46th Steelmaking
ISSN 1982-9345

HIGHLIGHTS IN CONTINUOUS CASTING PROCESS AUTOMATION*

Wolfgang Oberaigner[1]
Reinhold Leitner[2]

Abstract
Primetals Technologies has always been a driver of innovation in steelmaking, especially by providing sophisticated process expert models for continuous casting machines. This capability is demonstrated by recent advancements in automation solutions that include: DynaPhase, Dynacs 3D, and DynaGap. This state-of-the-art suite of dynamic secondary cooling and soft-reduction packages take into account thermodynamic effects such as shrinkage and phase transitions, and thereby significantly contribute to direct quality improvements during the solidification phase in the continuous casting process. Speed Expert calculates an optimum casting speed for every casting situation, and additionally recommends a strand speed so that the point of final solidification is positioned at the end of a segment for optimum soft reduction. In the case of steel grade changes, the Intermix Expert precisely calculates the chemical properties of the mixed steel, thereby minimizing losses due to deviations from required specifications. The Nozzle Expert is a new model that detects clogged nozzles and broken hoses in secondary cooling systems. The first installations were highly successful and customers are pleased with impressive reductions in maintenance costs and improved steel quality. This paper describes these innovative process automation solutions and gives an overview about the successful results achieved within the first installations.
Keywords: Automation; Continuous casting; Technological products; Primetals Technologies Brazil.

[1] *Engineer, MT EA ISC, Primetals Technologies Austria GmbH, Turmstraße 44, 4031 Linz, Austria.*
[2] *Engineer, MT EA EN L2T2 3, Primetals Technologies Austria GmbH, Turmstraße 44, 4031 Linz, Austria.*

1 INTRODUCTION

Automation and mechatronic packages improve and assert the quality of the continuous casting products (slabs, blooms and billets) in various ways. New challenges that stem from ever increasing quality demands as well as new ideas how to tackle well known issues in the casting process have led to the Primetals Technologies innovations that are presented in the following paper.
The new DynaPhase, Dynacs 3D and DynaGap Soft Reduction model suite takes the precision and control possibilities to the next dimension allowing completely new philosophies for secondary cooling and soft reduction.
A new and successful approach of Nozzle Expert allows early detection of clogged nozzles and broken hoses, which leads to a dramatically reduction of maintenance hours and supports operation to cast products with consistent strand surface quality.
Intermix assures that prime quality product in the strand is determined precisely in case of mixing different grades during sequence casting to allow the Yield Expert package to cut prime products before and after the incompatible section of the strand [1].
Quality improvement and throughput are the main issues of the Speed Expert, where factors that influence the casting speed are combined and an optimum casting speed for any casting situation is calculated.

2 MATERIAL AND METHODS

2.1 The 3rd Dimension in Secondary Cooling

The new model suite takes the precision and control possibilities to the next dimension allowing completely new philosophies for secondary cooling and soft reduction

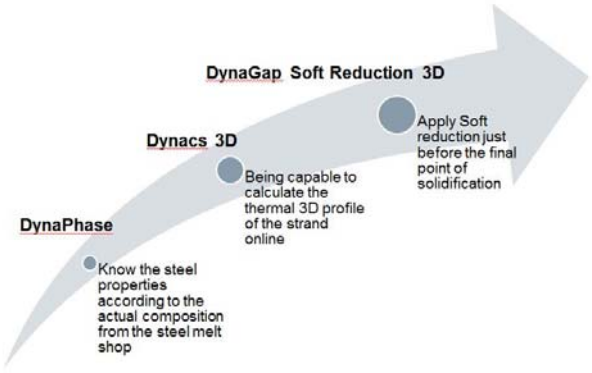

Figure 1. DynaPhase, Dynacs 3D and DynaGap Soft Reduction

2.1.1 Model suite setup

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 (Figure 2) to evaluate the spray water distribution.

Figure 2. Measuring nozzles at the nozzle test stand

This derived information is input to the maintenance and setup system (MSS) of the Dynacs 3D model. The visualized spray distribution can be seen in the maintenance system see Figure (Figure 3).

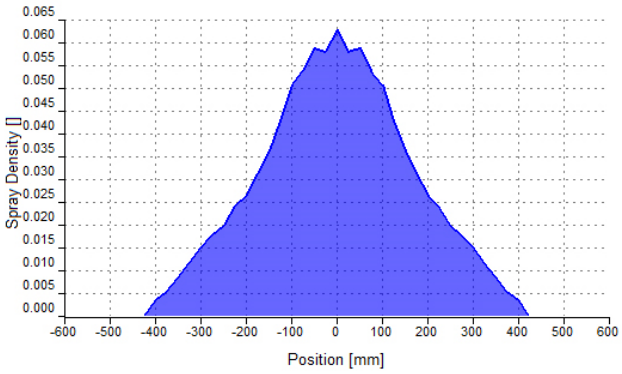

Figure 3. Spray distribution of one nozzle.

The exact positions of the nozzles in the cooling zones are entered and the spray distribution of one zone can be seen in the MSS see Figure (Figure 4).

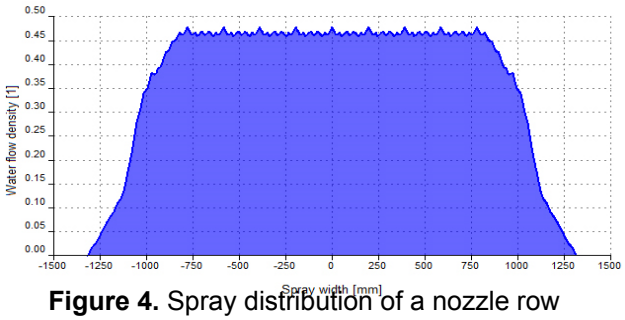

Figure 4. Spray distribution of a nozzle row

The heat removal of a cooling zone (black line) is calculated considering the heat removal of the spray water (blue), rolls (red) and heat radiation (pink) as shown in see Figure (Figure 5).

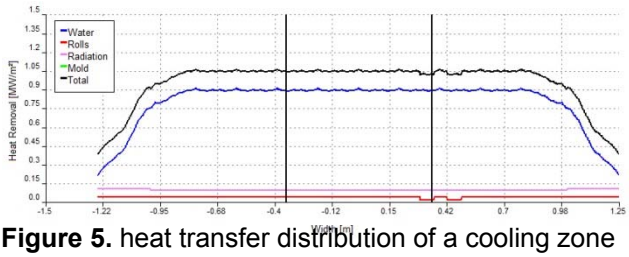

Figure 5. heat transfer distribution of a cooling zone

The MSS 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. A built-in offline simulation system enables comprehensive testing of new parameter settings prior to application in the production process.

2.2 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 in the MSS, which is very time-consuming. Usually the metallurgist will not know these thermo-physical properties. The software model DynaPhase calculates all the thermo-physical data used by Dynacs 3D. DynaPhase is available as an 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.
The traditional approach is to define the thermo-physical properties for grade groups with a predefined concentration range of the chemical analysis. Using DynaPhase these data can be calculated for each individual steel grade.
This makes the prediction of quantities such as the point of complete solidification on the strand and the temperature distribution of the strand during casting more accurate and therefore allows for precise metallurgical treatments that can lead to an enhanced quality of the products.
Moreover, DynaPhase indicates whether the current analysis of the steel is peritectic or not and alerts the operator in the event of an unexpected peritectic grade. This can reduce the risk of breakouts and improves quality.
DynaPhase is based on thermodynamical models. The liquid-solid phase transformation in the high temperature range is described by a Gibbs free energy model in combination with a microsegregation model. For solid-solid phase transformations in the low temperature range an Avrami type model is employed. The free parameters of the models are determined with help of experimentally measured quantities. Using offline simulations of DynaPhase together with Dynacs 3D allows metallurgical development of new steel grades.

ISSN 1982-9345

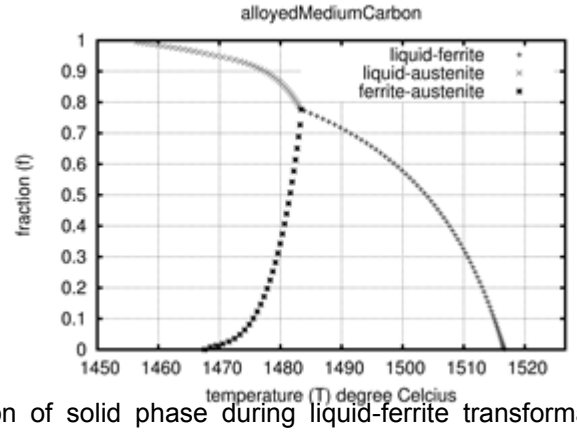

Figure 6. Phase fraction of solid phase during liquid-ferrite transformation (solid) liquid austenite (dashed), and the phase fraction of ferrite during ferrite-austenite transformation (dotted).Composition (in wt%): Cr 0.08, Ni 0.08, Mn 0.5, Mo 0.08, Si 0.2, Cu 0.08, Nb 0.03, Ti 0.008, Al 0.04, P 0.024, S 0.01, N 0.005, C 0.18.

Traditionally the steel grades are grouped and a typical chemical analysis for this group is used to determine the material properties. With DynaPhase the material properties are derived from the actual steel analysis. Calculations show that there can be a difference in the point of final solidification of half a meter or even more by comparing the results of the actual steel analysis versus the grade group analysis. This fact shows the importance of having an online calculation of the actual steel grade in order to improve the quality of the cast products.

2.3 Dynacs 3D – Secondary Cooling System

More than 100 Dynacs secondary cooling systems (predecessor of Dynacs 3D) have been installed in slab casters worldwide. The first-generation Dynacs solution, introduced in the 1990s, was characterized by a two-dimensional temperature calculation of the strand center. The strand corners were largely neglected by the process model. Continuous improvements in computer performance have now made it possible to calculate 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 see Figure (Figure 7) and (Figure 8).

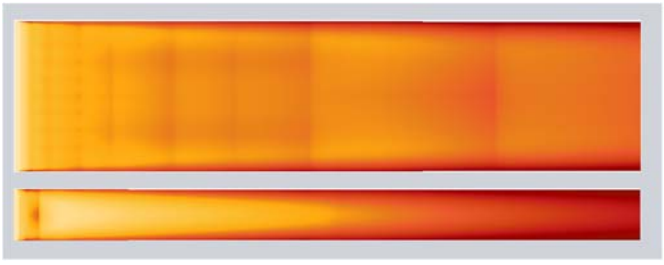

Figure 7. Calculated temperature profile of strand surface (top and side view, true colors)

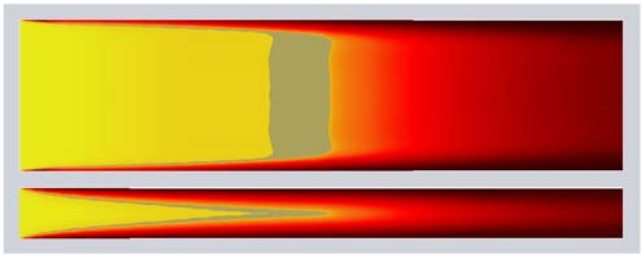

Figure 8. Calculated temperature of strand cross section (center view, enhanced colors indicating the mushy zone area)

Special temperature ranges are made visible by shading the corresponding strand ranges see Figure (Figure 9). The ductility range e.g. is shown in blue.

Figure 9. visualization of the ductility range in the cross-section view

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 (See figure 4) and the actual spray water temperature. This ensures an accurate spray-cooling heat transfer prediction to temperatures below 700°C when the Leidenfrost phenomena disappears. The result is an even more precise determination of the strand surface-temperature profile and the final point of strand 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.

Pyrometer measurement results see Figure (Figure 10) at voestalpine Stahl (steel industry located in Autria) show an excellent fit in between calculated and measured lateral strand temperature profile.

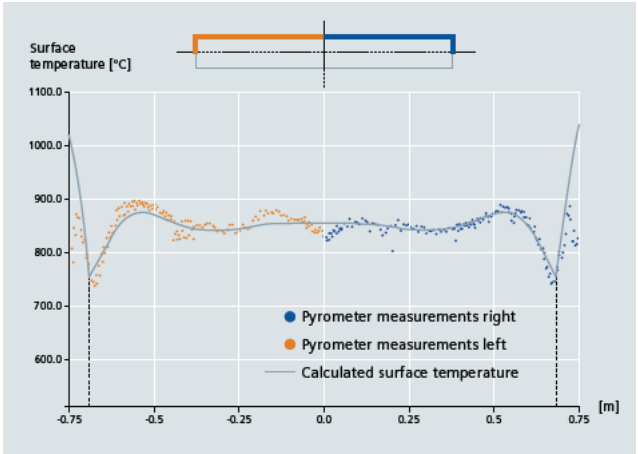

Figure 10. Pyrometer measurement results

Application of Dynacs 3D allows to introduce completely new philosophies to set up cooling practices for upcoming challenges in continuous casting. The combination with moveable spray nozzles (3D Sprays) yields unprecedented quality results.
Since 2011 the Dynacs 3D secondary cooling model has already been successfully installed on more than 40 slab casters worldwide and has become the standard Primetals Technologies secondary cooling system.

2.4 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 see Figure (Figure 11).

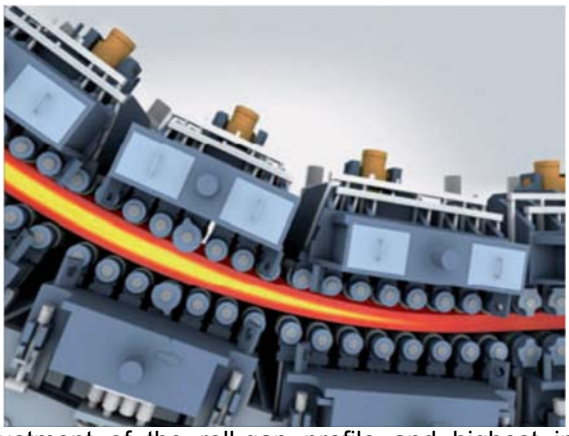

Figure 11. Optimized adjustment of the roll-gap profile and highest internal strand quality with DynaGap Soft Reduction

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 tail out 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.
Due to the modular setup the new DynaGap Soft Reduction model can be installed on existing caster equipment and basic automation systems even from other suppliers.

2.5 Nozzle Expert – Early Clogged Nozzle Detection

Cooling water is sprayed through nozzles onto the strand with the objective of achieving uniform cooling of the steel. If, however, one or more of these nozzles are clogged, a section of the strand cannot be uniformly cooled to the required temperature. This may lead to surface defects, and the cast product will possibly have to be downgraded. The issue of changing segments in the caster is also a source of difficulty. Hoses can easily be ruptured or jammed. Aware of the consequences of leakages or clogged nozzles, maintenance personnel spend a large number of working hours checking whether nozzles are operating properly.
The Nozzle Expert helps to detect clogged nozzles and broken hoses in continuous casting machines and consequently ensures that the strand is evenly cooled for high-quality steel production. It automatically monitors the condition of the nozzles during the casting process. The model can also be manually activated during casting breaks. The advantage is that nozzle status can be checked following maintenance work or segment changes and immediately repaired before the casting process is re-started.
The model calculation considers parameters like nozzle type (measuring results from the nozzle test stand), water pressure, height between pressure measuring device, pipe lengths, pipe diameters and nozzle positions. Any modifications to the secondary cooling system e.g. use of different nozzle types requires a change in the setup of the Nozzle Expert in order to get correct computational results.
The Nozzle Expert is based on statistical models and indicates the clogging ratio see Figure (Figure 12) in each zone (e.g., zone 2 clogged 8% with a probability of 95%). Operators need only to inspect zones for which an alarm is generated. Calculations begin automatically with the start cast signal, and the condition of the nozzles is monitored throughout the casting process.

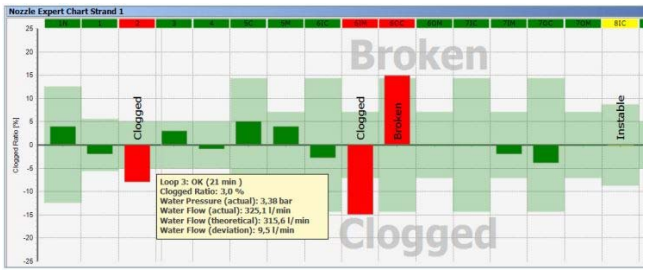

Figure 12. Nozzle Expert reports the ratio of clogged nozzles in percent for each zone

Within one year the Nozzle Expert has been successfully installed on more than 10 casters worldwide in 2014. The excellent customer feedback shows that the accuracy of detecting failures in the secondary cooling system is very beneficial to them. Several alarms helped to detect leakages, clogged nozzles and even falsely installed nozzles on a segment.

2.6 Intermix Expert – Improve Yield by Prior Simulations

During sequence casting, a mixing of steel grades takes place in the tundish and consequently in the strand with each ladle change. On the basis of the chemical composition of the steel, the Intermix Expert calculates whether the mixed steel zones may be used for the foreseen product application or if the steel has to be

downgraded or even scrapped. Information acquired from tundish flow experiments combined with analysis results of steel samples taken from solidified products ensures a high degree of accuracy of Intermix predictions with respect to the actual composition of the mixed steel zones.

The Intermix Expert see Figure (Figure 13) determines traces of the previously cast heat present in the current heat. Steel mixing takes place not only in the tundish but also in the mold and upper parts of the strand. Mixing in these areas is evaluated by a mixbox-type submodel of Intermix that makes it possible to calculate the chemical composition of the steel at any position along the cast strand.

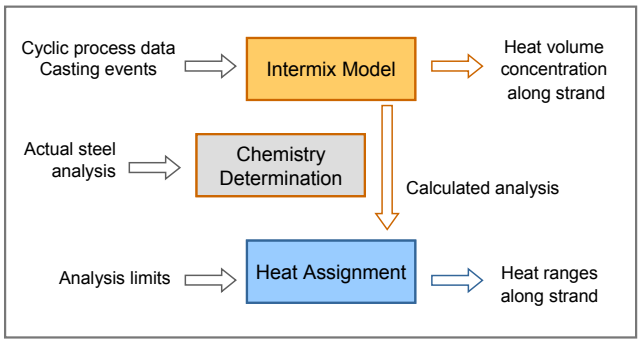

Figure 13. Basic structure of the intermix expert

Tundish changes or the use of separator plates are treated individually. Intermix calculations are cyclically performed for selected chemical elements starting with the “ladle open event” of a new heat. The final decision about the compatibility of heats cast in sequence is performed by the heat-assignment function of Intermix. The concentration profiles of certain critical elements that have an impact on the final product disposition – prime, downgraded or outright defect – are determined. A deviation is detected if one of the critical elements does not match the steel-grade specification.

The full benefit from the intermix model is achieved by combining the model output with the Yield Expert package that assures maximum prime quality yield by applying cut-length optimization to incompatiblesteel areas along the strand that are designated as scrap.

Metallurgists or process engineers work with our powerful simulation environment, which makes it possible to simulate any combinations of different steel grades. Input parameters like analysis, tundish weight and dimensions of the strand can be easily entered and modified and the computed results are made visible in the HMI.

see Figure (Figure 14) shows two incompatible grade analyses of two consecutive cast heats that lead to a scrap section in the strand. The length of the scrap section (red bar at the bottom of the graph) depends on different parameters like steel chemistries, tundish weight at ladle open, tundish filling rate and casting speed.

Graphs are displayed for single analysis elements (upper part of figures 16 and 17) or combinations of more elements. Valuable information like volume concentration, mixed steel length, scrap length and heat ranges on the strand are shown on the bottom of figures 16 and 17.

ISSN 1982-9345

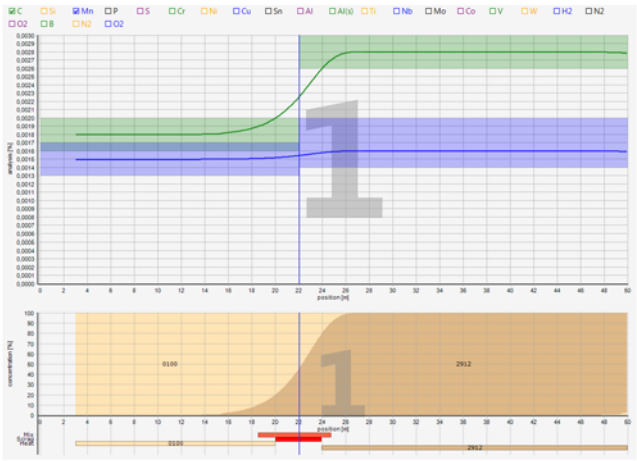

Figure 16. incompatible grade analyses lead to scrap sections in the strand

Figure (Figure 17) shows two different grade analysis where no scrap piece on the strand is produced.

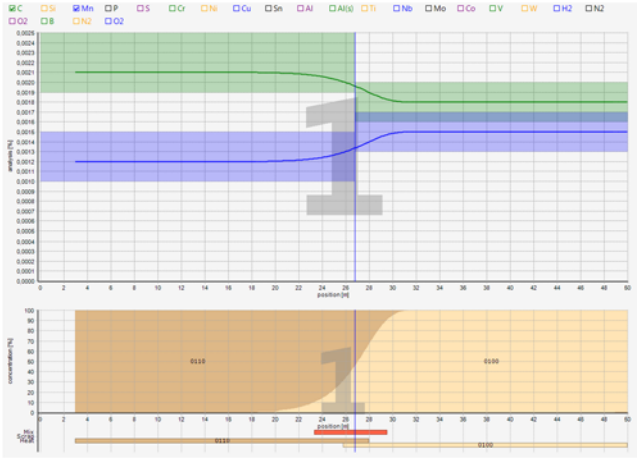

Figure 17. Compatible grade analysis

Configuration of the model can be easily done in the MSS. The metallurgist can choose which chemical elements should be used to determine the intermix for any grade link. A powerful simulation environment allows simulating the mixing behavior of 2 different grades and the computed volume concentration, calculated analysis along the strand and heat ranges including possible scrap sections are displayed.

2.7 Speed Expert – Optimum Casting Speed in any Casting Situation

Selecting a proper casting speed on a continuous caster is of high importance. Many aspects (e.g. quality, safety, machine limits and production requirements) influence the choice of the casting speed. These different aspects are often contradictory e.g. increase production calls for a high casting speed where safety requirements (whale prevention) limits the casting speed.
From the huge amount of projects we know that many customers have self-made software solutions to calculate the casting speed considering different aspects. The aim of our Speed Expert is cover most aspects and to provide our customers an easy maintenance tool which enables them to adjust the behavior of the Speed Expert to their special needs.

The Speed Expert calculates cyclically the optimum casting speed. The calculation of the casting speed is based on different rules, which consider the different aspects and are specified in the Speed Expert practice. Each rule determines a speed range that satisfies its requirements. The Speed Expert first determines the intersection of all these speed ranges. If the intersection is not empty, then it selects a casting speed depending on the predefined strategy, which can be Max Speed (use maximum speed of intersection), Aim Speed (use aim speed of production practice if within intersection), or Keep Constant (avoid speed changes as long as actual casting speed is in the valid range).
If there is a conflict between the different rules the intersection is empty. In this case the preselected Conflict Resolve Strategy is applied which can be:

- Priority (lower priority rules will be neglected till a solution can be found) or
- Min Of Max Speed (the smallest of all maximum speeds will be selected).

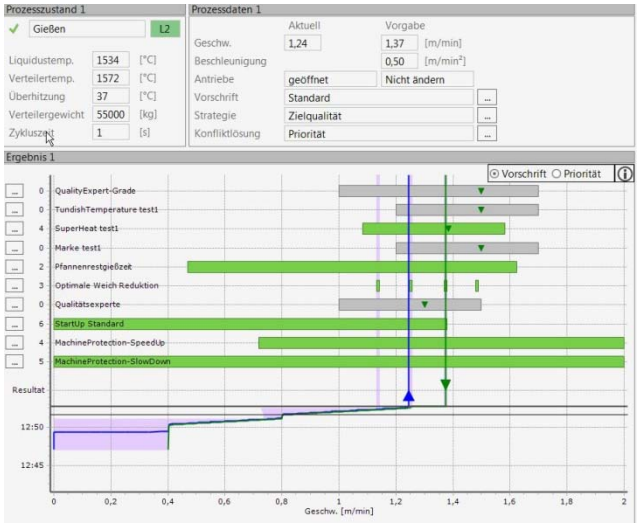

Figure 18. Speed Expert HMI

On the online HMI the operator can view the speed ranges (green bars) of all rules and the derived, optimum casting speed. The operator can change the priorities of the different rules, the strategy and the Conflict Resolve Strategy to fine adjust the calculation if necessary.
Speed set points are sent to Level1 and can be executed automatically.
MSS is used to define the Speed Expert practice considering following rules:
Quality

- Quality Expert Rule
- min/aim/max speed for the steel grade
- superheat
- Mn/S ratio
- low tundish weight
- optimum soft reduction

Production

- heat pacing
- start cast
- clearing

Safety

- Machine Protection

- Forecast calculation for min and max speed

Optimum soft reduction can be achieved if the final point of solidification is at the end of a strand segment. A precalculation assuming steady state conditions determines the required casting speeds for each strand segment.

3 CONCLUSION

Primetals Technologies provides a renewed suite of automation packages enhancing product quality by applying next level cooling and soft-reduction philosophies (DynaPhase, Dynacs 3D and DynaGap Soft Reduction). Dramatically reductions of maintenance costs and downtimes are achieved by the new model Nozzle Expert by early detecting clogged nozzles and broken hoses in all different types of continuous casting machines.
In case incompatible steel grades are cast on each other the Intermix model determines critical areas in the strand that may be downgraded or subject to the algorithms of the cut-to-length optimization package Yield Expert. A completely new approach was done with the flexible Speed Expert where standard and customer specific rules are combined to compute an optimum casting speed in all casting situations. Finally pure.hmi provides a consistent look and feel over the entire production chain and supports the operator in getting quick and intuitive access to the required information.

REFERENCES

1 Juza P., Leitner R., Hübner N., Pitzer W.: The next level of quality in continuous casting automation ECCC, P. 3-5 (2011).