DIGITAL TWIN FOR CONTINUOUS CASTERS – THE PLAYGROUND FOR METALLURGISTS AND PROCESS ENGINEERS*

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Abstract

State-of-the-art automation technology enables digitalization of the continuous casting process that goes far beyond conventional automation of industrial production. Primetals Technologies provides a digital twin that combines an intelligent digital representation of a casting machine as well as the casting process and the slabs, blooms or billets that are produced. It allows metallurgists and process engineers to predict the behavior of the involved complex production process and optimize parameters before using them in real production. New steel grades or production processes can be evaluated off-line without any risks to process stability and product quality. Primetals Technologies installs the digital twin with every new installation of a continuous caster optimization system. This paper describes how the setup and simulation possibilities of the digital twin provide numerous benefits by modelling and simulating the casting process. It allows for example the calculation of material properties according to the actual composition, strand surface temperature profiles and dynamic soft reduction before the final point of solidification. An outstanding feature of the digital twin is the replay functionality provided for various models to analyze and further optimize real production situations. The paper also gives an example how usage of the digital twin optimized production at a customer.
Keywords: Digitalization, modernization, Level 2, continuous casting, automation, digital twin, Replay, Dynacs 3D, cut length optimization, training simulator, process optimization..

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1 INTRODUCTION

DIGITAL TWIN

A digital twin provides the functionalities necessary for testing changes and training operators in an offline environment in order to achieve smooth start-ups, modifications or parameter optimizations. It creates a virtual instance of the actual plant facility – a "digital twin" of real-world equipment.

Figure 1: Digital Twin

This allows engineers to run extensive simulations of new equipment or operational parameters before they are introduced to the actual casting process and therefore reduces disruptions in ongoing production and minimizes the risk of unexpected outcomes.

The continuous casting Level 2 - Digital Twin considers several aspects

- PLANT - Continuous casting plant
- PROCESS - Continuous casting process optimization system
- PRODUCT - Products produced at this plant

2 DEVELOPMENT

PLANT

The Primetals Technologies Level 2 system provides a digital twin of the real continuous casting machine and its operational capabilities. By creating a digital representation of the machines mechanics, hydraulics and automation systems together with emulation/simulation functions and all relevant parameters in a virtual environment the real production system can be simulated as a whole.
With this twin system customers are able to test and verify any parameter, functional or physical changes to the machine beforehand and estimate the impact on the production process especially also in situations that do not happen frequently. The emulation features of the twin provide the possibility to create and run script files for testing special casting conditions such as tundish changes, grade mixing, strand stoppages and others to analyze the impacts on the overall casting process and the operational requirements, e.g. optimizing good product length in case of defects created by abnormal conditions. Another invaluable bonus is the possibility to train

new operators also in difficult situations and guarantee that all operational staff are able to handle situations in the best possible way.

PROCESS

The second point of view, that a digital twin of a continuous casting machine has to take care of are the complex metallurgical processes. By modelling the casting machine and all influencing factors of the production process, a simulation environment is created that allows metallurgists and process engineers to assess the current situation and production practice as a starting point for optimizations. Based upon this status quo the users can start to identify possible areas for improvement, try out optimized casting practices and also changes to the casting machine without the need of really producing products.
Ranging from relatively simple changes like adjusting a cooling practice and verifying the results for several formats and steel grades, which can be done within a couple of minutes, to testing complete new cooling nozzle layouts or new equipment like hard reduction segments all within one system. Together with the material property calculations even development of new products in a virtual environment is possible.
Another highlight feature of the process digital twin is the possibility to re-run actual casting situations. The online systems record all relevant information into script files that can be re-run on a standard computer to perform detailed analysis of casting situations.

PRODUCT

The digital representation of a product is the data generated during its production in the casting machine. One task of a state of the art continuous casting process optimization system is to collect, evaluate and store this valuable data.
Using this data sophisticated systems pre-evaluate the quality of the products already during production to enable the operation to take early actions in order to try and save the final products quality. This would not be possible without creating digital representations of the products and intelligently projecting sensor readings, process parameters and model calculation outputs onto an actual piece of steel in the machine.
Another application for the digital twin data is to provide product certificates containing all relevant process parameters and the actual casting condition for the end customer. By ensuring data integrity and safety the end customers can verify that the products meet their demands. In the end a digital twin of the product ensures customer satisfaction and therefore also greatly reduces costs for claim management.
The digital twin of a product must not be looked upon isolated to one aggregate like the continuous casting machine. In a fully digitized steel plant this information is invaluable if collected on all aggregates, like Primetals Technologies Through Process Quality Control – TPQC – does for analyzing and optimizing the quality over the whole production process.

AVAILABLE SIMULATION AND REPLAY FUNCTIONALITIES

Within the digital twin there are several simulation possibilities, depending what a process engineer or metallurgist wants to test/simulate. During a simulation the

outcome is presented in the same HMI as used in the online production system – the process engineer has the same information available that the operators will see during production.

- Level 2 Simulation – holistic simulation/ emulation of the whole continuous casting process in a digital twin of the online production system, including all interfaces, optimization functions and process models
- Model Suite Simulation environment – digital playground for metallurgists covering quality relevant process models
- Tundish/Mold steel grade mixing simulation – offline analysis of steel grade compatibility in casting situations

LEVEL 2 SIMULATION

The aim of a Level 2 simulation is to test and verify the behavior and interaction of all separate Level 2 functions like interfaces to the other systems (PPS, MES, CCM process control systems, melt shop, mill, laboratory, etc.), production tracking (heats, strands and products), process models and expert systems.

Simulations can be predefined in script files, which allows for preparation of distinct test scenarios (e.g. typical production plans, steel grades, how many heats in the sequence, tundish changes, …). During a simulation it is possible to change main casting parameters like casting speed or cooling practice. A simulation is performed in real time.

Primetals Technologies installs the digital twin with every new installation of a continuous caster optimization system. It is used for training of the operation crew by running close-to-reality and repeatable scenarios in a non-critical simulation environment. This will allow the operators to gain an overall understanding of the continuous casting processes by giving a realistic insight into system operation and the necessary tasks to perform their daily work. Custom-tailored and plant specific simulation scenarios, inputs and interactions, as well as emergency cases can be simulated for training purpose. E.g. if no production plan was received from the production planning system, the operator shall create a manual production plan in the human machine interface (HMI). Every Level 2 simulation can be repeated for training purpose.
The Level 2 digital twin helps to make the operational staff familiar with the system, reduces the operation errors, improves the performance and thus contributes significantly to keeping production at a high level.

A core function of the process optimization system is the cut length optimization. The aim is achieving a caster yield increase by applying optimization algorithms that are designed to cut as many prime length slabs as possible, to reduce the amount of scrap and also the production of slabs with alternative lengths. A basic cutting schedule is derived from a production planning system and may be modified by operators. Yield Expert considers scrap portions, quality defects, weight restrictions, sample cuts, and width changes while producing the maximum number of scheduled products. It also handles quality-related defects, and schedules mold-width adjustments. The cutting schedule is recalculated and optimized whenever a relevant

event (e.g. tundish change, intermix, end of cast) occurs or a slab is cut. The optimized slab lengths are transmitted automatically to the process control system.

Due to the high complexity and numerous influencing factors the outcome of a cut length optimization system can be hard to predict and even harder to understand for the operation crew, especially in challenging situations. By using the digital twins simulation capabilities this very complex process can be verified and explained to operation staff using the same interface and information that they will be using during production. This fact alone gives operational staff the confidence to trust in the outcome of the optimization systems and therefore reduce the number of unnecessary and undesired manual interactions significantly.

One of strongest features of the cut length optimization is the ability to replay production cut-to-length optimization steps offline. The optimization step by step replay allows to analyze the behavior of the cut length optimization in detail. With this tool process engineers can verify the functionality and configurations and identify areas for improvement. On demand these replay files can be shared with Primetals Technologies specialists for further analysis and support. The function also allows testing of what-if scenarios so that process engineers can try out various settings without risks. Yield optimization has never been so easy, straightforward, and transparent.

RESULTS

MODEL SUITE SIMULATION

Besides the holistic Level 2 simulation the digital twin also provides a standalone simulation environment for the model suite (DynaPhase - material property model, Dynacs 3D - secondary cooling system and DynaGap – dynamic soft reduction).

When setting up the secondary cooling system at a new or existing caster it is prerequisite to consider all known parameters that have a known influence to the calculation of 3-dimensional temperature profile of the strand.

All different nozzle types are measured at the nozzle test stand (see Figure 2) to evaluate the spray water distribution.

Figure 2: Measuring nozzles at the nozzle test stand

The derived spray distribution can be seen in the digital twin maintenance system (see Figure 3 and 4)

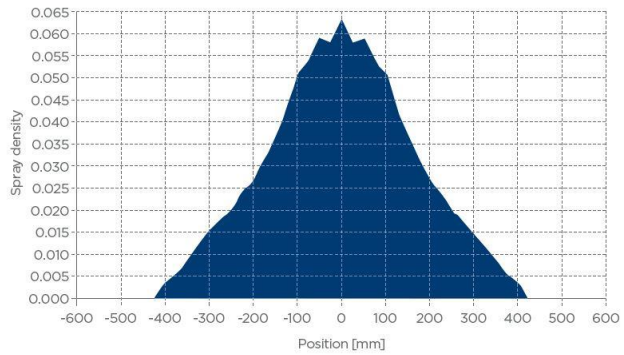

Figure 3: spray distribution of one nozzle

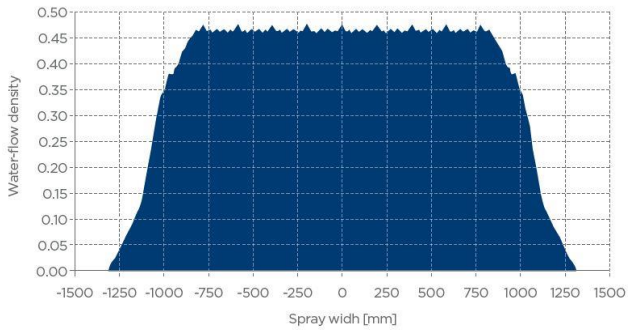

Figure 4: spray distribution of a nozzle row

The exact positions of the nozzles in the cooling zones are entered and the spray distribution of any zone can be seen in the maintenance system. The heat removal of a cooling zone is calculated considering the heat removal of the spray water, rolls and heat radiation.

DynaPhase – calculation of material properties

In order to calculate a 3-dimensional temperature profile of the strand material properties like enthalpy, solid fraction, density and conductivity as a function of the temperature have to be known. In case, these properties are experimentally known for a given steel grade composition, these functions can be entered by the metallurgists, which is very time-consuming. Moreover, even if the thermo-physical properties are known for a specific steel grade analysis, small variations of this analysis can alter the properties significantly. Therefore DynaPhase online always calculates the thermo-physical properties for the actual steel grade composition just before start-cast of a new steel grade. All calculated thermo-physical data are used by Dynacs 3D. DynaPhase is available as an offline and/or online tool to determine the material properties for the current steel grade analysis. This is a unique feature that makes it stand out from the competition.

Dynacs 3D – secondary cooling system

The advanced secondary cooling system calculates the temperature at any point within the entire strand in real time, in a full three-dimensional mode and in a sufficiently fine discretization yielding very detailed temperature profiles as can be seen for strand surface and strand center in Figures 5 and 6.

Figure 5: Calculated temperature profile of strand surface (top and side view, true colors)

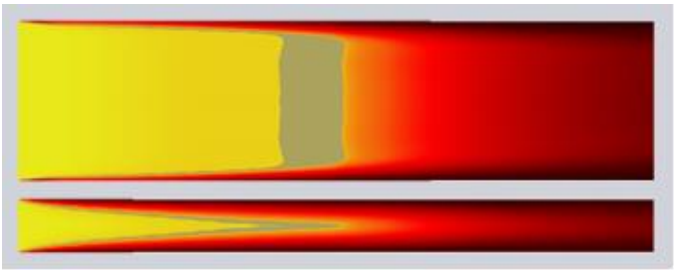

Figure 6: Calculated temperature of strand cross section (center view, enhanced colors indicating the mushy zone area)

The model is based on an explicit finite-volume approximation that solves the heat-transfer equation and takes into consideration temperature-dependent density as well as the position-specific slab thickness and width. Dynacs 3D accurately assesses the heat transfer from the slab surface resulting from radiation, heat transfer to the rolls, natural convection and spray water. Furthermore, Dynacs 3D can be applied for both spray cooling and air-mist cooling and takes into account the spray-distribution pattern of the nozzles and the actual spray water temperature. The result is an even more precise determination of the strand surface-temperature profile and the final point of solidification.
Based on the precise temperature calculations the Dynacs 3D model allows specifying the desired surface temperature not only along the strand length, but also across the strand width. Even individual control of the water flow and positioning of each cooling nozzle is possible. The control algorithms of Dynacs 3D calculate the water-flow setpoints to achieve the target strand-surface temperature values. The application allows to introduce completely new philosophies to set up cooling practices for upcoming challenges in continuous casting.

DynaGap – dynamic soft reduction

DynaGap Soft Reduction stands for dynamic roll-gap adjustment in continuous casting. This is made possible by specially designed strand-guide segments – known as Smart Segments – in which the roller gaps can be remotely adjusted for strand-thickness changes and for improved internal strand quality.

On the basis of the online information provided by the Dynacs 3D thermal-tracking model, DynaGap dynamically calculates the setpoints of the adjustable roll gap. Supervision of the roll engagement, depending on the state of solidification (liquid, mushy or solid) and the calculated strand-thickness profile, is a decisive factor for precise roll adjustments and thus improved product quality. An optimized roll engagement also reduces excessive forces on the strand and decreases roller wear.
The more accurate control of the roller gaps allows additional casting strategies to be implemented such as liquid-core reduction and intentional bulging soft reduction. I.e. intentional dynamic gap increase before the soft reduction area allows for higher thickness reduction in this area. This further increases casting flexibility and product quality. DynaGap Soft Reduction makes it possible to freely define scenarios for start-up, tundish change and tailout strategies based on the strand thickness, steel grade and casting status. In this way roll damage and production interruptions, which may arise from the different casting behavior of the cold strand head or end, can be avoided.

The interaction of the described models within the model suite is shown in Figure 7.

Figure 7: Process model integration

The digital twin maintenance system allows all cooling-relevant settings to be configured in such a way that the spray-water distribution in the cooling zones and the application of cooling practices are optimized for slab, bloom and billet casting machines. Customers' metallurgical know-how can be easily incorporated into the Dynacs 3D automation setup.
The offline simulation system of the model suite enables comprehensive testing of new parameter settings prior to application in the production process. The simulation of the model suite can be either be done in real time or in order to speed up an acceleration is built in. During simulation the metallurgist can decide to fasten the simulation or to slow down while the actual casting speed stays unchanged.
When introducing new steel grades into the production program, the risk of using unsuitable cooling or soft reduction settings is minimized by offline simulations. The behavior of the machine casting the new grades can be studied in detail prior to production. For instance, the soft reduction process of the new grade can be observed and casting speed can be adjusted to the new grade properties, if necessary. Process adjustments for quality optimization are also facilitated by simulation of the adjusted parameters in advance. The process engineer is enabled to evaluate the consequences of his adjustments and can use them with more safety.
During production Dynacs 3D stores all relevant data into files. This makes it possible that any casting situation can be replayed by a metallurgist or process engineer

offline at a later time. The files are stored with a time stamp. So the user just has to select the files in the time period he wants to analyze and then he can start the replay to check the behavior of the model suite.
A very useful feature is that he can even modify the replay situation. E.g. what would have happened in this specific situation if Dynacs 3D would have used the “hard” cooling practice instead of “medium” practice. This information can be very useful for upcoming productions scenarios.

SUCCESS STORY

At its plant in Duisburg-Beeckerwerth, Germany, Thyssenkrupp Steel Europe (TKSE) operates two slab casters that were upgraded with the advanced process models. The upgrade also included an installation of the digital twin. This allowed experts from Primetals Technologies to perform offline casting simulations, minimizing the impact on ongoing production. This led to remarkable results as early as during the commissioning phase. At the end of segment 0 (cooling zone 3), which is about 4 m below meniscus, the surface temperature across the strand width was extremely uneven (see Figure 8). It can also be seen that the surface temperature minima are around 1050°C at the end of zone 3 while the temperature maxima near the corners are almost 200°C higher.

Figure 8: Surface temperature across strand width at 4m from meniscus using existing nozzles

Since the problem obviously was the spray distribution over the width in zones 3, simulation runs were made using the Dynacs 3D offline simulation with different nozzle configurations. The original nozzles in this zone which were 90° flat spray nozzles (see Figure 9) seemed to cause the problem.

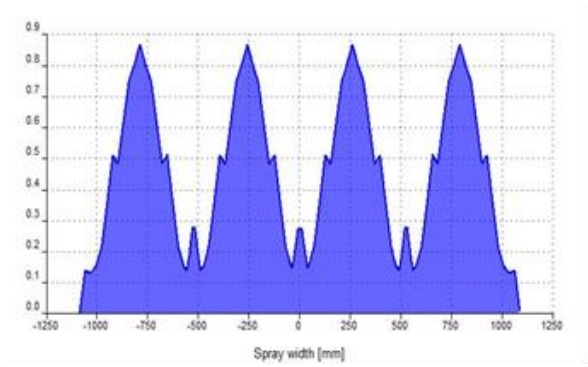

Figure 9: Spray pattern zone 3 – original nozzles (90°)

The best results were found using the 120° flat spray nozzles (see Figure 10).

Figure 10: Spray pattern zone 3 - new nozzle types (120°)

The more homogenous spray water distribution resulted also in a much better temperature distribution across the width which can be seen in Figure 11.

Figure 11: Surface temperature across strand width at 4m from meniscus using new nozzles

Simulations with new nozzle types performed in the digital twin promised significant improvements which fully materialized in the form of superior slab surface quality shortly afterward, when the changes were actually introduced in production.
After a representative number of slabs had been cast, it was found that the cracking of the surface crack sensitive high strength steel grades was drastically improved. A significant reduction of transversal, longitudinal and corner cracks by more than 50% could be achieved with Dynacs 3D surface control compared to the original nozzle configuration using speed control. Additionally the overall percentage of slab surface scarfing could be reduced from 15.8 to 11.4%.
In the conclusion meeting TKSE especially highlighted the improvement of slab quality reached by Dynacs 3D cooling model: “Based on the results of the off-line simulation we equipped segment 0 (zone 3) on one strand with a new nozzle type. Afterwards we evaluated the slab quality over a couple of months. The strand equipped with the new nozzles and cooled with Dynacs 3D definitely produces better quality than the strand with the original nozzles.”

3 CONCLUSION

Primetals Technologies has installed the continuous casting process automation system (Level 2) solely in 2018 over 30 times world-wide on all types of continuous casting machines. Especially with the capabilities of our digital twin and the replay functionality Primetals is able to support its customers in an unparalleled way that makes production processes more transparent. Using the digital twin the way of work for process engineers will be simplified and solving problems in their daily work by offline and quickly simulating process scenarios with mechanical or parameters changes will be supported in the best possible way without any risk. The continuous

casting digital twin is used for the whole product lifecycle to simulate, predict and optimize the continuous casting process. A vast suite of automation solutions and process-optimization models is available to our customers to optimize their production performance and maximize product quality.

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