# INTERSTAND COOLING – DESIGN, CONTROL AND EXPERIENCE

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## ABSTRACT

Inter Stand Cooling (ISC) can help to increase the productivity of the mill and improve the final mechanical properties of the strip. Constant Exit Rolling Temperature (ERT) can be ensured on the whole strip length eliminating temperature oscillations of the transfer bar caused by skid marks and other reasons.

The paper presents experimental possibilities of investigation and design of ISC headers. An experimental stand is introduced and a complex approach – experiment and mathematical simulations – are shortly described. Further a functionality of a developed control system is shortly explained. At the end practical experience of two hot strip mills are described.

*Keywords: Inter Stand Cooling, Cooling Headers, Strip Cooling, Hot Strip Mill*

## 1. INTRODUCTION

The Inter Stand Cooling at hot strip mills affects fundamentally reaching and maintaining the required exit rolling temperature (ERT). Thus it enables to reach better and more homogeneous mechanical properties of a strip, particularly in microalloyed steels. ERT can be maintained constant on the whole strip length, even when transfer bar temperature oscillates due to skid marks in slab or other reasons. The last but not least effect of ISC is an increase of the mill productivity due to rolling at higher speed or speed up.

For the correct function of the ISC it is necessary to fulfill two basic requirements – to keep at disposition an optimal hardware (cooling headers with sufficient cooling power including the possibility of fast and fluent regulation of cooling intensity) and the advanced control software - for cooling setup, feed forward and feedback control.

The initial stage of the ISC design is testing a variety of cooling headers at a laboratory test bench. These measurements provide a description of cooling intensity on a running hot steel surface. The studied parameters are as follows: type of nozzle, nozzle configuration, feeding pressure, spray height and impact angle.

A complex 3-D numerical model of temperature field in the rolled strip is used for the comparison of various configurations of the cooling headers and for the technological studies of the efficiency of ISC at a particular mill, measured by a maximum temperature drop for various materials cooled with various combinations of the cooling headers. The model is used in design stage of building or re-building the ISC.

## 2. DETERMINATION OF ISC HEADERS COOLING EFFECTS

In Heat Transfer and Fluid Flow Laboratory, Brno University of Technology, the methodology of determination of cooling effects during spraying hot surfaces was developed [1]. The basis is created by an experimental stand which enables study of cooling and mechanical effects of nozzles at linearly moving samples.

Structurally the stand is designed so that it enables progression of samples up to the weight of 50 kg with infinitely adjustable speed from 0 to 10m/s. On the supporting frame there is a carriage moving, on which the sample under examination with temperature sensors and measuring system – datalogger is fixed. The carriage's progression is provided by a hauling rope through a drive pulley and a motor with a gearbox. The motor is power supplied by a frequency converter with the possibility of a smooth change of rotation speed and changeovers. The direction of the carriage can be reversed and passages repeated in a requiring number. The whole cycle is programmed and controlled through the superior PC. There is a spraying section in the central sector where arbitrary jets configuration can be arranged (Fig. 1).

Fig. 1 Linear laboratory stand with test plate moving under group od full cone nozzles

There is a wide group of cooling headers used in practice. Fig. 2 shows examples of the tested headers. It is difficult to find a general optimal design of ISC because each rolling train has a different space configuration and limitations.

Fig. 2 Various types of cooling headers (full cone nozzles, drilled holes, adjustable slit, cluster of solid jet nozzles)

### 2.1 An Experimental Procedure of Cooling Effects Determination

The test plate is equipped with thermal sensors with thermocouples connected to the datalogger. The thermal sensors are calibrated before use and the results of calibration are used to eliminate dynamic error in measurement of highly transient thermal processes. Before the actual experiment the carriage with the sample is positioned to the utmost position and it is heated to the required temperature using an external furnace. After temperature stabilisation, the heating device is removed, the stand is turned to spraying position, the pump gets going and the carriage's travel gets started. The position of the cooled surface can be horizontal with spraying upper or bottom surfaces or vertical (for special cooling tests but not for ISC). Signals from the sensors are read by the datalogger which moves together along with the sample. At the same time, the signal indicating the actual carriage's position is sensed as well. After performing the required number of passes, datalogger's internal memory data are exported into the computer for further processing.

Information from temperature sensors (temperatures records in a particular depth under the surface) are used as entry parameters for the thermal conduction's inverse task [2]. Inverse task output is are surface temperature history, heat flows and Heat Transfer Coefficients (HTC) on the heat transfer surface. Most often, in mathematical models the boundary condition of the 3$^{rd}$ type is used where heat flow is specified by the heat transfer coefficient value and the cooling water temperature. An example of the heat transfer coefficient distribution for cooling header with two rows of full cone nozzles is introduced in Fig. 3. Geometry of spray jets is shown in Fig. 4. Results show influence of feeding pressure and strip velocity. Pressure increase from 2.5 bar to 5 bar is shown and changes because of increasing velocity from 2 m/s to 5 m/s.

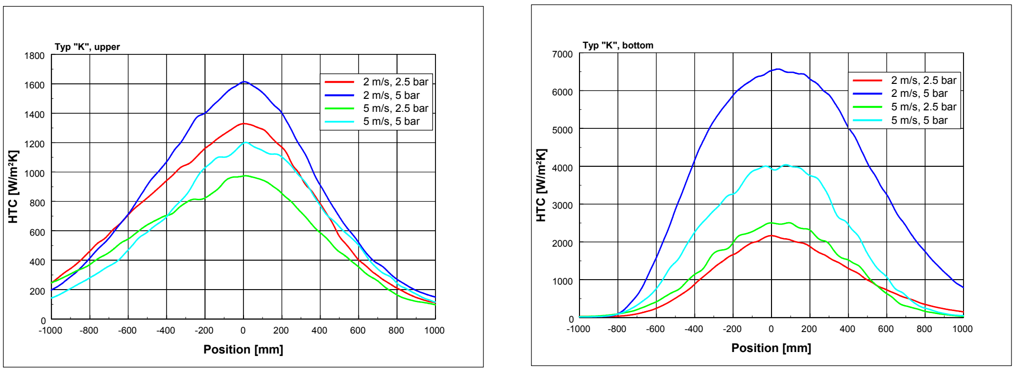


Fig. 3 Distribution of heat transfer coefficient for experiments with 2 rows of conical nozzles, upper surface (left) and bottom surface (right), influence of pressure and velocity is shown

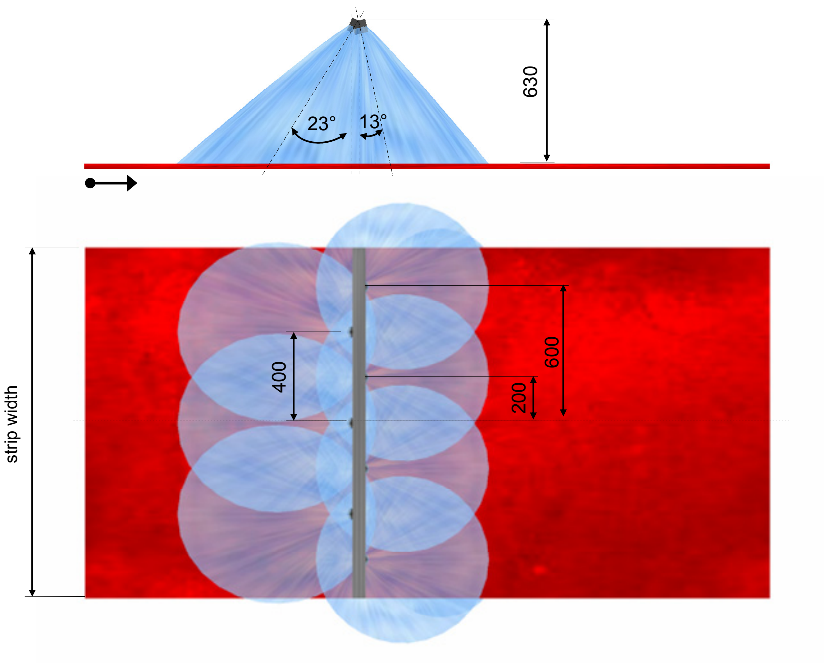


Fig. 4 Designed upper header of ISC (width conical nozzles)

An example of cooling intensity of spray header with five rows of solid jet nozzles (see Fig. 2) is shown in Fig. 4. Results show influence of increasing flow rate (pressure) and two rolling velocities. Parametres of measurement are in Tab. 1.

Tab. 1 Parameters of tests with header with solid jet nozzles

| | | | | |
|---|---|---|---|---|
| Experiments with velocity 1 m/s | SJ1Z | SJ2Z | SJ3Z | SJ4Z |
| Experiments with velocity 5 m/s | SJ5Z | SJ6Z | SJ7Z | SJ8Z |
| Coolant flow rate l/s/m | 11.0 | 17.3 | 24.5 | 31.7 |
| Coolant pressure bar | 1.0 | 2.5 | 5.0 | 8.0 |

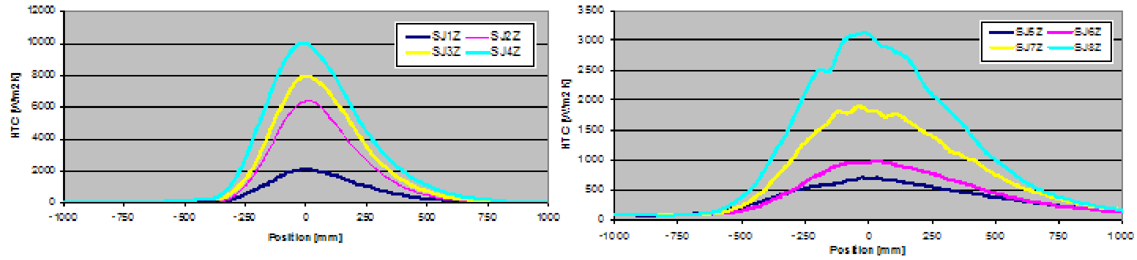


Fig. 5 Heat transfer coefficient distribution for header with five rows of solid jet nozzles, rolling velocity 1 m/s (up) and 5 m/s (down)

Headers with slits and water curtains are frequent. Slits are usually used for cooling of bottom surface where free falling laminar layer can not be used. An example of cooling intesity of slit 8 mm wide instaled at spray height of 300 mm under bottom strip surface is shown in Fig. 6. Result R14 is for flow rate of 4.7 l/s/m, R15 for 7.5 l/s/m and R16 for 10.5 l/s/m.

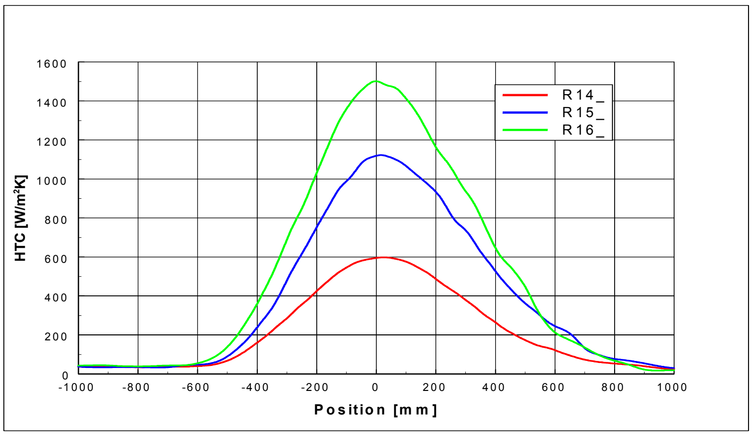


Fig. 6 HTC distribution for cooling with slit header and increased flow rate

## 2.2 A Verification of Inter Stand Cooling Effects with the Help of a Temperature Model

The Inter Stand Cooling detailed temperature model, which uses measured heat transfer boundary conditions, gives the answer whether the proposed method of cooling will meet the required parameters from the point of view of intensity and regulating range. This model is designed on the basis of knowledge of rolling mill conditions and it simulates an actual rolling campaign. Various factors influence (header type, working pressure, rolled material thickness, rolling speed) on the cooling efficiency can be verified computationally. This procedure enables to design optimal ISC headers made to measure for every hot mill or stand. Fig. 7 shows temperature field in the rolled material of final thickness of 3.4 mm. This detailed numerical model is used for final headers selection and setting of spray parameters for various pressure and flow rate settings. The model is used for checking of the system controllability.

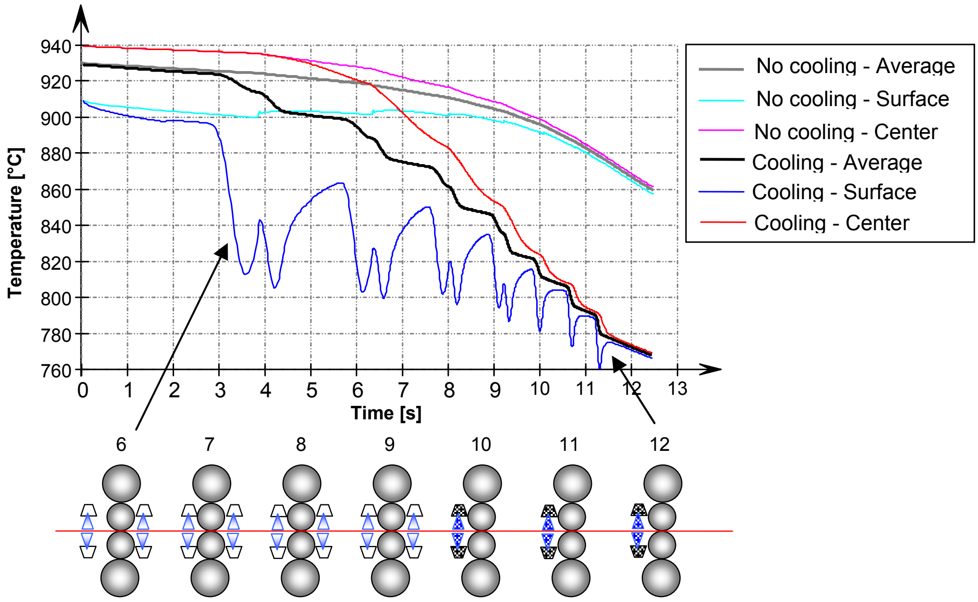


Fig. 7 Computed temperature history in several points using 2D numerical off-line model in design stage of project

## 3. CONTROL SYSTEM OF ISC

A presented control system of ISC has been developed in company ITA Ltd. It was designed to work either within existing Level2 of the mill or to work rather independently of it. It consists of three basic parts – Setup, V-Controller and T-Controller (Level1). Basis scheme of the system is shown in Fig. 8.

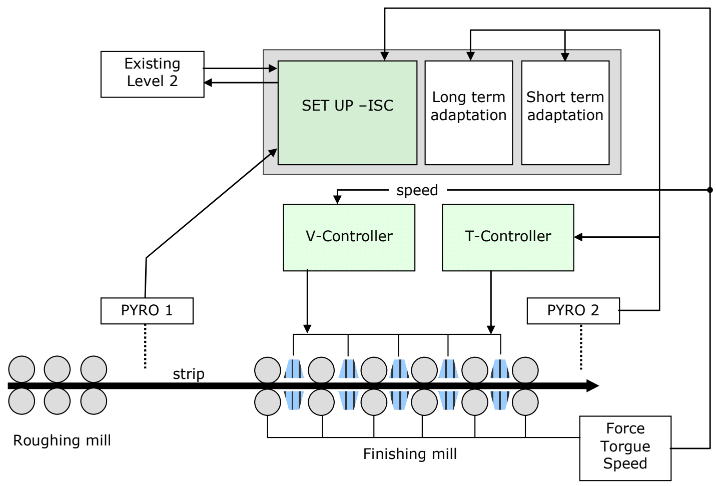


Fig. 8 Basic scheme of the control system

The main task of the setup is to calculate the number and power of cooling headers for reaching the temperature in the whole strip length. V-Controller is a feed forward regulator respecting the influence of the strip speed changes. T-Controller is a feed back temperature regulator.

The measured strip temperature is mostly available only at limited number of spots, at outlet from the roughing mill, before the finishing mill and at the finishing mill outlet. Nevertheless, the temperature measurements before the finishing mill entry are usually very unreliable because it is influenced by a thick scale layer, emissivity of which strongly depends also on the steel chemical composition. Temperature obtained from pyrometer at the outlet from roller table can be used to get more complex information but the control system can work without this information quite accurately.

As the transfer bar temperature oscillates, the number and cooling power of the headers must be calculated in several spots lengthwise (at 35 to 50 points). The points are situated in the local extremes of the temperature curve in the transfer bar. A special filter is used to get rid of incorrect measurements, to smooth the temperature curve and to find local extremes of the temperature behind the roughing mill. Measured deviations of the transfer bar temperature at the outlet of roughing mill can be seen in Fig. 9.

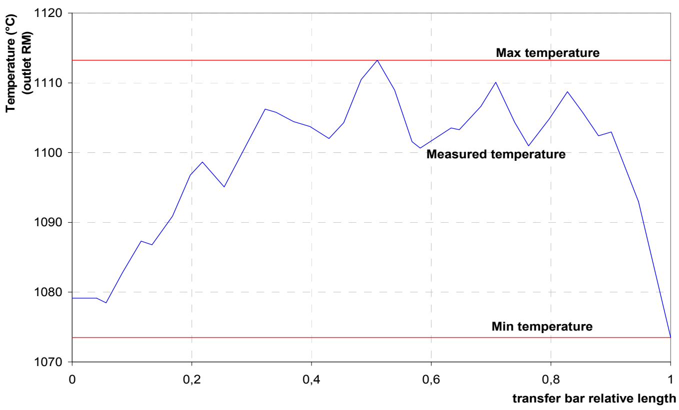


Fig. 9 Measured transfer bar temperature lengthwise (example of an older furnace)

Using the measured temperature setup of headers for every point is performed and so called cooling matrix is assembled. An example of the cooling matrix – providing number, position and cooling power of headers (in terms of normed flow rates) in every spot lengthwise can be seen in Fig. 10. (see Fig. 11 for position of headers). It is obvious, that the total cooling power of ISC varies lengthwise.

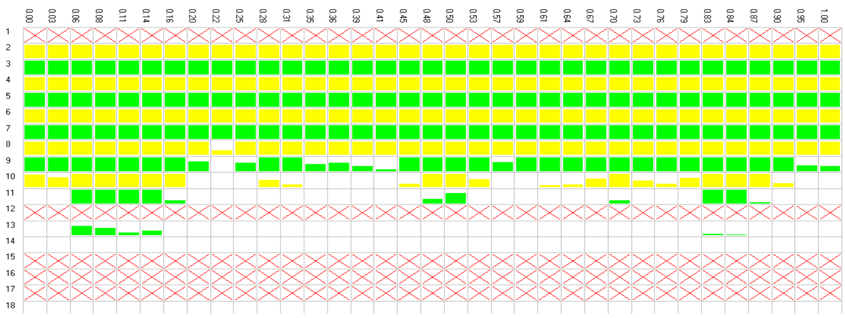

Fig. 10 Cooling matrix, horizontal axis – relative strip length, vertical axis - active cooling headers (green-upper, yellow-bottom headers)

## 4. COOLING POSSIBILITIES OF ISC

Inter Stand Cooling possibilities were determined by mathematical simulations and measurements at the hot strip mill 2000 mm. The scheme of finishing mill with headers is shown in Fig. 1. The ultimate possible temperature drop due to ISC varies from 80°C for the thick strip (thickness > 8mm) up to 140°C for the thin strip (thickness < 2,7 mm). However, this value is limited in its application in thin strips because intensive cooling in last stands may cause flatness problems.

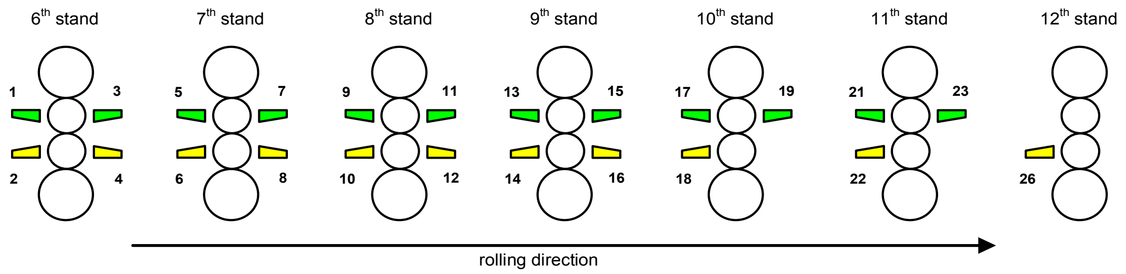


Fig. 11 ISC headers position in finishing mill

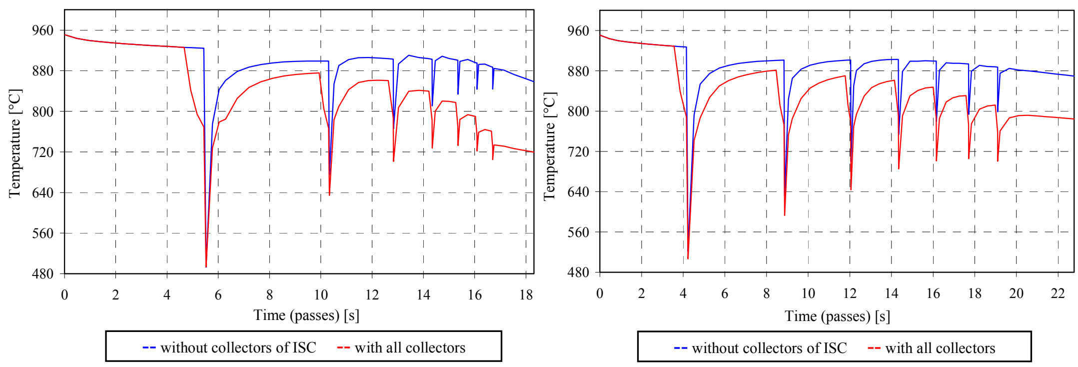


Fig.12 Efficiency of ISC in thin and thick strip

## 5. AN EXPERIENCE WITH RECONSTRUCTED ISC

Interstand cooling has been reconstructed in two hot strip mills. HSM 2000 Severstal, Russia – new control system working independently from existing Level 2, valves and some headers and in HSM 1700 in U.S. Steel Kosice, Slovakia - new headers and upgrade of the control system.

### 5.1 *Experience with reconstructed ISC in HSM 1700*

The most obvious improvement in reaching exit rolling temperatures can be observed in thick strips 10-12.5 mm. As demonstrated in fig. 13, the red columns (percentage of keeping rolling exit temperatures after reconstruction) are higher than before the reconstruction (in 2006).

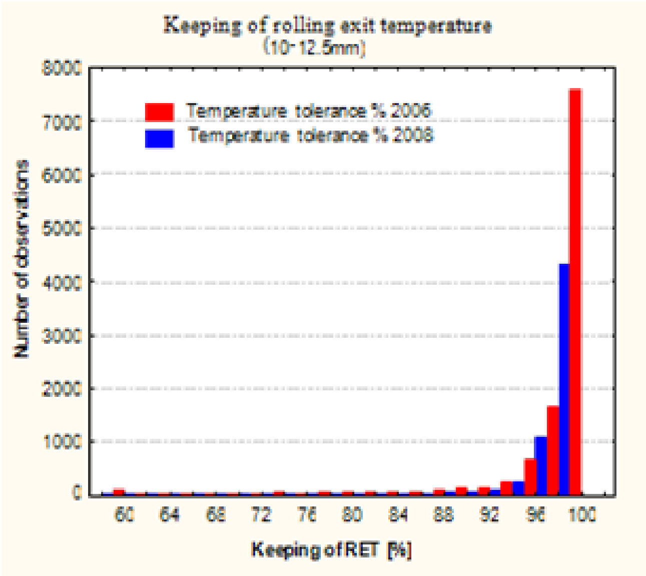

Fig. 13 Keeping of rolling exit temperature (left) and new interstand cooling header with full cone nozzles (right)

The new designed cooling headers equipped with full cone nozzles play a very important role in achieved (Fig. 13). In thin strips more precise control of exit temperature and less temperature deviations have been reached.

### 5.2 *Experience with reconstructed ISC in HSM 2000*

Target temperature (ERT) can be kept lengthwise with a tolerance of ±10°C from the target temperature. In thin strips (<5mm), the temperature deviations are less than ±5 °C. In thick strips (>10 mm) the tolerance ±10°C can be reached only if the temperature oscillation in transfer bar is less than 15°C. There are some problems in strip heads that cannot be cooled before entering first finishing stands.

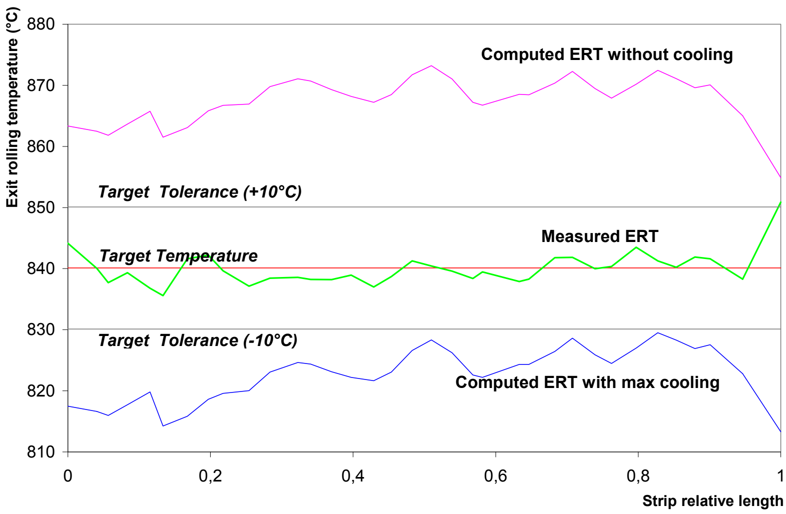


Fig. 14 Measured and Calculated ERT in control system

ISC proved to be very effective tool to eliminate skid marks. If the slab is heated in older furnaces the temperature oscillation in transfer bar can be more than 30-40 °C. Those oscillations can be completely eliminated in thin strips (< 6 mm). In thick strips (more than 12 mm) temperature deviations up to 20 °C in transfer bar can be suppressed. Higher oscillations (30-40 °C) cannot be removed completely, but they can be considerably reduced.

Required exit rolling temperature is one of the limiting parameters for speed and speedup of the strip. Providing that ISC has enough cooling power and flow rate on headers and can be controlled effectively then limits of speed and speedup can be raised. There are several metallurgical and technological aspects prohibiting extensive cooling in special steels where this way of increasing productivity can be used only in limited manner. Nevertheless, practical experience proved an increase of productivity due to ISC when compared with rolling without ISC or using ISC with constant cooling power (flow rate) lengthwise. Tested increase of maximum rolling speed was nearly 40% in thin strips (compared with rolling without ISC). Increase of rolling velocity in very thick strips (>14mm) was due to skid marks only 5-10%.

## 6. CONCLUSION

The complex approach of the ISC design was briefly presented in this paper. Possibilities of the experimental investigation of cooling characteristics for various types of headers and design of new ones were shown. Further a physical model of Inter Stand Cooling control, which can work quite separately from existing Level 2 control system was presented. Some practical experience with ISC on two HSMs were summarized. In both mills reconstructed ISC helped to achieve better keeping constant temperature and less deviations from target temperature. Temperature oscillations due to skid marks are eliminated or considerably reduced. The productivity of the mill can be increased.

## 7. LITERATURE


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