Microstructure Target Cooling for SIROLL\textsuperscript{CIS} HM

Control your strip’s properties and produce highest quality
Control your steel quality, not only the temperature

The challenge:
One of the most important processes in steel production is the cooling of hot rolled steel on the run-out table in hot strip mills. The cooling scheme and the temperature course over time have a major influence on the strip’s mechanical properties.

Until recently, it has only been possible to calculate the target coiling temperature, derived from the desired mechanical properties – a limitation that requires compromises to adjust for changing speeds and conditions.

Our solution:
Now, new developments in the physical modeling of the steel transformation make it possible to compute temperature and phase fractions along the entire cooling section – in real time. New developments in control technology enable the control of any strip point’s temporal cooling course, also at changing speeds.

This enables us to offer you a cooling section that works right on your targets: the microstructure properties of the strip. With an optional MSM package (Microstructure Monitor) direct data about mechanical properties such as tensile strength and elongation to fracture can be provided. As a result, you can easily define and maintain your targets even under changing conditions.

And if your cooling power or design is limiting your capacity or capability, we can provide you with the most accurate, powerful and flexible equipment solutions for your needs. These solutions also include layout services to develop upgrade concepts for product extension or production capacity enlargement.

With our mechanical design, it is possible to implement these features on shorter run-out tables with a flexible layout. This brochure describes the benefits your production will achieve through SIROLL® Microstructure Target Cooling.
Good reasons for SIROLL CS Microstructure Target Cooling:

Siemens VAI – one supplier gives you all you need for the best results:

- The latest physical models handling all types of steels, including modern grades such as dual phase and complex phase, making your plant fit for the future.
- Advanced control providing you with a flexible selection of targets and strategies based on temporal cooling courses, with focus on the steel properties.
- Precise control of the temporal cooling course along the entire cooling section also for the selection of classical coiling temperature – exploiting the full capability of machine construction to achieve high performance and deliver the highest-quality products for your customers.
- Cooling equipment that gives you a wide range of cooling power, even if your cooling section has limited space.
- Flexible automation systems that enable us to equip new plants, revamp existing plants or replace existing cooling sections in all types of mills at reasonable costs, while ensuring you a fast return on investment.
- The ability to predict the required water consumption for following strips, information that the water treatment plant can use to help avoid water shortages.
The curves show the comparison of the temperature values along the cooling section. A mobile pyrometer traveling from coiler to finishing mill and backwards took the measurements. This verification showed a very close match between the actual measured values and the computed values of the real-time model at the actual position of the moving pyrometer.

With the finite element calculation the heat flux dependence on strip speed and water speed was evaluated to optimize the physical models.
Sophisticated models supply control with microstructure information

One main innovation behind the automation of the cooling section is a physical model that enables calculation of phase equilibrium and generated transformation heat, as well as microstructure properties that contain the calculation of the dynamic growth of ferrite, austenite, cementite and pearlite content, including the lamella spacing with one set of parameters. In 2004 Siemens was awarded a patent on usage of Gibb’s free enthalpy, which is advantageous to describe phase transformation and transformation heat within one comprehensive concept.

This makes it possible to describe all steel grades with a unified concept, especially modern complex steel grades like dual phase or TRIP steels, and also to describe their behavior and phase and microstructure changes as they travel through the cooling section.

In addition, this innovation supports the design of new materials. Typically, there are three starting points: thermodynamic phase, equilibrium computations and simulations of dynamic phase transformation, conducted for example with the scientific software tools ThermoCalc and Dictra, as well as experiments performed on small probes. For these, several temporal cooling courses are applied within Dilatometer experiments. The same physical concept is now used within the cooling model. The ability to specify temporal cooling courses simplifies the procedure of establishing new steel grades.

With a sophisticated water flow and heat flow model, which takes into account the different water cooling techniques (laminar cooling, pressured cooling, water curtains, cross sprays, run-out table cooling, etc.), it is possible to model the heat transfer at each point in the strip in the mill at any given time. The model predictive controller concept enables a temperature course calculation at a point in time before this strip point enters the mill, thereby providing the temperature course for each strip point traveling through the cooling section to the coiler.

The adaptation with the pyrometers in the mill enables the close monitoring and adjustment of the model computations. It includes adaptation of heat transfer as well as adaptation of the phase transformation rate to achieve the best results for both.

At the participating test and development plant at Hoesch Hohenlimburg, these models of the SIROLL Microstructure Target Cooling package were tested and verified using mobile pyrometer devices to compare the temperature course over the cooling section length. The results show a very close match between the calculated results and the measured values, thus proving the high accuracy of the models.
The evolution of cooling technology into Microstructure Target Cooling: In older automation systems the cooling temperature has been the target. Our new cooling system, with cooling strategies based on the temporal cooling course definition, allows you to define both cooling courses and microstructure properties as targets. To serve standard applications as well as enhanced steel grades, individual cooling strategies are available.

Flexible target definitions give you more flexibility and easier handling

A strip monitor computes powerful models in real time. With a time resolution of 200 ms or faster, it updates the temperature course and the course of phase fractions along the entire cooling section, taking into account actual measurements and distortions within the plant. This gives you the ability to know the actual temperature and phase fractions along the entire strip and to create very flexible cooling strategies based on the temporal cooling course. Furthermore, it is possible to define different cooling courses and/or microstructure properties for different parts of the strip.

To control the course in accordance with the identified optimum course for the desired microstructure, Siemens VAI has developed the new Nonlinear Model Predictive Control technology. This feature generates a set of control strip points and makes predictive calculations for them along the entire cooling section until the strip points arrive at the coiler.

For each strip point, this control compares the computed future cooling courses to their desired ones and minimizes the deviations using fast mathematical optimization algorithms, taking into account existing plant limits. Siemens VAI developed these mathematical optimization algorithms especially for the purpose of creating fast online model calculations. As a result, offline models are not required on site.

Hence, model predictive control cyclically (e.g. every 200 ms) results in an optimal set of valve setpoint changes, exploiting the full capability of machine construction without any restriction on the switching location, which is the major drawback of classical cooling control.

To summarize, this model and this control give you a tool with which you can easily make adjustments to meet customer needs for new steel grades with defined steel properties in a close tolerance to the target, not limited only to coiling temperature.

From Coiling Temperature Control (before 2000) ... to Cooling Strategy Control (since 2000) ... to Microstructure Target Cooling based on temporal cooling course along the entire cooling section (since 2006).
The model is also capable of giving the actual temperature and phase fractions of any strip point at any place in the cooling section, making it possible to calculate the microstructure and handle the transformation points.
The intensive cooling header, using a pressured water jet, is controllable over a wide range.

The new quick switch header for fast switching times.
Top-class cooling equipment for top-class control

Siemens VAI offers you not only the best and most flexible models and control, but also the best mechanical cooling section equipment. As a result, we can ensure that your new plant starts right away with the best capabilities – or that you can upgrade your existing plant to produce the most advanced steel grades with minimal changes.

The well-engineered mechanics of our laminar standard cooling headers provide short and well-defined ON and OFF switching times, essential for good control of the water amount and the time to hit the strip. The construction ensures that the “tailing” after switching a header OFF is avoided which results in additional accuracy.

For more cooling power in a laminar cooling section, the turbo cooling header gives enhanced cooling power in the same space as a standard header. The construction principle is the same as for the standard header.

For those areas where it is essential to react very quickly to changing valve set-points, the new quick switch header with its unique design for fast switching times provides you with the ability to switch ON and OFF in less than one second. It also offers unmatched value regarding the repeatability of these times, giving you more control of the water amount on the strip than any other design.

In addition, the intensive cooling headers based on Siemens VAI’s pressured cooling system can give you the maximum cooling power on short distances with a wide range of cooling capacity. These equipment options give you the ability to match the varying needs of your cooling rates for standard steels as well as for dual phase and other complex phase steels.

The wide range of cooling rates with the different header types also supports revamp strategies to produce modern steel grades on limited-length cooling sections.
Flexible configurations for flexible needs

If you build a new mill or revamp an existing one, we can provide you the solution that you need at the optimum cost level possible.

The modular design of the automation as well as our mechanical equipment provides a wide range of possibilities for a solution that fits to individual requirements.

With our experience in building new mills and cooling sections, combined with our extensive knowledge in revamps, we can offer all the solutions required to make your cooling section ready for the challenges of the future. This means that all kinds of simple and complex steel grades are covered.

We provide defined interfaces at the different automation levels – i.e. from the connection of the valves to the basic automation to the link of the process automation to the plant environment – so that flexible combinations are possible to fit in each setting and fulfill your requirements.

The before mentioned models, control strategies and tracking functionalities are part of the SIROLL CR® HM cooling section model server, whereas the SIROLL CR® HM basic automation is mainly used for interconnection to the individual equipment.

Example: modernization of the cooling section automation

Example: new cooling section in combination with existing finishing mill

Example: upgrade to enable dual phase steel cooling with means of intensive cooling headers

Our flexible and modular system also makes mixed low-cost solutions possible, depending only on your existing automation and your future needs.
Top-performance supplier for the most plants worldwide

<table>
<thead>
<tr>
<th>Customer/Plant</th>
<th>Country</th>
<th>Plant type</th>
<th>Cooling section type</th>
<th>MSM package</th>
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1) ON/OFF valves    2) Regulated flow valves    3) Quick switch headers    4) Turbo headers

MSM: Microstructure Monitor
HSM: Conventional hot strip mill
CHSM: Compact hot strip mill; casting and direct rolling
ESP: Arvedi ESP; endless steel production with direct linkage of casting and rolling process
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