XII International Conference on Computational Plasticity. Fundamentals and Applications
COMPLAS XII
E. Oñate, D.R.J. Owen, D. Peric and B. Suárez (Eds)

INDUSTRIAL APPLICATION OF ADVANCED ADAPTIVE CONCEPTS FOR AUTOMATIC PANEL BENDERS

WOLFGANG KUNZE*, CHRISTIAN ZEHETNER† , FRANZ HAMMELMÜLLER†, EUGENIA C. COJOCARU† , HELMUT J. HOLL[X] AND HANS IRSCHIK[X]

[*] Salvagnini Maschinenbau GmbH
Dr. Guido Salvagnini-Straße 1, 4482 Ennsdorf, Austria
e-mail: wolfgang.kunze@salvagninigroup.com, www. salvagninigroup.com

[†] Austrian Center of Competence in Mechatronics (ACCM)
Altenbergerstraße 69, 4040 Linz, Austria
e-mail: christian.zehetner@accm.co.at, www.accm.eu

[x] Institute for Technical Mechanics, Johann Kepler University of Linz
Altenbergerstraße 69, 4040 Linz, Austria
e-mail: hans.irschik@jku.at, www.jku.at/tmech

Key words: Sheet bending process, Finite Element Simulation, Efficiency, Model Based Engineering, Smart Crowning.

Abstract. Recently, the requirements on sheet metal production processes have increased significantly. Highest precision and flexibility with efficient energy consumption and short cycle times can be achieved by advanced concepts only. This requires a deep insight into the non-linear bending process. For this sake, efficient simulation models have been implemented to model the bending process: two and three dimensional finite element models combined with multibody simulation tools, contact mechanics algorithms and substructure techniques. The simulation tools have been successfully calibrated by measurement results. With the obtained detailed process knowledge, new adaptive concepts have been introduced, e.g. a smart crowning system in order to achieve straight profiles. The industrial application has shown the advantage of utilizing the above mentioned techniques. The straightness of the bends has been significantly increased, while energy consumption and cycle times have been reduced. Secondly, the development time of new machine concepts has been drastically reduced, such that the first prototype can be transferred to series production within short time. Moreover, the applied strategies show a large potential for future developments.

1 INTRODUCTION

Modern bending machines allow complex products consisting of a large number of sheet parts to be manufactured efficiently. Figure 1 shows, for example, cabin parts for the elevator industry which were manufactured by a panel bender from the company Salvagnini. One important criteria is the straightness of the bends at various part lengths. In order to mount the bent parts next to each other and to meet high visual requirements at the same time, the manufacture of the sheet parts must be done with the highest precision (Figure 1b).

a) not optimized

b) optimized

Figure 1: Cabin parts for the elevator industry

The requirements placed on bending machines are high, cf. Kunze et al. [1]: The production needs to be done with batch size 1, a great degree of precision and low energy consumption; the manufacture must be flexible with regard to profile form, construction dimensions and surface quality. To achieve these goals, the development process is supported by computer-aided methods and modern measurement technology, see also [2] and [3].

2 MODELING AND SIMULATION OF BENDING MACHINES

The fundamental functionality of a bending machine is schematically shown in Figure 2 in cross section. The sheet is clamped between two clamping tools and bent by the movement of the bending tool. The important process parameters are sheet thickness, material behavior, properties of the sheet surface, bending angle, leg length, radius of the bent contour, tool path, clamping force, bending forces, geometry of the clamping and bending tools, general machine dimensions, etc.

In addition, the following must be taken into account during the modeling of the forming process:

- Non-linear material behavior
- Large strains and large rigid body movements
- Complex contact problems with friction

This highly non-linear behavior places especially high requirements on the computer-aided modeling. Dependent on the specific task, different simulations methods are utilized, including finite element methods [4], multi-body dynamics [5], analytical methods and similarity methods [6]. A modular implementation enables the efficient coupling of the individual methods.

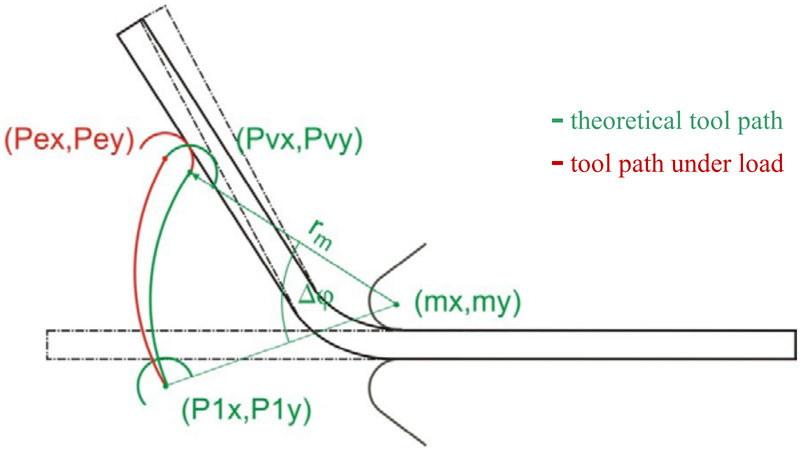

Figure 2: Functional principle of a bending machine

3 PLANE FINITE ELEMENT SIMULATION

This simulation is mainly used for the profile precision optimization of the metal sheet. Since the length of the bent sheets is much larger than the thickness, the bending process can be approximated to a good degree through a plane-strain modeling. With the two-dimensional simulation models, the effects of sheet thickness, material behavior, tool path, bending force, clamping force, etc. can be included with great precision. An efficient collision monitoring is additionally facilitated which takes the deformations of the components and the sheet into account. The plane model is particularly suitable for parameter studies due to the very short computing times. With the results, we achieve a very detailed and comprehensive understanding of the operational process.

An exemplary simulation result is shown in Figure 3. Figure 3a shows the calculated v.Mises stress for a selected bend. Figure 3b shows the forming force, i.e. the resulting contact force between sheet and bending tool. The comparison with measurement results shows a very good conformity so that we attain very good information about the occurring forces with the performed parameter studies.

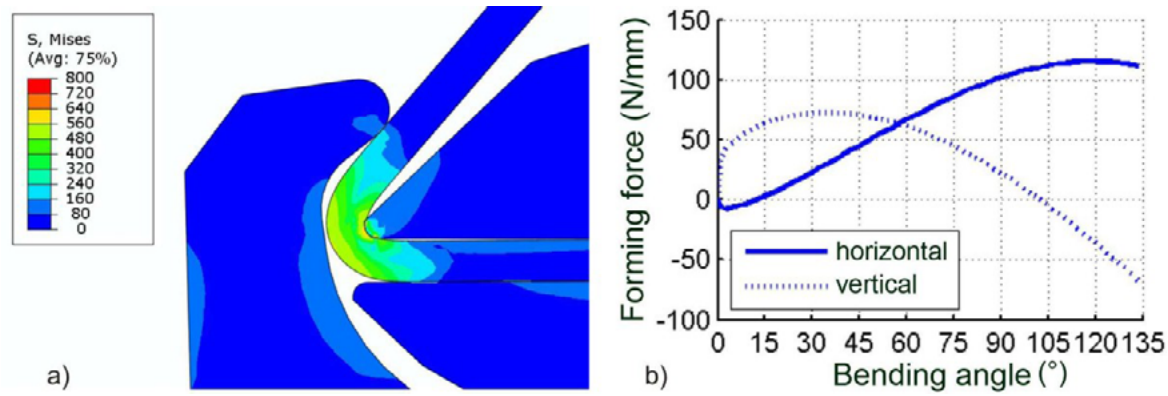

Figure 3: Comparison stress in sheet and tools, forming force

A further significant result of the two-dimensional simulation is the optimization of the tool path dependent on all process parameters. Here we differentiate between two strategies: With point contact, the bending tool remains in contact with the first boundary point on the sheet during the entire bending process. With this strategy, the width of the contact surface on the sheet is minimized. In contrast, with the rolling movement, the friction at the contact surface is minimized whereby the sheet surface is spared and deposits on the tool are prevented.

ANALYTICAL METHODS

The essential physical effects are taken into account in the finite element models. Moreover, different analytical methods are used to include additional effects and achieve a generalization of the simulation results.

For example, through geometric considerations, the influence of bearing clearance can be taken into account. The actual bearing clearance is identified from measurement results and the tool path is adapted accordingly.

The plane finite element model primarily applies for a specific sheet length, since the elastic deformations of the machine depend on the total forming force and thus from the sheet length. Using substructure technology, this length effect can be modeled in an efficient way. Another application of substructure technology is the accounting for mechanical properties of very different bending tool types.

One large disadvantage of the plane finite element simulations is that every result is only valid for a specific combination of parameters. A large number of simulations is thus necessary for comprehensive parameter studies. With the help of similarity methods, the computational complexity can be reduced significantly. An example is shown in Figure 5: Similarity methods provide us with three-dimensional forming force, whereby the results for a range of bends with different parameters coincide on a curve, for further details see also [7].

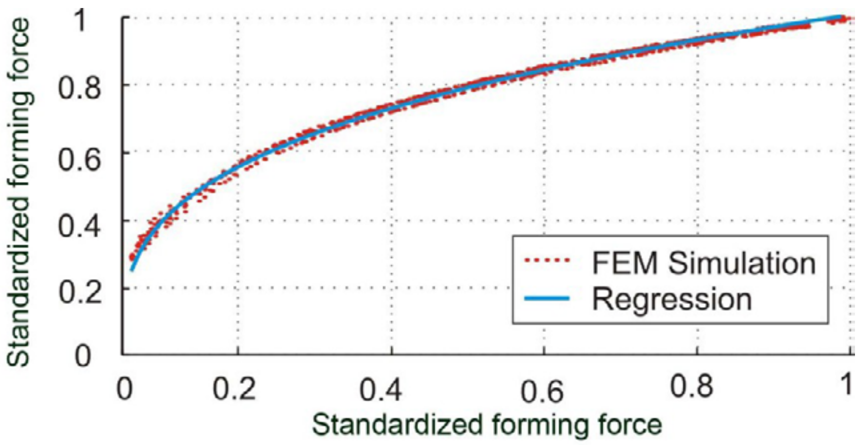

Figure 4: Generalized depiction of the forming force through similitude methods

A very good coincidence is achieved for the developed simulation model when compared to the measured results. Adaptive methods were developed for taking component tolerances, parameter uncertainties, unknown material data, etc. into account. For example, an adaptation of all parameters is carried out when commissioning a machine with a low number of bending attempts. A parameter adaptation for specific material lots through individual bending attempts is also possible.

4 THREE-DIMENSIONAL FINITE ELEMENT SIMULATION

This simulation is used for the optimization of the straightness of the formed metal sheet. The comparison with measurement results shows that the important process parameters are included with very good accuracy with the two-dimensional simulation model. For further refinement, three-dimensional simulation models were developed with which effects in the longitudinal direction of the machine are taken into account. This includes: Segmenting of the upper clamping tool, longitudinal warping of the sheet, cambered bending and clamping tools, detailed modeling of the components of the machine frame as welded construction, etc.

The efficient three-dimensional modeling and simulation is made possible by modern hardware and software. Only few years ago, a two-dimensional simulation pushed the limits of computing power. Today, a simulation of a complete forming process with a detailed 3D full model can be carried out in just several days - with outstanding conformity with the measured results.

Three-dimensional simulation methods allow us to achieve a significant acceleration of the development process. Prototypes can be saved so that we can usually manage with only one single prototype which, in the mean time, goes over to 95% in the series production. In the process, approximately two months are needed for the fine adjustment. In contrast, before the use of model-based development, a period of one year was required.

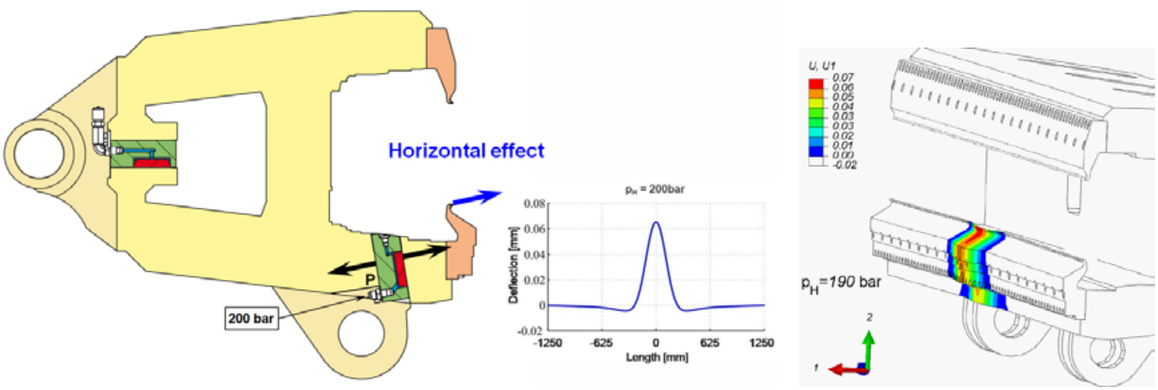

Figure 5a: Result of the 3D simulation model for the horizontal actuator

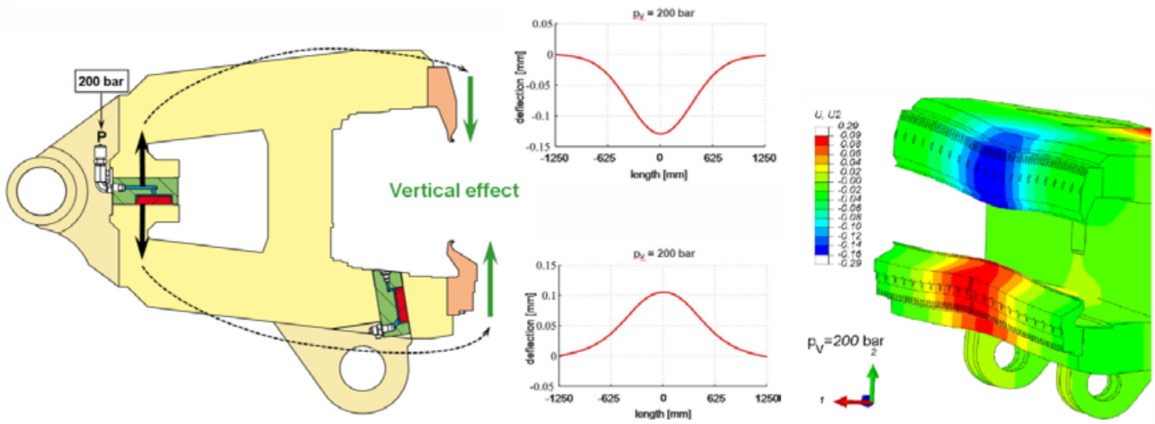

Figure 5b: Result of the 3D simulation model for the vertical actor

One important result of the three-dimensional simulation is the optimization of the tool holder, incorporating an advanced smart crowning system, to achieve precise straightness at different load. The new incorporated actuators of the smart crowning system for both directions, horizontal and vertical, are shown in Figure 5. Figure 5a shows the built-in actor for the horizontal deflection compensation and its result. Figure 5b shows the built-in actor for the vertical deflection compensation and its result. With this new possibility a wide range of new application areas arise. As an additional side-effect a wear and tear on the bending tool can be compensated for.

ADVANCED ADAPTIVE BENDING MACHINE

Through the use of the computer-aided methods presented above, the flexibility and efficiency of the bending machine was optimized in several regards. Several important examples are mentioned in the following.

1. **Minimal clamping force**. The minimum required clamping force was determined using two-dimensional simulation results and theoretical considerations. This showed that the force was able to be reduced by up to 50%. A reduced force means that working marks and thus wear are reduced.
2. **Minimal forming force**. With the results of the plane finite element simulation, the production with batch size 1 is possible for a large parameter range without additional adjustment complexity. Thus, provided no other restrictions are specified, the tool path can be set so that the forming force is minimal for every individual bend. This leads to the same advantages listed under point 1.
3. **Significant reduction of the energy consumption**. By minimizing the bending and clamping forces, the energy consumption was able to be drastically reduced in the last decade. Depending on the machine type, the energy consumption was reduced by up to 75%.
4. **Collision monitoring**. Based on simulation results, a collision monitoring was implemented which takes into account the elastic displacements of the tools as well as the elastoplastic displacements of the sheet. Thus, collisions of individual components

can be prevented and the permissible bending range is known precisely so that it can be utilized to the greatest extent.

5. **Identification of material parameters.** A very detailed understanding of the operational process allows us to draw conclusions about the material parameters and adapt the tool path accordingly. The production can thus be adapted to new sheet types with little time and effort, such as with high-strength steel used in the automobile industry.
6. **New smart crowning system.** With the obtained detailed process knowledge, new adaptive concepts, such as a smart toolholder with incorporated actuators have been implemented in order to achieve straight profiles.The industrial application has shown the advantage of the above mentioned technique.
7. **Production with batch size 1**. The use of model-based engineering leads to an increased understanding of the process with which the production with batch size 1 is possible. The machine only needs to be adjusted accordingly during commissioning and the respective material specifically matched one time.
8. **Savings for setup cycles and storage space**. Through the production with batch size 1, the adjustment complexity is reduced. That means a significant saving of time and material. An additional advantage is the reduction of storage space since the production follows the assembly expiry.
9. **New areas of application.** One example is the efficient manufacture of cabin parts for the elevator industry, so that it is possible to mount the bent parts next to each other and to meet high visual requirements as well. The manufacturing of the sheet parts must be done with the highest precision.

CONCLUSIONS

High demands are placed on modern bending machines, for example extreme precision, efficient manufacturing, short process cycles, low energy consumption and production with batch size 1. This requires a very high degree of flexibility of the metal forming process with regard to sheet length, sheet thickness, bending angle and profile form. An important requirement is the compliance with the construction dimensions. This includes the bending angle, radii and leg lengths, which all must be as constant as possible over the entire length of the bend. In addition, great importance is placed on the straightness of the formed sheet.

To achieve these goals, the development process is supported by computer-aided simulation and modeling methods, analytical methods, similarity methods and modern measurement technology. This includes coupled finite element and multi-body dynamic analyses, which take into account non-linear geometry and complex contact problems with friction. Different simulation models are employed depending on the particular task. A modular implementation facilitates the efficient combination of the individual methods.

Two-dimensional finite element analyses, under the assumption of a plane state of stress, are utilized for comprehensive parameter studies on the forming process in order to record the influences of construction and process parameters on the deformed sheet geometry, forming force as well as deformation and stresses in the individual machine parts. For a generalized observation, methods from similarity mechanics are used with which a reduction of the significant influencing variables can be achieved. Thus, constructive optimizations can be efficiently carried out.

Three-dimensional models are used to analyze the influences in the longitudinal direction of the bent sheet. Efficient simulation times are achieved through the use of the substructure technology. The use of 3D models, for example, allowed optimization of the tool holder to achieve a precise straightness at different load. This opens up a wide range of new application areas.

Using the example of a bending machine, we have shown how an efficient combination of modern simulation and modeling methods can optimize both the development and production process. The individual simulation tools can be flexibly utilized through the modular implementation. The resultant improved understanding of the process offers the potential for further effective optimizations of the entire system.

REFERENCES

[1] Kunze, W., Zehetner, C., Cojocaru, E., Hammelmüller, F., Holl, H., Irschik, H., Advanced mechanical modelling of automatic panel benders with higthest accuracy demands: Process control for a one-piece flow production, Proceedings of the 4th European Conference on Structural Control (4ECSC, St. Petersburg, Russia, 2008, ed. A.K.Belyaev and D.A. Indeitsev), Volume 2, S. 445 – 452, Russian Academy of Sciences, St. Petersburg, 2008.

[2] Holl, H., Zehetner, C., Hammelmüller, F., Irschik, H., Rechnergestütze nichtlineare Modellierung von Abkantautomaten, e&i, Elektrotechnik und Informationstechnik, Heft 9/2004, S. 319-324.

[3] Hammelmüller, F., Zehetner, C. Pechstein, A.S., Kunze, W., Holl, H. and Irschik, H., Advanced mechanical simulation models for automatic panel benders, *Proceedings of COMPLAS XII*, E. Oñate, D.R.J. Owen, D. Peric and B. Suárez (Eds), Barcelona, Spain, 3-5 September 2013.

[4] Bathe, K.J., *Finite Element Procedures*, Prentice Hall, 1996.

[5] Shabana, A.A. *Dynamics of multibody systems*, Wiley, 1989.

[6] Baker, W.E., Westine, P. S. and Dodge, F. T., *Similarity methods in engineering dynamics*. Hayden Book, Rochelle Park, NJ, 1973.

[7] Zehetner, C., Kunze, W., Heuer, R., Irschik, H. On the influence of material properties in sheet bending processes, *Proceedings of COMPLAS XII*, E. Oñate, D.R.J. Owen, D. Peric and B. Suárez (Eds), Barcelona, Spain, 3-5 September 2013.