

Towards workshop application of ring rolling simulations with embedded machine control

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Radial axial (RAW) ring rolling is a well-established incremental forging process which produces seamless rings and shells, both with rectangular as well as with profiled cross sections. Due to the complex interactions between the mutually influencing radial and axial roll gaps, the ring position, and the numerous simultaneous tool movements, finite element (FE) simulation has become an established method for process modelling and analysis. Although FE ring rolling simulation coupled with closed-loop control is sometimes reported as state of the art, the process control was only approximated before. Due to this, very large rings and large profiled rings have proven almost impossible to simulate. A direct coupling between FE-simulation and the real RAW machine control overcomes these difficulties by utilizing the sophisticated control algorithms enabling real-world virtual production of such very large rings.

To simulate ring rolling processes as close to reality as possible the SMS group's real machine control (CARWIN®) is embedded in the FE-simulation. Feasibility has been proven and the model is validated by industrial ring rolling processes. The industrial relevance of these coupled ring rolling simulations has been demonstrated at Bohemia Rings. The machine control including interface to the FE-simulation – Rolltech RPS – operates independently and can be implemented in various commercial FE-software. A roll-out to SMS group ring rolling machine operators, with emphasis on accessibility for SME, is available.

KEYWORDS: RING ROLLING; PROCESS MODELLING; MACHINE CONTROL; CLOSED LOOP; CONTROL; FINITE ELEMENT SIMULATION; VIRTUAL PRODUCTION.

INTRODUCTION

Radial axial (RAW) ring rolling is a well-established incremental forging process which produces seamless rings and shells with outstanding productivity, both with rectangular as well as with profiled cross sections, with high demands in terms of mechanical properties and microstructure. Rolled rings and shells are applied in many industrial fields, e.g. wind power, nuclear industry, general construction of vessels, flanges, valves and bearings.

Due to the complex interactions between the mutually influencing radial and axial roll gaps, the ring position, and the many simultaneous tool movements, finite element (FE) simulation has been established as a method for process modeling and analysis. However, many parameters of the ring rolling process are highly dependent on changes during the process. Consequently, realistic

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modeling requires adaptive adjustments of tool movements during the rolling process. This is not possible with conventional pre-defined tabular specifications of tool movements in the simulation and highlights the need for integrating control within the simulation model. Although the FE simulation of ring rolling combined with closed-loop control is sometimes considered state-of-the-art [1-3], process control has mostly been approximated. As a result, simulating the rolling of very large rings and large profiled rings has proven to be nearly impossible. A direct coupling between FE simulation and the real RAW machine control overcomes these difficulties by utilizing sophisticated control algorithms that already enable the production of such challenging rings in an industrial setting. To address this, the SMS group integrated its actual machine control system (CARWIN®) into the FE simulation through a bi-directional interface, forming a closed-loop control system.

MODEL SETUP

The model setup is essentially carried out in two steps.

First, the FE model is set up using commercial simulation software tailored for metal forming and specifically ring rolling processes. The geometries of the tools and the ring blank can be imported from CAD software or Rolltech Profiles [4]. Optionally, the result of a previous process stage, such as upsetting and piercing, is transferred as preform into the ring rolling simulation. An approximate initial positioning of the tools should be performed during model creation, while precise tool positioning at

the start of the rolling process is managed by the control system. In the model setup, only realistic boundary conditions for all degrees of freedom present in real ring rolling processes are assumed; additional stabilization measures are not required.

In the second step, the control module, including the communication interface and machine parameters, known as "Rolltech RPS," is deployed. The geometry and process specifications for the rolling process (preform and rolling geometry, rolling curve specifications, ring growth speeds, etc.) are entered identically to the input at the control panel in the control cabin of the real ring rolling machine. Based on this, the module accounts for process limits as well as the constraints of the radial-axial ring rolling machine, making it suitable for rings of all dimensions, including very large ones, with both rectangular and profiled cross-sections. Instead of determining optimized, potentially fictitious load paths for individual tools [5], the comprehensive simulation of all machine functionalities allows for the nearly complete determination of ideal process parameters for real rolling operations, without prior test rolling. This is achieved independently of the plant or software supplier, ensuring that the user's specific expertise remains protected at all times.

Another advantage of the module is its independence from the simulation software used, allowing it to be combined with solutions from various manufacturers. The simulations presented here were conducted using Simufact Forming [6, 7].

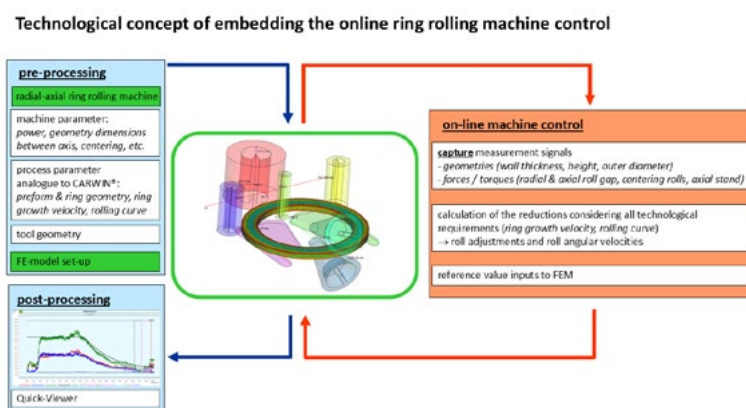


Fig.1 -Technological concept of embedding the online ring rolling machine control.

During the simulation—specifically the solution phase—data exchange occurs before and after each time increment between the FE model and the control module (figure 1). Measurement data captured in the FE model, such as geometry, rolling forces, and roll drive torques, are transmitted to the control system. The control system then determines the current state of the process and subsequently calculates new target specifications for tool movements, aligned with the capabilities of the machine. The ring rolling process can be monitored both in the simulation software and in a “Quick Viewer”, where the ongoing recording of process data during the simulation can be tracked. The visualization of this data, such as the current ring growth speed, forces, and drive torques, allows for an assessment of the actual state within the process and the decision on whether manual intervention might be necessary. Such manual intervention, typically possible through handwheels on the real machine, is also possible in Rolltech RPS via digital handles, ensuring that

the full range of capabilities available on real machines is accessible in the simulation.

The coupling does not exclude the integration of custom subroutines. Furthermore, microstructure simulations, as described in [8], can continue to be applied with the module.

VALIDATION BY MEANS OF ROLLING A RING WITH A RECTANGULAR CROSS-SECTION

The model was validated in two ring rolling processes with identical settings and specifications. First, a rolling process for a 184 kg ring was simulated, expanding from an outer diameter of 464 mm to 1418 mm. Subsequently, two rings, as similar as possible, were rolled on the real counterpart of the simulated machine, an SMS radial-axial ring rolling mill of type RAW 100/100-1500-500, using the same setting parameters and specifications. The simulation results were then compared with those from the real rolling operations.

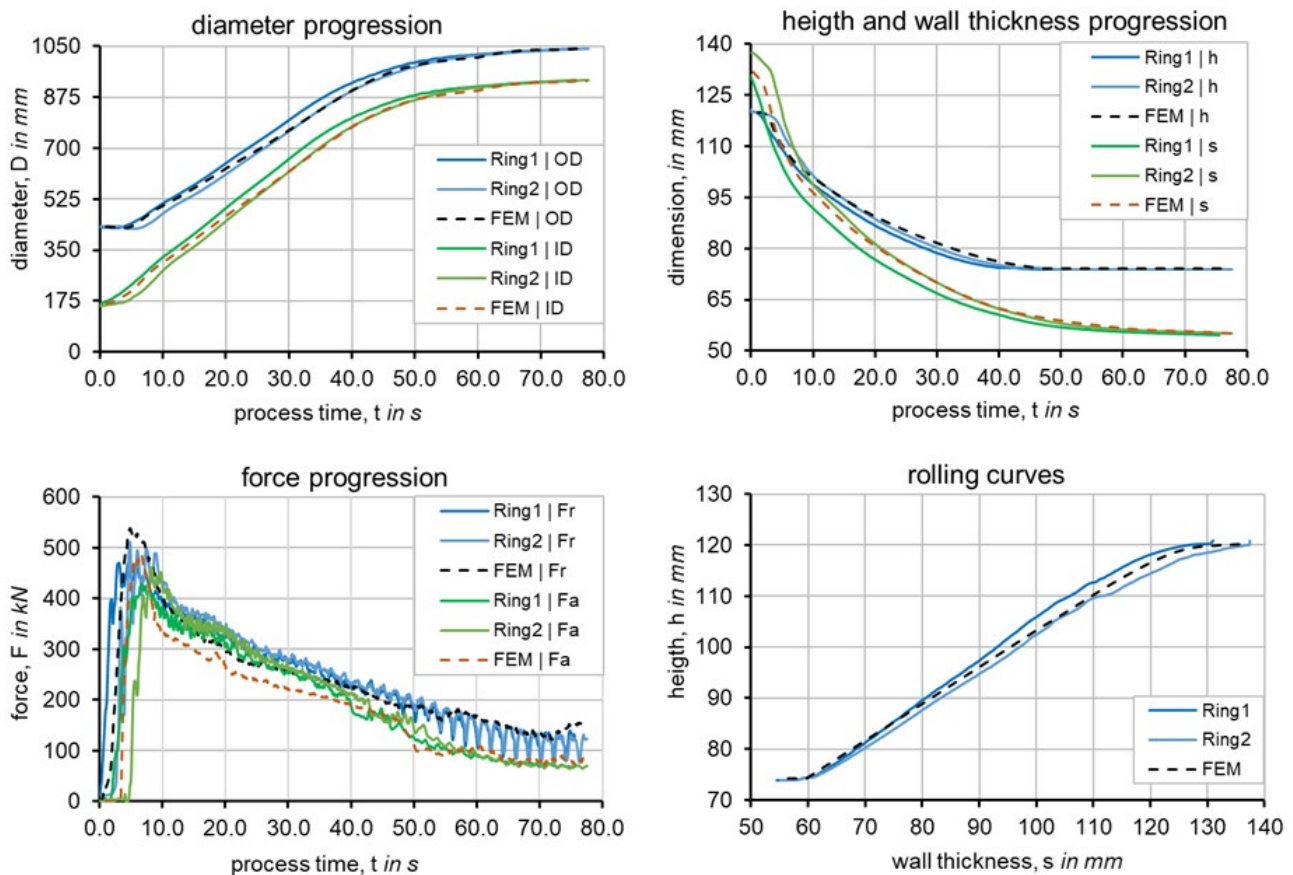


Fig.2 - Comparison between measured and calculated rolling force, ring geometry, and rolling curve.

A comparison of the logger records indicates small volume differences due to production (forming of the pre-form) compared to the simulation, in which the ideal ring volume matching the trials was used. Nevertheless, the 77.3 seconds rolling time of the model falls exactly between the real measured times of 75.6 and 77.6 seconds. Furthermore, the geometry progression, measured by means of the outer diameter (OD), the inner diameter (ID), the height (h), and the wall thickness (s), in the model

aligns well with the real progressions (figure 2). The comparison of the rolling curves shows that the volume loss due to scale loss is absent in the simulation but does not lead to significant deviations. The calculated rolling forces also agree well with the measured forces (figure 2).

The comparison confirms that the simulation with the integrated control system effectively models and predicts real-world ring rolling process.

ROLLING OF A RING WITH PROFILED CROSS SECTION



Fig.3 - Comparison distribution in the cross-section of the profiled ring within the radial roll gap before and after the ring rolling process.

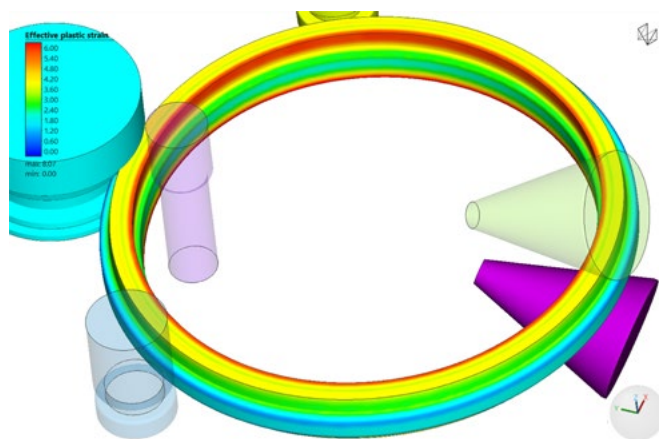


Fig.4 - Effective plastic strain distribution from the FE simulation with coupled machine control of the rolling process for a 4.3-ton complex profiled ring featuring a symmetrical outer profile and an asymmetrical inner profile on a RAW 500/400.

An example of the capabilities is demonstrated by the design of the second stage of a complex profiled ring with a symmetrical outer profile and an asymmetrical inner profile, see figure 3. The 4.3-ton ring is initially rolled rectangularly to approximately 2.1 meters in outer diameter and 330 mm in height on a RAW 500/400. Immediately af-

ter, i.e. in the same heat, by transposing the main roll and the mandrel via special functions of the SMS system, or after reheating and replacing the tools with profiled ones, the ring is rolled to have a profiled cross-section and the target dimensions of approximately 3.1 meters in outer diameter while maintaining the same height. This second

rolling stage is completed in approximately 380 seconds. Manual displacement of the ring using a handwheel, combined with the selection of an appropriate intermediate geometry determined through simulation, the complex profile is fully filled, and the occurrence of retractions on the front faces of the profiled ring is minimized. In the FE model, the ring's mesh began with 45,000 elements and grew to 67,000 elements during the simulation. Figure 4 illustrates the situation at the end of the process, where the ring meets all requirements for roundness and profile filling. This confirms that the ring can be successfully manufactured using the described process sequence and management.

ROLLING OF A GIANT NON-PROFILED RING

To further demonstrate the system capabilities, a 22-ton ring was rolled on an SMS radial-axial ring rolling mill of

type RAW 1250/800 9000-1600, maintaining a constant height of approximately 1.5 meters, expanding in diameter from 1.8 meters to 6.2 meters. The model was enhanced with ring carrier rolls, which are installed on the corresponding machine to prevent sagging of rings with large diameters. The initial mesh of the shell consisted of 47,900 elements, expanding to 166,700 elements during the simulation. The rolling process was completed in approximately 380 seconds. The unstable ring geometry, with a wall thickness of less than 100 mm at the end of the process, requires extremely precise coordination of tool movements, particularly the guidance of the ring by the centering rolls, to prevent collapse. Figure 5 shows the final result: the ring successfully achieved the target dimensions, exhibiting uniform deformation around the circumference, and both ovality and conicity are within a range of a few millimeters.

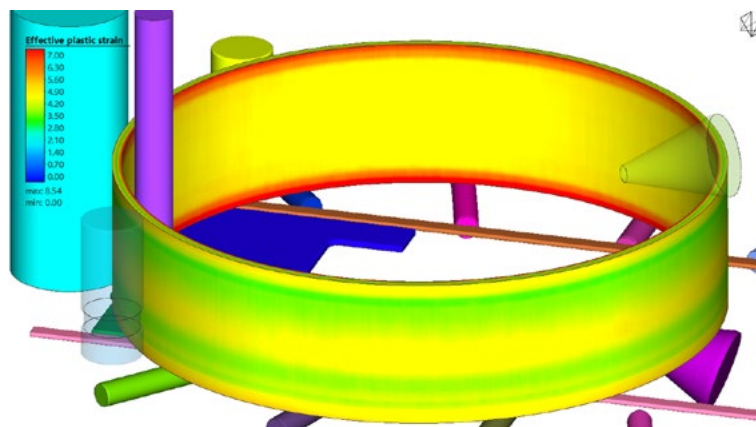


Fig.5 - Effective plastic strain distribution from the FE simulation with coupled control of the rolling process for a 22-ton shell with a final diameter of 6.2 meters and a height of 1.5 meters on a RAW 1250/800 9000-1600.

INDUSTRIAL APPLICATION AT BOHEMIA RINGS

The industrial relevance of these coupled ring rolling simulations has been demonstrated at Bohemia Rings. In 2025, Bohemia Rings acquired Simufact Forming and Rolltech RPS to (on the one hand) simulate and optimize current production of non-profiled rings made from various alloys and (on the other hand) develop new products within its portfolio. Bohemia Rings operates an SMS radialaxial ring rolling mill, type RAW 250/200 4200-660; its specifications and parameters are fully implemented in the machine control. As the Rolltech RPS interface closely reflects what

the rolling mill operator sees and sets at the control panel during operation, it enables direct know-how transfer from simulation to the workshop and significantly improves process understanding.

As one example among many simulated processes, the rolling of a 351 kg thin-walled aluminum alloy (AW7075) ring is presented here. The preform and ring dimensions are given in table 1. The initial preform mesh comprised 27,900 elements and increased to 30,700 during the simulation. The real rolling process was completed in approx-

imately 203 s, while the simulation predicted 224 s. Force development in the radial and axial roll gaps, ring height, and outer diameter over time have all been successfully validated. The deviation between the final dimensions of the real and simulated ring is below 1.5% (table 1).

At Bohemia Rings, ring rolling simulations with embedded machine control have progressed from basic ring rolling analysis toward a high-performance tool for developing new products with workshop-oriented application.

Tab.1 - Preform and ring dimensions of thin-walled aluminum alloy ring, rolled and simulated by Bohemia Rings.

dimension	preform Mm	ring			
		CARWIN target mm	real process mm	simulation mm	deviation %
outer diameter	790	2209	2210.3	2208.9	0.063
inner diameter	230	2023	2021.5	2022.4	-0.045
wall thickness	319	93	94.4	93.2	+1.27
height	280	196	197.5	196.3	+1.2

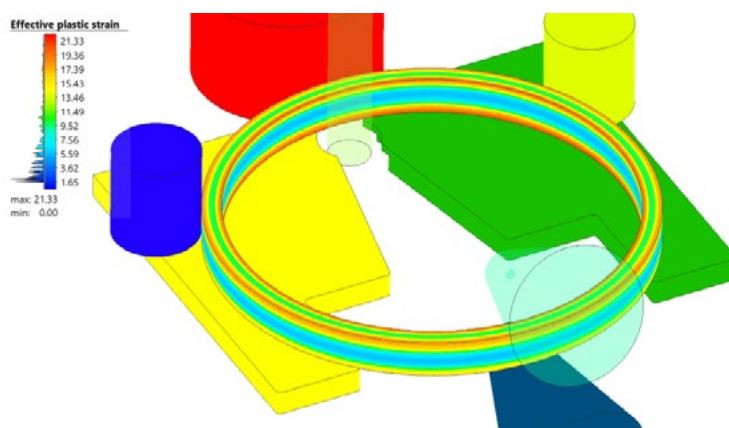


Fig.6 - Effective plastic strain distribution from the FE simulation by Bohemia Rings with Simufact Forming and coupled control by Rolltech RPS of the rolling process for an aluminum alloy thin-walled ring with a final diameter of 2.2 meters and a height of 196 millimeters on a RAW 250/200 4200-660.

CONCLUSIONS

To achieve realistic simulation of ring rolling processes, especially for large rings and large profiled rings, direct coupling between FE simulation and the actual RAW machine control is indispensable. The SMS group has embedded its real machine control system (CARWIN®) fully into the FE simulation through a bi-directional interface as a closed-loop control system. This coupled model creates a digital twin of the ring rolling process with the following advantages:

- Realistic simulation of the ring rolling process in very close agreement with reality, successfully validated

through industrial trials.

- Consideration of the process limits as well as the constraints of the radial-axial ring rolling machine.
- Interface and operation analogous to the control panel in the control cabin.
- Applicable for ring rolling simulation of non-profiled as well as profiled ring cross-sections.
- Includes all functionalities of the simulated machine, such as manual ring displacement and automatic ring positioning control.
- Ability to consider intervention by handwheels during simulation directly.

- Enables direct transfer of conclusions from simulation results towards the real physical process.
- Industrial relevance has been demonstrated at Bohemia Rings, where ring rolling simulations with embedded machine control have progressed from basic ring rolling analysis toward a high-performance tool for developing new products with workshop-oriented application.

OUTLOOK

The "Rolltech RPS" control module, designed for integration into finite element simulations, is available for SMS radial-axial ring rolling mill operators. It is independent of

the simulation software used and can be combined with various commercial FE software tailored for metal forming and specifically ring rolling processes. The coupling between "Rolltech RPS" and the FE software is straightforward and emphasizes accessibility for small and medium-sized enterprises (SMEs).

As of June 2025, a fully integrated coupling between "Rolltech RPS" and Simufact Forming (versions 2025.2 and onward) has been established. Additionally, efforts are underway to ensure compatibility with other software providers, such as Forge NxT.

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