



A railroad wheel is formed on a Schuler ring-rolling mill. Designed by Schuler

# Design, Control and Optimization of Process Chains

**Dirk Klug – Schuler Pressen GmbH; Germany**  
**Hendrik Schafstall – Simufact; Germany**  
**Markus Bergmann – Fraunhofer IWU; Germany**

Bulk metal-forming processes contribute to the efficient, sustainable use of resources through their precise design and the implementation of process combinations. The design of process chains is used to achieve targeted form and material characteristics and is based on the premise of fast and flexible production – with a simultaneous reduction of costs. This requires a preferably simple analytic approach to defining the required early and intermediate forms and the generation of data for process control and tool design. It also calls for examining individual forming operations, as well as the modeling aspects of the entire process chain. The concept is presented here using the example of railroad-wheel production.

In bulk metal forming, the challenge of reducing costs and increasing competitiveness is met through the increased use of automation while concurrently cutting resource input and improving product quality. Manufacturers are confronted with the task of having to guarantee fast, reliable and flexible production utilizing an optimal process design. An array of (oftentimes linked) systems is used to aid the manufacturer in this task. However, these systems are specialized, complex and time-consuming.

The aim of the manufacturer is to design simple and expedient production sequences while maintaining product accuracy. To help in this process, we collaborated to develop a concept implementing linked proven analytical approaches to process-chain design, the generation and provision of data for manufacturing processes, and the continuous digital simulation of the forming process chain within a modern engineering environment.

## Process Chain

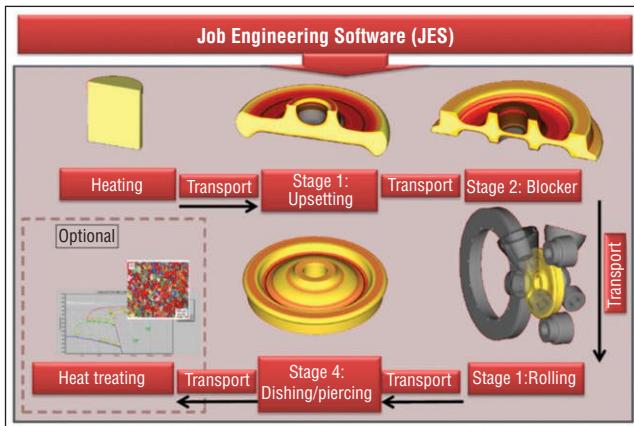
At its most basic level, the production of railroad wheels via bulk metal forming uses the following steps in the process chain:

- Separation of billets
- Heating of billets

- Preforming
- Intermediate forming
- Final forming
- Cooling and heat treatment

The shaping of a wheel solely through forging is only found in small wheels. Because of the more complex and varied cross section of larger wheels, it is essential to achieve the targeted final cross section through a graduated process. Generally, the forged early-form cross section is formed while concurrently increasing the diameter through multiaxial rolling. The final form is achieved through dishing and punching. Because of the complexity and size of the final product, an iterative process is necessary.

The initial design of the intermediate forms and tool geometry is created based on analytical approaches backed by empirical and experimental/theoretical knowledge. As part of the analytical approach, fundamental aspects such as the upset ratio, forming capacity, degree of deformation and the influence of yield stress are considered. Simplified approaches, however, do not allow the precise calculation of the forming processes necessary for the complex optimization of the process chain. This requires a numerical solution of the operations of the elemental and general theories of



**Figure 1. Process-chain modeling in the manufacture of railroad wheels**

plasticity. Through such analyses, questions concerning temperature distribution, material composition, structure and heat transfer, and the processes at the part/tool contact area can be answered.

## Forming Simulation

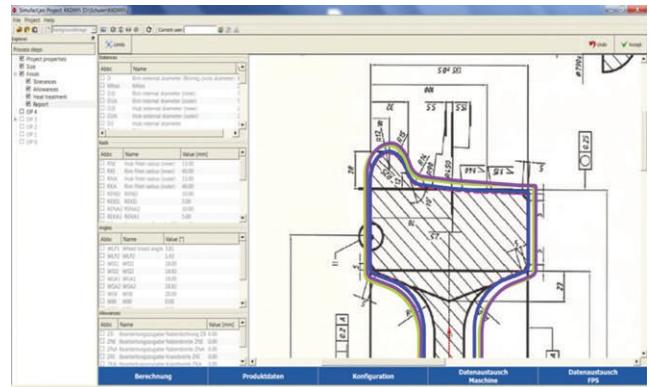
Finite-element methods (FEM) are preferred to analyze the mechanics of forming processes. The assessment and illustration of process parameters occur based on the most accurate description of the thermomechanical process. After the integration of the fundamental control algorithm of the simulation software, the determination of machine parameters is of particular importance. Additionally, the available material models (full elastic-plastic, isotropic, anisotropic, kinematic hardening, Bauschinger effect, etc.), the performance of the contact algorithm, and the description of friction, heat conduction, dynamic effects and complex tool movements play an important role in the quality of the final product.

Providing the highest possible modeling accuracy and quality results in the shortest time, which necessitates high-performance solvers. Individual optimized core technologies, tailored to the specifics of each forming process (in this case forging and rolling) and in conjunction with self-controlling optimization strategies, are available for forming process simulation.

The process simulation is only one aspect of the entire manufacturing process analysis and/or design. It is also necessary to consider the forming history of upstream processes, which is realized through the simulation of multistage processes (Fig. 1). This takes into account part and material prehistory in the process simulation. A particular challenge for the simulation of entire process chains is that they are close to production, user-friendly and easily interpretable. Also, they should allow for the possibility of being integrated with the actual manufacturing system and the process-chain design.

## Engineering Environment

The modeling environment for the manufacture of railroad wheels is based on two independently executable software



**Figure 2. Input mask JES**

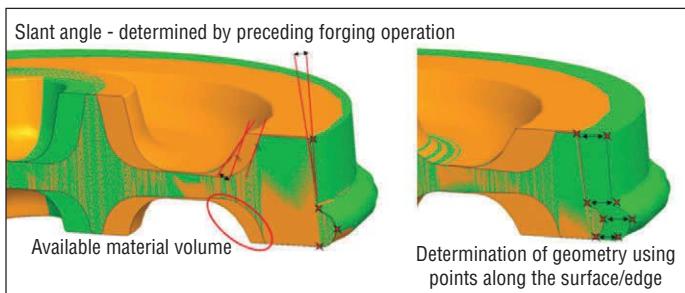
solutions. An adapted user interface is used to exchange and process data at defined interfaces with each other and with the railroad-wheel manufacturing line. At the core of both software solutions lies the information analysis and processing of the forming operations that must be considered.

On the one hand are the software solutions related to the part, such as FEM. On the other hand is the process-chain simulation of the forging and rolling operations of Simufact.forming. This job engineering software (JES) feature is included as a new tool to design stages and generate appropriate machine parameters, which in this case is the rolling strategy. The input parameters generated by the JES and the target geometry of the part and tool are utilized for machine control and for process-chain simulation. The user has the flexibility of designing and optimizing individual process stages as well as the whole process chain.

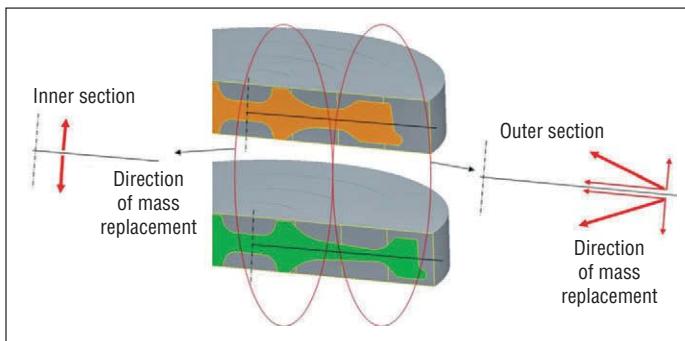
## Analytical Approach

The development of product-specific stages (termed OP) and the corresponding intermediate shapes is a complex process. It relies on proven analytical approaches, including a number of marginal conditions (such as material, billet diameter, distortion) and the machine and process parameters (the adherence to which needs to be monitored). Starting from the final geometry of the railroad wheel, the billet geometry is developed in reverse along the intermediate forms of the process chain (Fig. 2). Essential criteria for the intermediate form design are the adherence to the consistent volume and volume distribution in the wheel rim, web and hub. This approach is clarified by determining the intermediate form of OP<sub>2</sub> out of OP<sub>3</sub>.

The rolling of OP<sub>3</sub> results in a volume shift in both the axial and radial directions in the area of the wheel rim. Only a minimal volume shift occurs in the axial direction at the hub-bridge area. The fundamental structure of OP<sub>3</sub> is already contained in OP<sub>2</sub>, and the rolling only shapes the detailed contour (Fig. 3). If the total volume of the intermediate form OP<sub>3</sub> is divided into individual volume parts on the basis of simple ring-shaped cross sections, the parts are equal to the expected volume shift. As a result, the intermediate form of OP<sub>2</sub> can be calculated (Fig. 4).



**Figure 3. Derivation of the intermediate form profile**



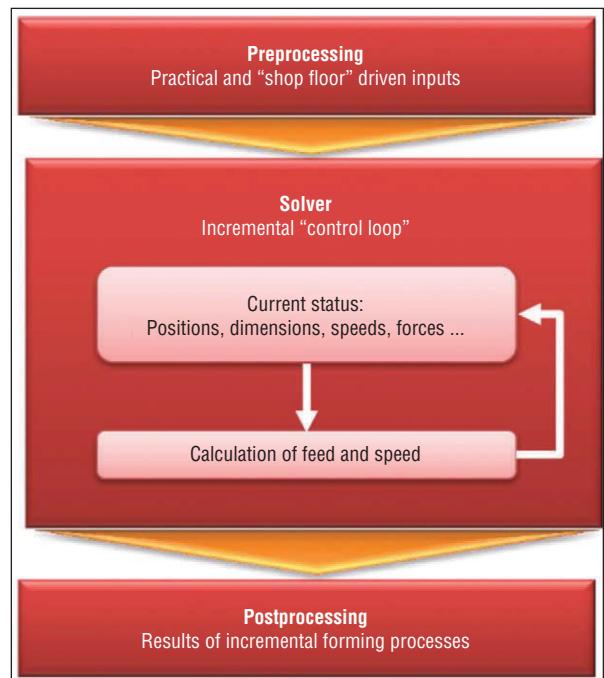
**Figure 4. Volume shift between  $OP_3$  (upper) und  $OP_2$  (lower)**

This principle, along with consideration of the marginal forming conditions, allows the design of all intermediate shapes in the sequence of forming operations for railroad wheels.

## FEM Process-Chain Simulation

Obtaining realistic simulation results requires modeling the entire forming process chain of railroad-wheel manufacturing and also necessitates the modeling of the tools and the kinematics of the fundamental process. The user is provided with a process-chain model preconfigured by JES as part of the engineering environment. Beside the possibility of model refinement (tool design, for example), this process-chain modeling can be augmented by the addition of, for example, heat treatment or the targeting of a preferred microstructure in the finished part. In the process-chain model, the part parameters of the preceding process stage are generally used as the input parameters for the next consecutive simulation calculation.

In the case of railroad wheels, the forging parts of the process chain are set up as two-dimensional, rotationally symmetric models (FEM calculations). The handling of parts during the time between individual forming processes (resulting in a homogenization of the overall part temperature by temperature equalization) is considered to be air cooling by the simulation calculation. For the simulation of the wheel-rolling process, the 2-D part contour is automatically transformed into a rotationally symmetric 3-D part contour. Temperatures and degrees of formation are transferred into 3-D as well. A continuous acquisition of measurements, velocities and forces enables the calculation of updated velocities and delivery in closed control loops.



**Figure 5. Solver principle for incremental processes**

These control loops are fully integrated in the solver, which permits a faster, more reliable and more realistic calculation (Fig. 5).

## Summary

As demonstrated by railroad-wheel manufacturing, the concept of an engineering environment for process chains in bulk metal forming facilitates the fast design of intermediate and billet forms, based on proven analytical approaches. The generated data serve as parameters for the control of the forming machines used in the process chain and as an entry point for the process optimization.

The interchange of (consistent) data between the modules of the engineering environment occurs at defined interfaces and in defined data formats. To ensure the easiest handling, the user interfaces of the design software, machine control and FE simulation were aligned and laid out identically in important areas. The available process-chain model offers comprehensive options within the FE simulation for the vertical (structure) and horizontal (process-chain augmentation) scaling, in addition to the integration of the upstream and downstream process simulations. 

*Co-author Dr.-Ing. Dirk Klug is manager R&D Forming Technology, Hydraulic Systems, Numerical Simulation at Schuler Pressen GmbH, Waghäusel, Germany. He may be reached at [dirk.klug@schulergroup.com](mailto:dirk.klug@schulergroup.com). Co-author Dr.-Ing. Hendrik Schafstall is managing director & CTO at Simufact Engineering GmbH, Hamburg, Germany. He may be reached at [hendrik.schafstall@simufact.de](mailto:hendrik.schafstall@simufact.de). Co-author Dr.-Ing. Markus Bergmann, Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik IWU, Chemnitz, Germany, may be reached at [markus.bergmann@iwu.fraunhofer.de](mailto:bergmann@iwu.fraunhofer.de).*