficulties prior to them appearing.

With FEA widely understood to be a pre-requisite for flexible roll forming in a productive environment, practical experience of the flexible roll forming process in production is minimal, compared with the respective experience that companies have in the field of conventional roll forming. Therefore the quality management must be an integrated approach of design, hardware (machine and tooling), control of the machine and scientifically substantiated investigations of the behaviour of the process.

4.1 Competition with press forming operation

Press forming is prevalent in automotive industry; with the introduction of flexible roll forming into the automotive production environment, there has been some rivalry between the two processes. Most automotive companies have well equipped press forming lines and the parts are highly adapted to the forming process. Typical parts are U-shaped or top-hat-profiles with a non-perpendicular side leg to the profile web (figure 8) because of the removal out of the tool die.

An advantage of (flexible) roll forming compared to press forming is the fact that along with top-hat-type profiles, also C-type or even closed profiles can be produced in flexible roll forming. There are no strict conditions to forming angles of bends, as found in the press forming process. See also figure 9.

4.2 Process oriented design

The production process should be given serious consideration during the definition of the profile, in order to achieve good tolerances and to minimize eventually negative influences of a specific forming process. A change of the flexible radius within acceptable dimensions, often leads to a relative large reduction of the “geometrically necessary” elongation and compression of the transition zones.

A serious definition of product-families with similar shapes for different automotive segments like small, medium, large and commercial cars in the design stage, is an important challenge which will boost the effectiveness of a flexible roll forming line, and is an opportunity to reduce costs in a productive automotive environment drastically.

5. Conclusion

The introduction of finite element analysis as a part of the roll forming design process, has boosted the understanding and company internal knowledge base of the roll forming process, over the last half decade. This allows a scientific substantiated and practically oriented development of the flexible roll forming process these days. This article shows the need for both roll forming experience and an analysis tool to overcome the complex problems and to deal with the behaviour of flexible roll forming.

While flexible roll forming for profiles with a variation in width are becoming standard, investigations in to flexible roll forming in depth, is currently a serious topic of research and development at data M. So far data M has been delivering feasibility studies, tooling and the roll forming concept to its customers. These services now include a machine which can produce prototype “flexibly - formed” rolled sections. Therefore experience in both conventional roll forming, flexible roll forming with width variation and the application of simulation software, have been essential prerequisites to discover this new and entirely different type of flexible roll forming process.
Two of Europe’s best-known experts on advanced technology for the cold rolled sector, gave the CBM’s newest trade arm a high-profile launch.

Albert Sedlmaier, the founder and MD of Data M Sheet Metal Solutions, and Professor Peter Groche, from Germany’s famed Darmstadt University, outlined the latest innovations in roll-forming manufacturing, and provided incisive analysis of the sector’s likely future.

The line-up of guest speakers for the National Metalforming Centre event was completed by Wim Laging; a specialist researcher in roll-forming materials with Corus.

Director General John Houseman told the 35 invited delegates that a specialist sector group for cold rolled sector companies had been created, to provide advice, support and networking opportunities.

“We have not previously had a trade group dedicated to cold rolling of sections, but we have now identified around 70 businesses across the UK either directly or associated with this exciting technology. We believe they would benefit significantly from the wide range of services the CBM offer to other the metaforming sectors,” he said.

“Adrian Nicklin is meeting the management teams from these companies, hoping to persuade them of the benefits of membership, and I hope he will have signed up many of the companies by Christmas, which will give the cold rolled sector group the critical mass it needs to function effectively”.

“One of the most important functions of all our trade divisions is to give their sector a voice, at the national and international levels, and I am sure member companies will swiftly come to appreciate everything the new group can do for them.”

A similar event for cold rolled sector companies is expected to be held early in 2011, and anyone interested in attending, or in finding out more about the new group, should contact Adrian at the CBM on 0121 601 6350 or by email: adrian.nicklin@britishmetalforming.com, and in his absence, inquiries should be directed to his colleague, Kirsi Lintula: kirsti.lintula@britishmetalforming.com)

The necessity of such studies is given by the demand from the automotive industry, for profiles with a discontinuous height of the profile like top hat profiles with the mounting ear in one plane. First studies of real automotive parts showed the feasibility of this process, and quantify the need for an integrated approach of design, machine tool control, hardware and simulation is essential in order to keep control of budgetary costs. A well considered definition of product-families with similar shapes for different automotive segments is an important challenge which will boost the effectiveness of a flexible roll forming line and is an opportunity to reduce costs in a productive automotive environment drastically.

6. References