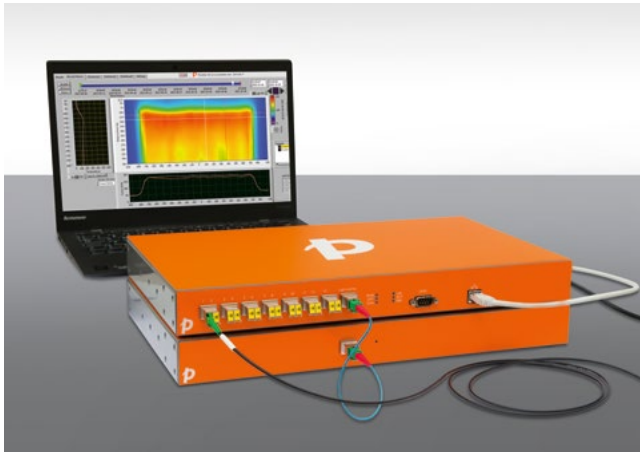
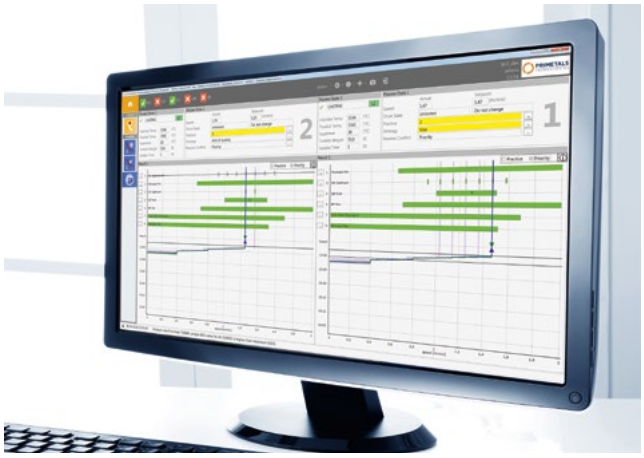
A SELECTION OF THE MOST REMARKABLE SOLUTIONS OF PRIMETALS TECHNOLOGIES FOR THE DIGITALIZATION OF

CONTINUOUS CASTING

The vast experience of Primetals Technologies in the field of continuous casting directly leads into the age of digitalization. Expert systems, advanced simulations, and high-end measuring devices are among the new solutions that propel continuous casting to new heights.



Mold Expert Fiber uses thousands of fiber-optic sensors to provide an astonishingly detailed "inside look" into the mold.



Example of a Speed Expert HMI. The green bars represent acceptable speed ranges for different requirements in casting.

MOLD EXPERT & MOLD EXPERT FIBER

Sticker-related breakouts are one of the major reasons for high repair costs and production losses. Product defects can mostly be traced back to processes in the mold, but conventional detection tools do not offer directly accessible information. Disturbances in the solidification process such as poor casting-powder performance, tilted submerged entry nozzles, improper taper settings, or bad steel-flow patterns are frequently overlooked due to the lack of reliable information from the mold. The Mold Expert system from Primetals Technologies collects exactly that information: comprehensive data on temperature, oscillation, primary cooling, mold level, and casting speed is fed into the Mold Expert server and interpreted. This allows for rapid alerts in the event of critical conditions. In addition to breakout prevention, the system provides an ever-increasing number of expert packages that are used to detect possible surface defects and inform operators about other challenging casting conditions. Mold Expert has become the world's leading system
for mold monitoring, and Primetals Technologies recently celebrated its 200th installation.

The cutting-edge incarnation of the system—Mold Expert Fiber—takes measurement accuracy and resolution to a whole new level. It builds on the technology of fiber Bragg gratings to integrate fiber-optic sensors into the mold. This dramatically increases the number of measurement points—from a mere 120 in the standard Mold Expert installation up to in excess of 2,000. The massive amount of resulting data allows for an astonishingly detailed, real-time "inside look" into the mold. Among other benefits, the system more precisely detects critical events such as stickers and longitudinal cracks, and it calculates meniscus flow speed. Mold Expert fiber has already been sold and is on track to be deployed in production for the first time.

SPEED EXPERT

Selecting the proper casting speed in continuous casting is critically important for the productivity of a caster and the quality it produces. Many factors and requirements have to be considered when choosing the right casting speed: superheat, steel-grade requirements, quality, safety, machine limits, and other production aspects. In many instances, these requirements are at odds or effectively contradict one another; increasing production, for example, calls for higher casting speeds while safety requirements demand lower speeds.

Speed Expert from Primetals Technologies was engineered to take all of these requirements into account and find the optimum balance between them in any given casting situation. It is based on a set of rules—one for each requirement relating to casting speed. Each rule defines the ranges of speed needed to satisfy the appropriate requirement. Rules can also be assigned priorities—if two rules yield contradictory requirements on casting speed, the rule with the lower priority is ignored. Speed Expert then determines the intersection of suitable speed ranges and makes a selection based on a predefined strategy. Depending on the situation, this strategy may be to maximize speed within the possibilities, to aim for a particular speed, or to avoid any speed changes as long as all requirements are met. In continuous casters that apply soft reduction prior to solidification of the strand, Speed Expert will set the casting speed in such a way that the soft reduction process is completed right at the end of a movable segment. Most remarkably, the system can determine the casting speed necessary to achieve this online during a casting sequence.

Since its introduction in 2015, Primetals Technologies has added eight references for Speed Expert.

QUALITY EXPERT

Quality Expert is a computer-aided quality-control system for all types of continuous casters. It is designed to determine the definitions necessary for quality-related process parameters, to track data during production, and to predict the quality of cast products so that potentially defective products can be separated. It provides plant operators with online quality alerts and a preview of the quality of the casting strands in the machine. Quality Expert comes in two editions with either basic or comprehensive product-quality rating capabilities.

The online quality-control functions are configured in the Maintenance and Simulation System. The flexible rule editor enables end users to adapt or add quality rules without the support of specialized software engineers. Rule systems for predicting the quality of product-defect types (cleanliness, surface quality, inner quality) can be configured. The Quality Expert then evaluates quality rules online and displays the resulting quality rating. The quality previews are available for hot strands currently being cast and for products already cut, along with a root cause explanation of the quality rating. The knowledge-base component means that Quality Expert is easy to configure, enabling process engineers to react quickly to changing quality demands and production requirements. Quality Expert records quality-critical process data at high resolution as it is transmitted from the basic automation system and process computers. All tracked data and calculation results can be transferred from the Quality Expert's production module to a solution called the Discovery system, which is dedicated to the long-term archiving and evaluation of tracked data in accordance with ISO 9001 standards. Quality Expert represents a milestone in improving quality control in continuous casting. Cost savings can be achieved by avoiding product inspection and conditioning activities, thereby minimizing material losses and handling costs.

Visualization of Quality Expert's results

Quality Expert is easy to configure, enabling process engineers to react quickly to changing quality demands and production requirements.

YIELD EXPERT

The aim of the Yield Expert is to minimize scrap and to optimize yield. It considers scrap portions, quality defects, weight restrictions, sample cuts, and width changes while producing the maximum number of scheduled products. Yield Expert optimizes product length or product weight whenever scrap sections need to be taken care of, thanks to advanced algorithms that determine the area that should be allocated as a scrap section. It also handles quality-related defects, and schedules mold-width adjustments to amend the casting process. Yield Expert's optimization algorithms can easily be switched on or off via direct on-line control. One of Yield Expert's strongest features is the ability to replay previously used cut-to-length optimization steps within actual production setups. Yield optimization has never been so easy, straightforward, and transparent.

Yield Expert minimizes scrap during production, optimizes the casting process, and handles quality-related defects.

INTERMIX EXPERT

The Intermix Expert for all types of continuous casting machines calculates the mixed-steel area and incompatible strand portions along the entire strand. The information gathered allows the Yield Expert to cut prime products before and after the incompatible section of the strand, so maximum prime-quality yield is ensured.

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 mix-box-type submodel of the Intermix Expert, which makes it possible to calculate the chemical composition of the steel at any position along the cast strand. Based on the chemical composition of the steel, the Intermix Expert calculates whether the mixed steel zones can be used for the desired product application or if the steel has to be downgraded or even scrapped. Input parameters such as analysis, tundish weight, casting speeds, and dimensions of the strand are taken into account. The computed results are visualized in the human machine interface. Graphs are displayed for single-analysis elements or combinations of multiple elements. Valuable information including volume concentration, mixed steel length, scrap length, and heat ranges on the strand are displayed on the screen. Configuration and simulation of the model are easily carried out in the Maintenance and Simulation System. Metallurgists can choose which chemical elements are used to determine the intermix for any steel grade. At the same time, Intermix Expert will provide them with precise information on the chemical analysis at any position on the cast slabs. The Intermix Expert's powerful simulation environment allows the intermix of different steel grades to be accurately tested.

EQUIPMENT EXPERT

The Equipment Expert is designed to monitor the installed equipment of the caster and provide operators with valuable feedback about any maintenance work required. Equipment could include, for example, an entire segment, individual rolls, a mold, or mold plates. Equipment test reports, manuals, and instruction documents for equipment are viewed in the human machine interface. For every piece of equipment, lifetime or partial-lifetime criteria are defined. Such criteria might include the number of heats, casting time, casting length, tons, durations, or any other factors. The Equipment Expert collects these criteria for each piece of equipment and notifies operators when a lifetime criterion is due to be reached, in order to facilitate preventive maintenance.

A single Equipment Expert can handle several casters at once.

NOZZLE EXPERT

The Nozzle Expert helps to detect clogged nozzles and broken hoses in all types of continuous casting machines, and ensures that the strand is uniformly cooled during the continuous casting process. The steel is cooled by spraying water onto the strand through nozzles. To avoid surface defects and possible product downgrading caused by clogged nozzles or ruptured or jammed hoses, the Nozzle Expert automatically monitors the condition of the nozzles during the casting process.

The Nozzle Expert features online and offline monitoring. In online mode, calculations begin automatically with the "Start Cast" signal, and the condition of the nozzles is monitored throughout the casting process. In offline mode, the secondary cooling system can be tested by manually activating the Nozzle Expert during casting breaks, with the advantage that any problems with the nozzles can be detected and repaired before the casting process is re-started. In idle mode, the Nozzle Expert can perform a more detailed check because proper water-flow rates can be selected. During a manual check, the water-flow rates cover the full range from minimum to maximum flow, and the performance of the controllers can be examined. The results are documented in a report, which shows the states of all cooling zones and contains a detailed section for each zone with the time trends of all relevant zone data. The Nozzle Expert is based on statistical models and indicates the ratio of clogged nozzles in each zone. Therefore, operators only have to inspect zones for which an alarm is generated. This highly efficient setup minimizes maintenance efforts and reduces the hours involved in checking nozzle status.

With the Maintenance and Simulation System, a customer can grant experts access to real-time data for remote advice.

MAINTENANCE AND SIMULATION SYSTEM
FOR TESTING PROCESS CHANGES IN CASTING

The steel industry is well on its way toward fully automated continuous casting, which is going to minimize the risk of human error and increase workplace safety considerably. Meanwhile, tried and tested automation products from Primetals Technologies provide sophisticated opportunities for optimizing and monitoring the casting process, while their pioneering component-based architecture offers a high degree of flexibility.

MAINTENANCE AND SIMULATION

Primetals Technologies provides an all-in-one setup, testing, and maintenance tool as an integral part of the Continuous Casting Optimization package. The "Maintenance and Simulation System" (MSS) facilitates the maintenance of parameters and configurations for the automation system, including the process model suite Dyna-Phase, Dynacs 3D, and DynaGap Soft Reduction, described in more detail on pages 62-63. The MSS thus supports metallurgists in their daily work and enables them to enter the machine geometry, cooling requirements, and formulas describing water distribution and heat removal for each cooling loop, radiation, roll-heat removal, mold-heat removal, and natural convection. It also comprises the following additional functions:

- Software deployment, configuration, start, stop, restart, and the ongoing supervision and troubleshooting of caster optimization processes
- Online checks of basic automation data and an overwrite function for emergencies
- Long-term monitoring of basic automation data consistency during cold testing or parallel runs with legacy systems

A "DIGITAL TWIN" OF REAL-WORLD EQUIPMENT

The simulation part of the MSS provides the functionality necessary for testing parameter changes and training operators in an offline environment in order to achieve smooth system start-ups. It creates a virtual instance of the actual plant facility—a "digital twin" of real-world equipment. This allows engineers to run extensive simulations of new equipment or parameter changes before they are introduced to the actual casting process. It eliminates any disruptions in ongoing production and minimizes the risk of unexpected outcomes. Using predefined script files, it facilitates tests of various casting scenarios and can replay past events. The digital twin also allows for stress tests in order to predict the long-term effects of any modifications.

OFFLINE SIMULATIONS **FOR SUPERIOR SLAB QUALITY**

At its plant in Duisburg-Beeckerwerth, Germany, thyssenkrupp Steel Europe (TKSE) operates two slab casters that were upgraded with the advanced process models from Primetals Technologies. The upgrade also included an installation of the Maintenance and Simulation System (MSS). This allowed experts from Primetals Technologies to perform offline casting simulations by means of a remote connection, minimizing the impact on ongoing production and limiting the team's presence on site. This led to remarkable results as early as during the commissioning phase: Working offline, the Dynacs 3D secondary cooling model was able to identify uneven spray-water distribution in two cooling zones of the strand. Simulations with new nozzle types performed in the MSS promised significant improvements—which fully materialized in the form of superior slab-surface quality shortly afterward, when the changes were actually introduced in production.

"Digital twin" offline simulations avoid disruptions in ongoing production when changing parameters or introducing new equipment.

CASTING-PROCESS OPTIMIZATION **WITH MACHINE LEARNING**

Daniel Fuchshuber is Head of Process Optimization, Continuous Casting at Primetals Technologies.

Which types of plants benefit the most from the kinds of "digital twin" offline simulations that the MSS makes possible?
Fuchshuber: I think plants that are trying to extend their product range to special alloyed steel grades and need to invest in new or upgraded equipment benefit the most. It is invaluable to be able to simulate the outcome of these modifications in detail beforehand and plan investments accordingly.

Where do you see the most potential for future developments in the digitalization of casting?
Fuchshuber: Currently, I see two trends: autonomous casting and data analytics. Modern casting machines incorporate very complex systems that require vast knowledge to operate correctly. To achieve the best quality, an automation system needs to assess the current casting situation and take the correct actions autonomously. Long-term data analytics based on collected production data gives steel producers the foundation to identify areas for improvement.

Do you see artificial intelligence and machine learning playing a big role in the mid-term?
Fuchshuber: Long-term data analytics will become very important, but these analyses are very complex and time-consuming, and require extensive know-how. By incorporating machine learning into analytical methods, we are creating tools for the plant operators to interpret their data in a feasible way.

PIONEERING THE FUTURE
OF CONTINUOUS CASTING

As one of the pioneers of continuous casting technology—a legacy extending back to the 1960s—Primetals Technologies has always been the leader in the development and implementation of sophisticated process models geared toward maximizing operational efficiency and the quality of the cast products. As far back as the 1970s, Voest-Alpine Industrieanlagenbau (VAI), a predecessor company of Primetals Technologies, introduced complex nonlinear models for evaluating strand mechanics such as bulging and material creep at high temperatures. Results of these investigations led to the application of many of the process and machine design features that Primetals Technologies still incorporates into its casting machines today.

The use of advanced process models in continuous casting remains indispensable today to meet new challenges arising from changing and increasingly difficult market requirements. The models also help to satisfy the need for new and special steel grades for ever-demanding downstream applications. Primetals Technologies therefore continues to drive innovation in this area, especially by offering a complete range of expert technological packages and models that cover all aspects of the casting process—from the casting platform to the strand run-out area.

This capability is impressively demonstrated by recent advancements in caster-automation solutions with the introduction of the DynaPhase, Dynacs 3D, and DynaGap Soft Reduction 3D models. This suite of dynamic secondary cooling and soft-reduction packages takes into account thermodynamic effects such as steel shrinkage and phase transitions, thereby significantly contributing to impressive quality improvements during the strand-solidification phase.

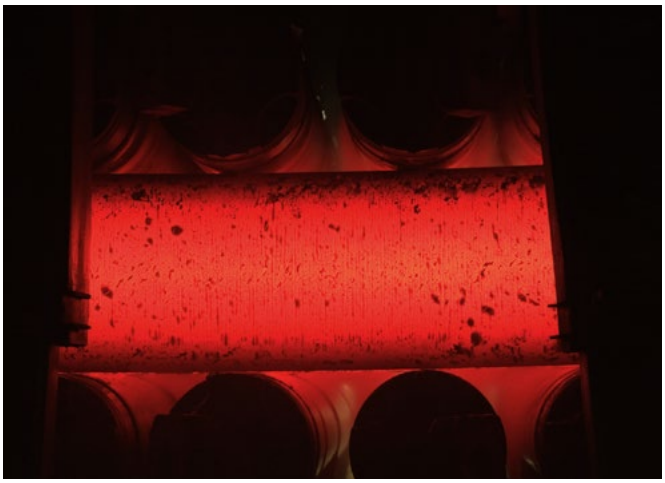
All process models from Primetals Technologies are being increasingly integrated with each other to take operating efficiency and product quality to the maximum level. This not only eases the work of the operator but also ensures that customers will have at their disposal the tools and capabilities to thrive and excel in their respective markets.

DYNAPHASE

Calculation of the 3D temperature profile of the strand requires accurate knowledge of the thermodynamic properties of steel, which includes enthalpy, solid fraction, density, and conductivity as a function of the steel temperature. However, in most cases the metallurgist does not know these thermophysical properties in advance. In order to obtain an approximation of these values, steel grades are normally grouped together and an average chemical analysis is made of each steel group. The various material properties of the respective steel groups are then experimentally determined. The resulting data is then manually entered into the Maintenance and Simulation System (MSS) tool by the metallurgist, which is a time-consuming procedure. However, casting operations show that there can be a difference in the point of final strand solidification of half a meter and more when different steel grades are cast within a particular steel group. This fact underlines the need for a process tool capable of performing online calculations of the actual steel-grade properties.

With the DynaPhase software model, the thermodynamic properties of each steel grade are calculated online on the basis of the relative proportions of coexisting steel phases at a particular temperature. This information is entered into the Dynacs 3D system, which then maps a 3D temperature profile of the strand. The combination of the DynaPhase and Dynacs 3D process models is unparalleled in the industry.

Number of references: 14 since the introduction of this process model in 2013; 14 additional projects will be implemented in 2018 and 2019.



Steel-grade properties can be calculated by the DynaPhase process model on the basis of the actual steel-melt composition.

DYNACS 3D

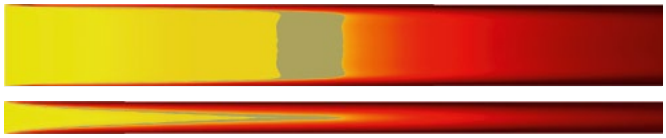
Thanks to continuous improvements in computer performance, it is now possible to calculate the temperature at any point within a continuously cast strand in real time. Using this information, the Dynacs 3D process model generates detailed 3D temperature profiles that serve as the basis for totally optimized secondary cooling. The model solves the heat-transfer equation and takes into account temperature-dependent steel density as well as slab thickness and width at a specific position. Heat transfer from surface radiation and natural convection, and heat transfer to the rolls and the spray water is accurately calculated by Dynacs 3D. The model is applicable for both spray-water cooling and air-mist cooling. It also considers the spray-distribution pattern of the nozzles and the actual spray-water temperature.

Thanks to the precise temperature calculations, individual control of water-flow rates and precise positioning of each cooling nozzle with movable 3D spray nozzles are possible. In this way, the targeted strand-surface temperature values are obtained for homogeneous surface cooling and excellent surface quality.

Knowledge of the temperature distribution along and throughout the strand during casting enables the point of final strand solidification to be accurately determined. Optimized soft-reduction can then be performed beforehand to eliminate center-strand porosity. The combination of the Dynacs 3D and DynaPhase process models also serves as a powerful off-line simulation tool for defining the cooling strategies required for the development of new steel grades.

Number of references: installed in more than 60 casters since the introduction of this process model in 2011; 17 additional projects will be implemented in 2018 and 2019.

Calculated temperature profile of strand surface (top and side views)



Calculated temperature of strand center (top and side views)

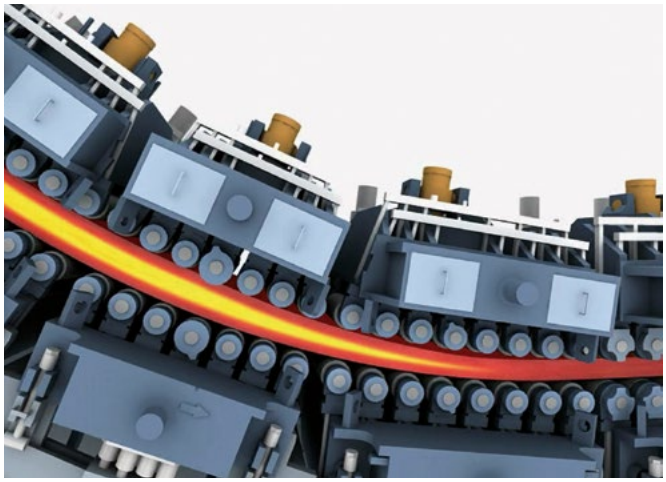
DYNAGAP 3D

DynaGap Soft Reduction 3D (DynaGap 3D) is a sophisticated process model that allows for dynamic roll-gap changes in slab and bloom casters. Working in combination with remote adjustable segment types such as Smart, Single Roll DynaGap (SRD), and Withdrawal Straightening Unit (WSU), roller gaps can be adjusted to perform strand-thickness changes, eliminate centerline segregation, and reduce porosity for substantially improved internal strand quality.

On the basis of detailed online information provided by the Dynacs 3D thermal-tracking model that includes steel shrinkage, DynaGap 3D dynamically calculates the required set points of the roll gap. Supervision of roll engagement, depending on the state of strand solidification and the calculated strand-thickness profile, is decisive for ensuring precise roll adjustments and outstanding product quality. Optimized roll engagement also prevents excessive forces from being exerted on the strand and reduces unnecessary roll wear.

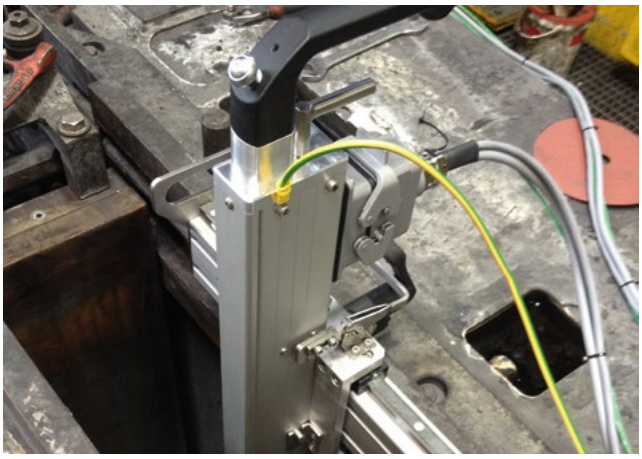
Highly accurate control of the roller gaps also allows additional casting strategies to be implemented that include liquid-core reduction for high-speed casting, extended soft reduction, and also hard reduction to further reduce porosity for additional product quality improvements. Thanks to its modular setup and design, this process model can be used on existing casters with basic automation systems supplied by third parties.

Number of references: installed in more than 50 casters since the introduction of this process model in 2011; 11 additional projects will be implemented in 2018 and 2019.



Precise adjustment of the roll-gap profiles based on DynaGap Soft Reduction 3D contributes to superior product quality.

OsciChecker Wireless analyzes oscillator behavior and helps to minimize strand breakouts and improve surface quality.



The Automatic Thermocouple Checker is suitable for all types of thermocouples and is geared toward optimum performance.

OSCICHECKER WIRELESS

OsciChecker Wireless is designed to analyze the behavior of oscillators on continuous casting machines and accordingly optimizes maintenance time, reduces downtime, minimizes strand breakouts, and improves surface quality through optimized lubrication conditions at the mold. The device enables plant operators to measure mold stroke and oscillation frequency, as well as sinusoidal and non-sinusoidal movements. It can be used for straight and curved oscillations, and is suitable for slab, bloom, and billet casting machines.

OsciChecker Wireless comprises up to four measuring sensors, a calibration plate, a measurement unit, a data acquisition and evaluation program, and a measuring box in a heavy-duty protection case. It picks up mold movement spatially using capacitive acceleration sensors placed on the mold, pointing horizontally in casting direction and vertically in stroke direction. The sensors, which can be charged via standard USB or mini-USB cable, feature magnetic fixings to ensure stable measurements and a high level of accuracy. Once placed on the mold or the oscillator, the measurement sequence can be started. Movement in and perpendicular to the casting direction can be detected, as well as negative strip time and percentage. OsciChecker Wireless is also able to spot total harmonic distortion of the oscillation frequency.

The compact yet powerful OsciChecker Wireless is suitable for the measurement of oscillator movement in all three directions and for the storage and visualization of measurement data in 3D. A wireless data connection ensures maximum user comfort and flexibility, entirely eliminating the need for cumbersome cables. The system is transportable, which means it can be carried easily between strands, and predictive maintenance means that shutdowns and breakouts can be avoided.

AUTOMATIC THERMOCOUPLE CHECKER

The Automatic Thermocouple Checker is a computer-aided tool designed to test the quality of a thermocouple installation. The test involves heating the copper plate in the same position and with exactly the same intensity each time so that it is impossible to damage the copper plate.

The device delivers highly accurate temperature measurements with deviations within a range of only 0.1°C. Any bad contact between the thermocouple and the copper plate can also be detected. The automatic, repeatable heating of thermocouples allows the quality of thermocouple installations to be markedly improved, while keeping the exchange of molds from bad thermocouples to a minimum.

The Automatic Thermocouple Checker is delivered as a transportable unit that is connected to standard thermocouple connectors. It is suitable for testing the integrity of narrow faces as well as broad faces and can be used to measure either single-mold plates (maintenance area) or mold plates at the assembled mold (in the machine). The measuring arm is positioned manually by the operator to a predefined (lockable) thermocouple column requested by the software. In a fully automatic procedure, the thermocouples in a column are heated one after another, and the temperature reaction is evaluated. Once an entire copper plate has been checked, any thermocouples with bad contacts are flagged and a report is generated.

The Automatic Thermocouple Checker eliminates measurement errors as a result of incorrect heating positions and guarantees the optimum performance of thermocouples. Consequently, maintenance work can also be kept to a minimum and quality management improved based on the recorded data.

The high-precision, robustly designed taper measuring system can be applied in any conventional slab caster.

TAPER CHECKER WIRELESS

The Taper Checker Wireless is a taper-measuring system designed to check and adjust the mold within the required tolerances before casting begins. The taper of the lateral mold surfaces is precisely measured with long-term stable inclinometers, a critical procedure given that correct tapers of mold narrow faces can minimize the number of breakouts and improve the surface quality of cast slabs.

The Taper Checker Wireless eliminates virtually all human error, such as entering incorrect calibration values. The operator's only job is to measure both narrow faces, and by pressing the transmit button, the measured correction value is sent to the automation system wirelessly.

A small display on top of the measuring device shows the correction values, enabling the user to check the plausibility of the measured taper. The Taper Checker Wireless can also be used in the maintenance area, where no Wi-Fi calibration is done.

The Taper Checker Wireless is designed to be extremely stable, which means that under normal circumstances accuracy and usage are not affected by the actual measuring process. The robustly designed system makes taper measuring a quick and easy process. As such, it can be applied in any conventional slab caster. Thanks to its modular block design, the measuring system can also be cost-effectively tailored and configured to meet individual customer needs.

Learn more about the "Industry 4.0" measuring devices of Primetals Technologies by downloading our product brochures at **bit.ly/checkerspt**

OBTAINING MEASUREMENTS **THE INTUITIVE WAY**

Nicole Oberschmidleitner is Head of Mechatronic Products at Primetals Technologies, and has been with the company for 16 years.

What are the most important objectives for current-generation measurement devices?
Nicole Oberschmidleitner: The main objectives are to ensure optimal operation of all involved production equipment, streamline maintenance efforts, enable seamless documentation, and allow for product analyses.

Have measuring devices changed due to the trend toward digitalization?
Oberschmidleitner: Certainly. In general, there has been a push toward more software-led devices that make the operators' lives easier. You can compare this development to that of recent smartphone cameras. They take great photos thanks to their software even if you don't know much about the internal workings. Also, measurement data is now automatically fed into automation systems for calibration to avoid human error.

In the future, will less human labor be required in taking measurements?
Oberschmidleitner: The process of taking measurements has clearly become more efficient. Multiple readings can now be obtained at the same time. The main benefit of today's technologies is that operators don't have to be experts, because the measuring process is largely self-explanatory.