DEVELOPMENT OF THE OFF-LINE SIMULATOR OF THE HOT STRIP MILL MATHEMATICAL MODEL FROM GERDAU OURO BRANCO*

Altair Lúcio de Souza[1]
Luiz Bruno de Oliveira Araujo[2]
Luiz Gustavo Pedrosa de Melo[3]
Luciano Morais Teixeira[4]
Jacson Morais Borges[5]
Willy Schuwarten Junior[6]

Abstract
The off-line simulation of the metallurgical process in an industrial line brings several benefits such as: evaluation of the influence of the main parameters that affect the results of the process, comparison between different set ups, greater assertiveness in operational adjustments, process optimization and reduction tests for development of new products. With this objective, a software for offline simulation of the hot strip mill process of Gerdau Ouro Branco was developed based on the logic of calculations implemented in the online model. The software results in important process variables such as mill pass scale, load, torque, and power at each pass, temperature and the hot mean flow stress of the simulated material. During rolling mill process the strip presents different temperatures and time between passes for different points along the length, which directly influences the hot strength of the product and consequently in the calculated variables, thus the calculations executed by the software were divided to three points of the strip, head, body and tail bringing the individual results to each of these positions.

Keywords: Computer simulation; Mathematical modelling; Hot Strip Mill.

[1] Metallurgy Engineer, Metallurgy Master, UFOP and UFMG, Technical Advisor, Hot Strip Mill, Gerdau Ouro Branco, Ouro Branco, Minas Gerais, Brazil.

[2] Metallurgist Engineer,UFMG, Product Engineering Manager of Gerdau Ouro Branco, UFMG, Ouro Branco, Minas Gerais, Brazil.

[3] Graduating in Automation Engineering, UFOP, Trainee of Hot Strip Mill, Gerdau Ouro Branco, Ouro Branco, Minas Gerais, Brazil.

[4] Electrical Engineer, UFMG, Technical Advisor, Central Maintenance, Gerdau Ouro Branco, Ouro Branco, MG, Brazil.

[5] Production Engineer, FASAR, Technical Advisor, Hot Strip Mill, Gerdau Ouro Branco, Ouro Branco, Minas Gerais, Brazil

[6] Mechanical Engineer, Metallurgy Master, Unileste and UFMG, Hot Strip Mill Manager, Gerdau Ouro Branco, Ouro Branco, Minas Gerais, Brazil

1 INTRODUCTION

1.1 Hot Rolling Process

The hot strip mill process is divided into two steps, the roughing step, where the slab, initially with a thickness of 220 or 250 mm in the case of Gerdau Ouro Branco, is subjected to large reductions at high temperatures, above 1000 ° C, eliminating the heterogeneity of the melt structure of the slab along the cross-section and also with austenitic grain refining until the thickness is between 25 and 30 mm forming the rough, and the finishing step occurs at lower temperatures and with lower absolute reduction, where the rough formed is reduced to the thickness of the final product. The bite angle, force, and torque limits of the mill are the main factors that determine the number of passes in each of these steps [1]. Figure 1 shows a schematic representation of the steps in the rolling process.
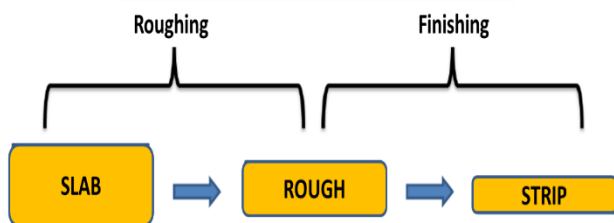

Figure 1. Schematic representation of the division of the rolling process.

The Gerdau Ouro Branco hot strip line was divided into two phases of implantation. The first phase consists of only a steckel mill that performs both the roughing and the finishing steps in reversible passes. The second phase is in the stage of contracting for start-up scheduled in 2021 with the implementation of a roughing mill with edge mill. The figure 2 shows the hot strip line, with the current and future equipments.
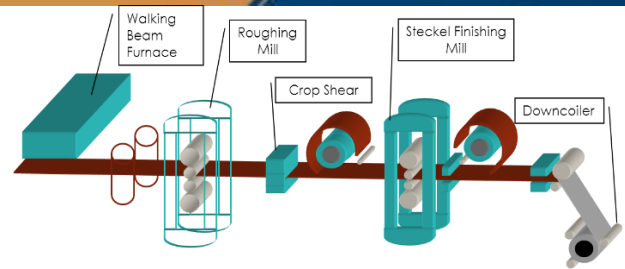

Figure 2. Gerdau Ouro Branco Hot Strip Line.

1.2 Process Simulators

The automated process control of a Hot Strip Mill, one of the most complex cases in the area of metal forming, is done at several levels, level 3 where it is executed detailing and planning the production and sending the data of PDI (primary data input) to the process, level 2 where the process control is performed, level 1 where the dynamic process control is performed and level 0 which are the sensors, actuators and measuring equipment. The levels have decreasing complexity and increasing speed of action [2]. Level 2 is considered the brain of the process, where the different mathematical models that make the calculation of the setup are found and allow to define the operational parameters objectified of each equipment.

Figure 3 presents several interfaces between the different levels of automation of the hot strip line of Gerdau Ouro Branco highlighting level 2 where the calculation of the rolling mill setup is performed [3,4].
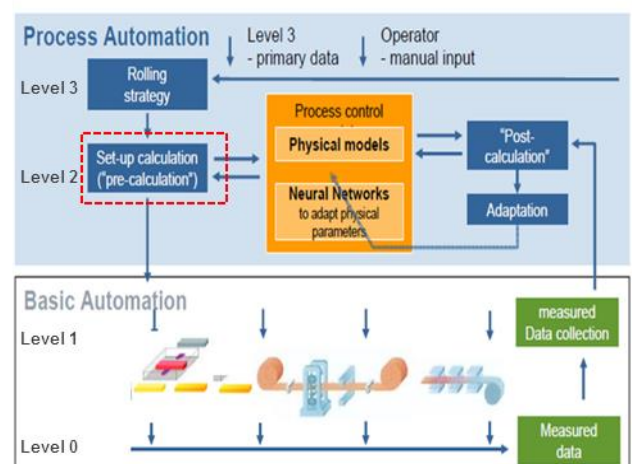

Figure 3. Representation of interconnection between automation levels in the hot strip line.

For development and optimization of the process it is of fundamental importance to know how the setup calculations are processed, which models and interfaces that correlate to their operation and input parameters that feed the calculations [2]. Normally the calculation of the setup of modern rolling mills is carried out from the modeling of mechanical, thermal and microstructural events refined by neural network to absorb unforeseen situations in the process.

The use of computer applications for the simulation of industrial processes is an increasingly applied practice in the industry, which brings several benefits such as subsidies for optimization and development of the online process and reduction of the number of industrial tests for new product development [5]. In addition, simulators can be used as a tool for operational training, disseminating the technical knowledge behind the process and allowing the visualization of setup changes for various rolling conditions.

Usually new large industrial equipment, such as the Gerdau Ouro Branco hot strip mill, installed in 2013, already have tools for process simulation, but with adjustments focus on the line commissioning stage. These simulators are not very flexible tools with very specific calculations and require the user to be trained and with considered automation knowledge. Often the operation of these tools compete with the online model, using the same platform, which restricts its use only at times of line stop because of risk of locking the level 2 system.

For the development of the simulators it is required a thorough knowledge of the process in question, the physical phenomena that involve it and the necessary computational tools [5]. This is particularly important for scaling the requirements and software design phases.

The calculation nuclei of these simulators are mathematical models, usually associated to numerical solutions, on the phenomena related to the process. For its development, a visual platform has been used, which privileges the usability and flexibility in the construction of the interfaces of presentation of results to the user [5].

In this context, a computational simulator was developed for the setup calculation of the Gerdau Ouro Branco steckel mill. In the present work will be approached general characteristics of the simulator, applicability and some validation results of this tool.

2 MATERIAL AND METHODS

For the development of the simulator was used the Windows Presentation Foundation (WPF) that offers consistent model for Web application and Desktop. The biggest advantage of using WPF as a tool is due to its clear separation between the user interface, which uses XAML as a markup language, and mathematical calculations. The language defined for implementation was C#.

For the development and implementation of the mathematical calculations of the setup, it was necessary to study and understand the calculation and logic routines of the models implanted in the online system (level 2), making some adaptations for deployment in the offline simulator.

2.1 Passes Scale

Calculation of the minimum number of passes to obtain the final thickness of the product takes into account the equipment's material shape and limits, such as maximum bite angle, maximum pass reduction, maximum rolling force and torque, and the flatness of the strip. Here

are some of the key information needed to calculate the setup:

- Primary data: plate size, final size of strip, chemical composition, reheating temperature, target finishing temperature, etc.;
- Stand mill data: characteristics and limitations (force, torque, speed, etc.) [3].

Figure 4 shows the sequence of rolling mill scale calculations. From the initial thickness of the slab, small reductions are applied while making the calculations of all the limits. When one of the limits is reached, finish the pass and reapply the reductions by calculating the limits successively until reaching the final thickness [4].
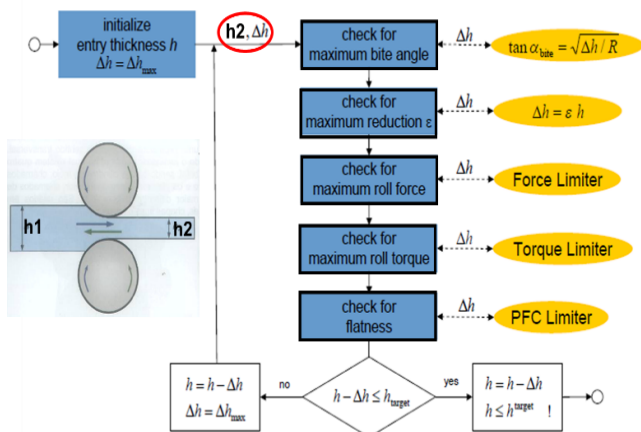
Figure 4. Schematic representation of the Rolling Pass Scale calculation

During hot rolling, different temperature changes occur along the length of the slab until the strip is obtained. These changes cause the material to exhibit differentiated hot properties along the length. The online model performs a multiple setup, dividing the strip into 20 parts along the length to work through these differences [3]. In the case of the developed offline simulator, the calculation was divided into 3 main parts of the strip, head, body and tail. For simulation these parts represent well the simulated material, besides not compromising on the calculation performance. Figure 5 shows the

representation of the considered parts of the material for simulation.
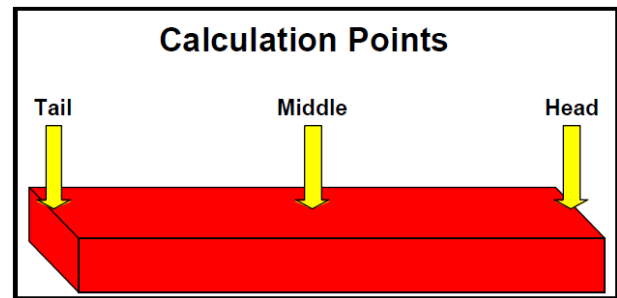
Figure 5. Parts of the material for simulation

The calculation of the scale of passes takes into account the point of first reaching one of the limits for the sequence of the calculations.

2.2 Offline Simulator Features

The developed simulator is presented in a lightweight platform that is easy to install and can be used by several users. The initial screen presents the fields for input of primary data (PDI) to run the simulator, such as slab and final product dimensions, temperatures and chemical composition.

The average chemical compositions of the types of steels produced at Gerdau were registered in the simulator. When choosing one of the standards the chemical composition is automatically filled. The user can change the default values just by clicking on the box for each element.

Figure 6 shows the initial screen of the simulator, with all the primary data fields and boundary fields used in the calculation of the rolling passes scale.

Figure 6. Initial screen of the simulator

After entering all the PDI data the user must select the validation button. If any of the parameters are outside acceptable ranges, a message is displayed warning that the data needs to be corrected. All the data used to calculate the scale of passes, such as limits of force, torque, absolute reduction and percentage, speed etc. can be edited before executing the simulation in case the user wants to see other possibilities of rolling.

Completing the editing and filling of the PDI data has the option of saving data, which has the application to be able to replicate input data in the future or use the results of the simulation for comparison with other simulations, in screen developed for that purpose.

By clicking on the simulate button, the simulation is executed and the calculations are carried out quickly. The data is visualized on the results screen with the option of presenting some main data in the form of graphs. The results screen shows all the main information relevant to the analysis of the rolling passes scale.
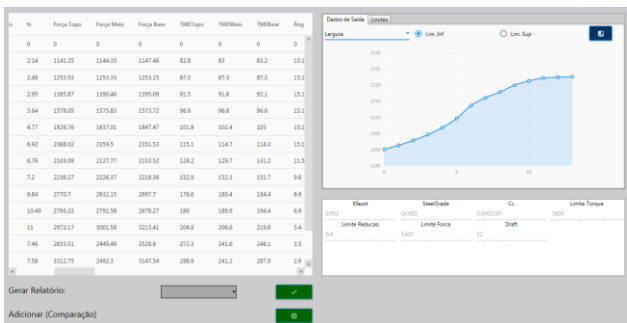

Figure 7. Results screen

The calculated variables that resulted in the pass scale can be visualized in bar graphs along with the limits considered. In this screen it is possible to identify which or which passes have reached the limit for the observed parameter.
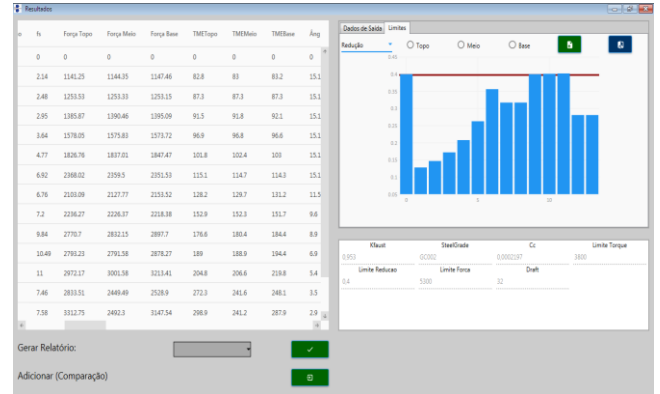

Figure 8. Results screen with the limits of process.

The simulations that had the save option selected in the initial screen of the simulator can be compared in the option to compare in the results screen. Clicking on this option will list all the saved simulations, which can be selected two or more to be displayed in the same graph and the variable to be compared.
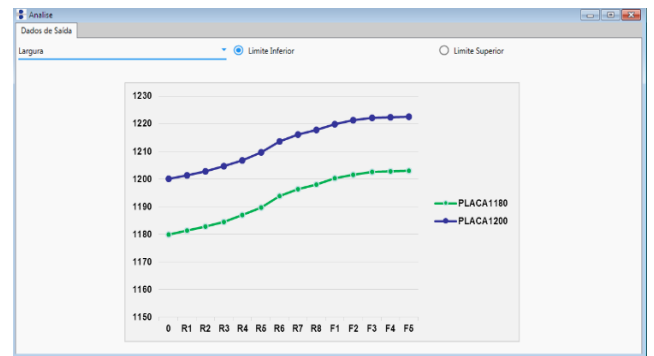

Figure 9. Result comparison screen

All calculated data can be sent to Excel software, as well as a PDF report with key simulation information.

Predicting the implementation of the second phase of the hot strip line with the assembly of the roughing and edge mill, a setup routine was developed in the simulator considering these two equipments. Above the layout of the line on

the initial screen, it has icons that enable or disable the roughing mill. In addition to the crop shear, and the steckel furnaces can be disabled.
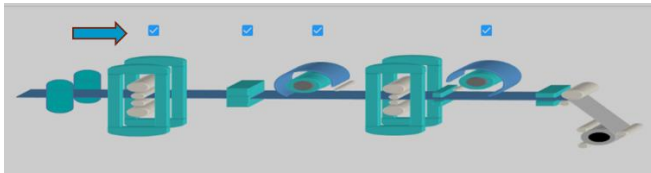
Figure 10. Icon to enable or disable line equipment.

By abiliating the roughing and edge mill the logic of the calculation of the pass scale is changed, such as the side finishing the roughing passes, the width, the time and temperature for the beginning of the finishing passes. In the current condition the roughing step ends on the even side, with the roughing mill the calculation considers that of this phase for the odd side, the distances involved for calculating time and temperature, and the mechanical data of the mill as roll diameter, Young module among other parameters are changed in this condition.

Gerdau Ouro Branco has been using the MicroSim-PM, software developed by CEIT-IK4 (Center of Studies and Technical Research) for metallurgical evaluation of the hot rolling process, that was customized for the Gerdau Ouro Branco Steckel mill. This software requires a series of input data regarding the rolling conditions. It was developed, in the off-line simulator of Gerdau, the option in the results screen to generate the txt extension report already in the format to run MicroSim-PM. This has contributed to the use of this tool in the analysis of the process for the development of new products.
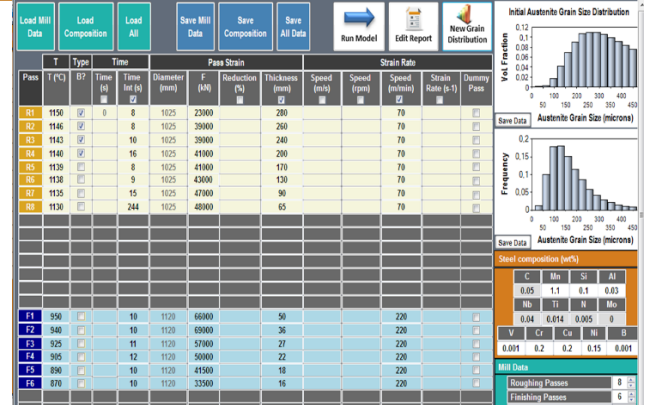

Figure 1. MicroSim screen with PDI generated by the Gerdau simulator.

3 RESULTS AND DISCUSSION

The validation of the simulator was performed by comparing the data resulting from the offline simulation with the values generated by the online model setup calculation using the same PDI data of the analyzed coil.

Figures 11, 12 and 13 show a comparison between simulation and setup of three SAE1012 steel coils in the width of 1200 mm in three different thicknesses, 3.00 mm, 6.30 mm and 12.50 mm for Temperature, Thickness, Mean Flow Stress and Force in the Roughing passes and Finishing passes (represented by letters R and F respectively).
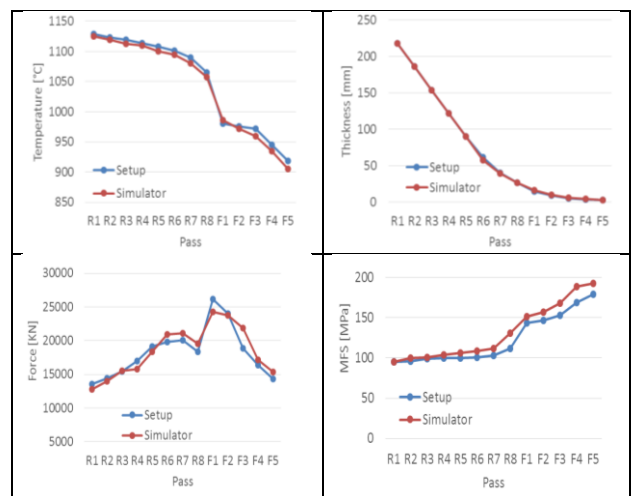
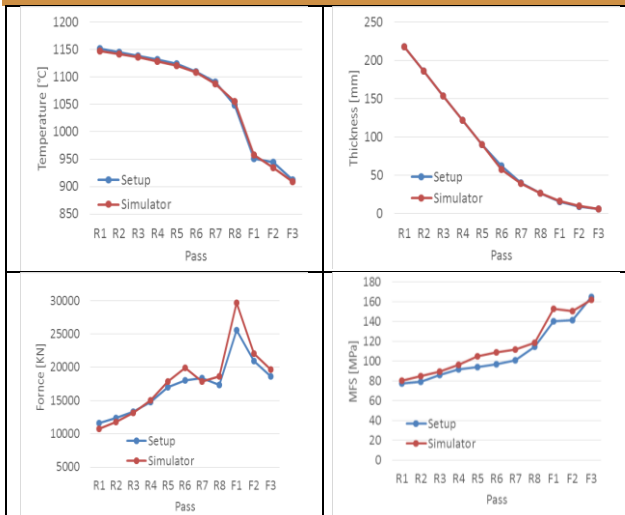**Figure 11.** 3,00 mm x 1200 mm.
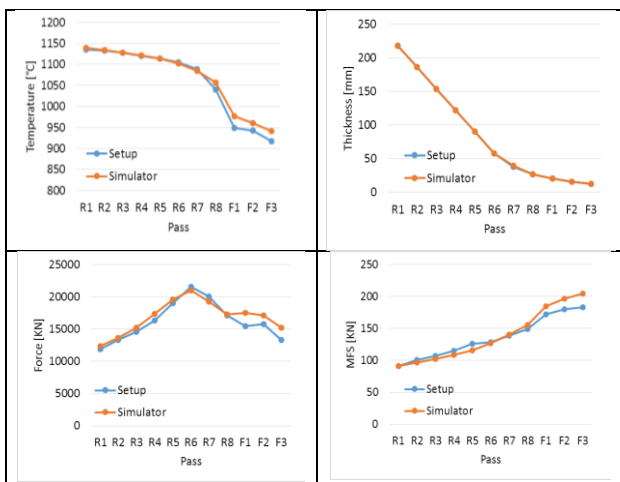
Figure 12. 6,30 mm x 1200 mm.

Figure 13. 12,50 x 1200 mm.

The results of the off-line simulations evaluated were well adhered to the online model of the hot strip mill setup, with a good reproduction of the values of thickness and temperature in each rolling mill pass, and small differences in the calculations of strength and heat resistance of the material, showing to be a powerful tool that can be used for evaluation and optimization of the online model as in the development of new products.

4 CONCLUSION

We can conclude that the developed application is apt to be used as an offline simulation tool of the online calculation model of the hot strip mill setup. With the implementation and consolidation of this software for process simulation, a range of possibilities for process development is opened, allowing to add other functionalities and mathematical models to this tool that can help in the evaluation of alternatives to increase line productivity, development of new products and in the evaluation of microalloying reduction contributing in the reduction of the cost of raw material, besides facilitating the dissemination of the technical knowledge of the process.

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