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Optimization of working roll cooling in hot rolling

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ABSTRACT

The cooling of working rolls is an important process in the hot rolling technology. The optimal cooling of rolls should be designed with respect to two aspects. The first is the wearing of a roll where high temperature decreases the durability of the surface layer. The second aspect is a thermal deformation of a roll. This is critical for the shape and tolerance of flat products. Cooling at rolling mill should be designed with consideration to both aspects. Finding optimum pressure and flow rate is a difficult task. In regards to water quantity, the experience shows that the phrase "more is better" is not valid here. In other word – an increase in the amount of water can even cause a decrease in cooling intensity. Water nozzles are typically used in this case. There are many of factors which can influence the efficiency of the nozzle cooling system: Type of a nozzle, geometrical configuration (nozzle pitch, distance from the roll, orientation, number of manifolds), coolant pressure and temperature.

Cooling intensity is mostly specified through Heat transfer coefficient (HTC) or heat flux (HF) distribution. Coolant flow on the rotating roll surface makes the problem complex. Surface temperature of the cylinder plays an important role in the heat transfer mechanism, especially for higher temperatures where boiling must be considered. No analytical or numerical solution of heat transfer and fluid flow for this case is known. The task can be successfully solved experimentally. An experimental bench and methodology of realistic boundary conditions determination was developed in the Heat Transfer and Fluid Flow Laboratory (HEATLAB).

The strategy of optimization is based on two steps. First is investigation of present situation of work roll cooling system and second is design of a new system. Criterion of optimization is saving of cooling water with remaining or increasing of cooling intensity. Comparison of the original design and new design was done numerically, using special software and experimentally by temperature measurement of working roll after specified rolling campaign.

Optimized cooling system was applied on hot flat rolling mill in voestalpine Stahl GmbH.

INTRODUCTION

There is neither an analytical nor a numerical method for predicting the distribution of heat transfer coefficient on the surface of the cooled roll when knowing the spray conditions. The HTC distribution is quite different to the coolant distribution, so the only possibility is to carry out the measurements. The experiments done under industrial conditions are rare and very expensive. The experiments of roll cooling, started at the Brno University of Technology in 1988. Initial tests were done for a single nozzle. The test program has continued with a row of nozzles. It became more and more obvious that the generalization for a complete cooling configuration based on separate measurements of components of cooling sections did not bring reliable results. The only acceptable way was to prepare a full-scale experiment[4]. The full-scale experiment uses an identical configuration of rows of nozzles as would be at the rolling mill and the same pressures, velocities and coolant temperatures are also used. Cooling intensity described by heat transfer coefficient distribution reflects the real mill conditions.

Because, there is a lot of parameters, influencing cooling intensity and efficiency, parametric study was done first. The aim was to investigate influence of chosen parameters in the laboratory conditions. The criterion was to reach maximum cooling intensity with minimum water consumption. Two types of nozzles were study – flat jet and full-cone. Flow parameters were adjusted according to feeding pressure or flow-rate. Geometrical conditions (nozzle pitch, distance from the roll, orientation, number of manifolds) were adjusted with respect of space limitation on the real roll-mill stand.

EXPERIMENTAL DEVICE AND PROCEDURE

It is out of scope of this paper to give the details about the test bench and experimental procedure [1-6]. The principal arrangement of the experimental equipment is shown in Figure 1. The experiment starts by the heating of a test segment while the roll is stationary. As soon as the initial temperature of the experiment is reached the heater is removed, rotation starts and the pump is switched on with a closed deflector. The deflector prevents the roll surface from being sprayed at. By opening the deflector the sprays reach the roll surface.

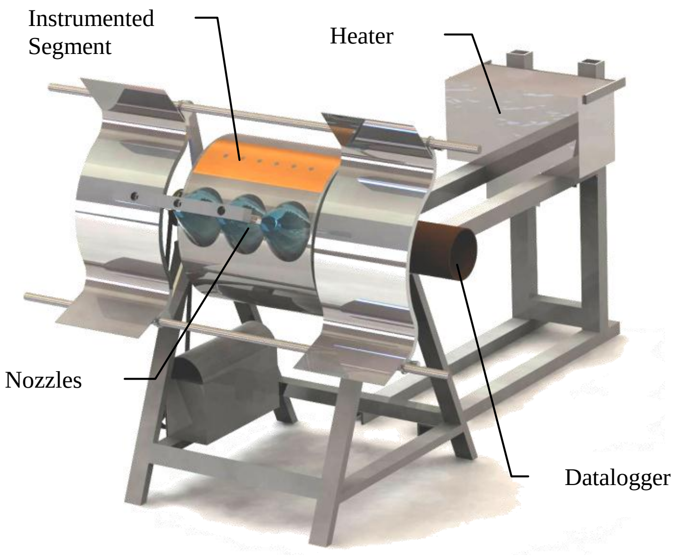


Figure 1 Experimental device

Temperatures and roll circumferential position is recorded in a data logger rotating with the roll. The data are transferred to a computer when the experiment finishes and rotation stops.
All the measured temperatures go through a standard inverse procedure [7, 8]. Surface temperature, HTC and heat flux are computed. Each data point carries the information about position. The data of the "time" order are converted into the position order**.** The position is connected with the roll geometry not with the positioning of the nozzles. A program for interpolation of HTC by a single curve has been designed. The program uses the convolution with Gaussian distribution and the export vector of HTC.
HTC distribution is used as a boundary condition for rolling-simulation program "CoolRoll". The program allows simulating the rolling campaign and provides temperatures fields and roll thermal deformation (roll crown).

PARAMETRIC STUDY

Nozzle type

Working roll cooling is the case where very high cooling intensity is demanded. Water only nozzles are typically used for this purpose. Footprint of water beam on the roll surface can be in principal elliptical or circular. Then the specification of nozzles is - flat jet and full - cone.

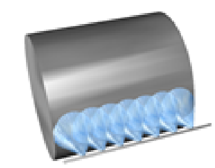
Figure 2 Flat jet (left) and full-cone nozzles

It is difficult to say, which type is better, it can be case to case different. Flat jet nozzles have usually higher impact pressure, so they can be used in a case where water layer is present on the roll surface. Full-cone nozzles are more efficient in situation, where no water flow is on the roll surface.

Feeding pressure

Feeding pressure is parameter which can be relatively easily used for controlling of cooling intensity. Feeding pressure is in proportion to flow-rate for given nozzle size. A study with full-scale arrangement using full-cone nozzles was done on HEATLAB experimental device. Configuration of experiment and tested parameters are specified in the Table 1.

Table1 Parameters and configuration of experiments
- influence of feeding pressure, increasing flow-rate

Pressure [bar]	Flow-Rate [l/min.m]	
3	250	
7	350	
10	400	

The average value of HTC on the half of roll perimeter is used as the criterion of cooling intensity is used. Results are obvious from Figure 3. Average HTC is increasing with pressure most intensively in the range from 3 to 8 bar, but is observed up to maximum studied pressure 10 bar. The best efficiency is usually reached in the feeding pressure range 4-8 bar. Also nozzles are typically designed and optimized for this pressure range.

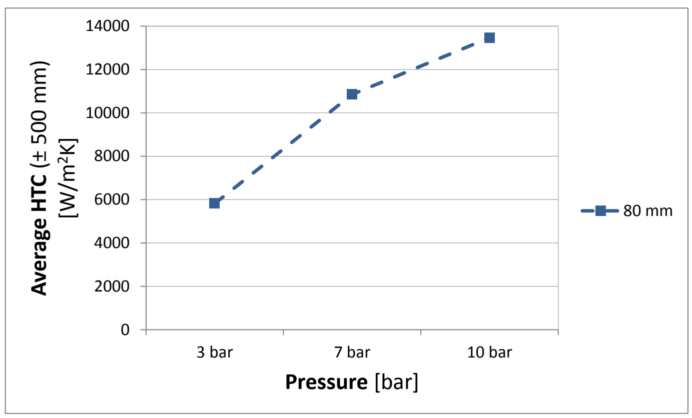
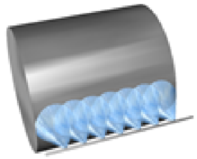


Figure 3 Dependence of cooling intensity on feeding pressure -increasing flow-rate

Similar study can be done for constant flow-rate. It means that for increasing pressure, smaller nozzles must be used, to ensure the same value of flow-rate. Parameters of these tests are specified in the Table 2. As the criterion of cooling intensity is again used average value of HTC on half of roll perimeter. Results are summarised in Figure 4.

Table 2 Parameters and configuration of experiments
- influence of feeding pressure, constant flow-rate

Pressure [bar]	Flow Rate [l/min.m]	
2.5	350	
7	350	
13	350	

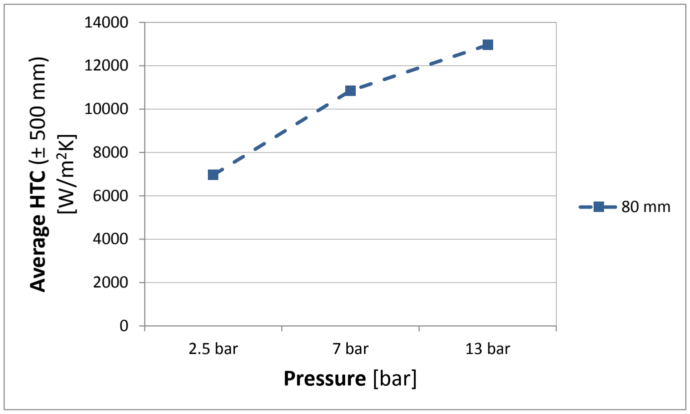
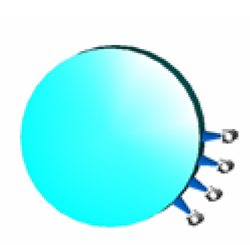


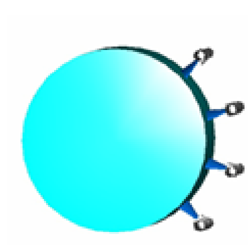
Figure 4 Dependence of cooling intensity on feeding pressure - constant flow-rate

Nozzle position

Nozzle position in the sense of distribution around the roll perimeter can influence intensity and efficiency of cooling system. First row of nozzles should be as close as possible to rolling gap. Next rows should be situated at optimal distance from the first one. The aim is to reach maximum value of HTC and cover as large roll surface area as possible. Situation for two different configurations is demonstrated in Table 3 and Figure 5. When the nozzles are closer, higher value of HTC is reached, but smaller area is covered. Optimal situation would be in the case when high value of HTC is reached and is constant for the whole cooled area. There should be no "valley" between peaks of HTC (see Figure 5 right – not an optimal situation).

Table 3 Configuration of experiments
- influence of nozzle position





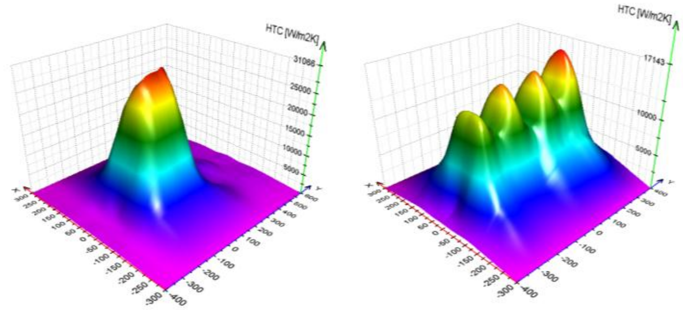
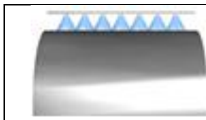
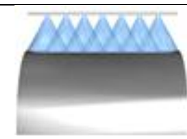
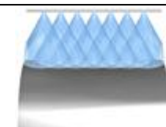


Figure 5 Two different nozzles arrangement (Table 3) and corresponding HTC distribution

Nozzle distance

Nozzle distance from roll surface is parameter which can strongly influence cooling intensity. There are two parameters which influences total heat transfer. The first one is impact pressure, the second one is area covered by spray. Usually, higher impact pressure means also higher heat transfer coefficient. Impact pressure is higher for smaller distances but on the other hand also area covered by spray is also smaller. So, this parameters work in the opposite way. It means that, in principal, optimal combination of these parameters could be found. Tests were done with full-cone nozzles for three distances (see Table 4).

Table 4 Configuration of experiments
- influence of nozzle distance

		
80 mm	160 mm	240 mm

Results of this investigation are presented in Figure 6. It is obvious that for the used type of nozzle the optimal distance is about 200-250 mm.

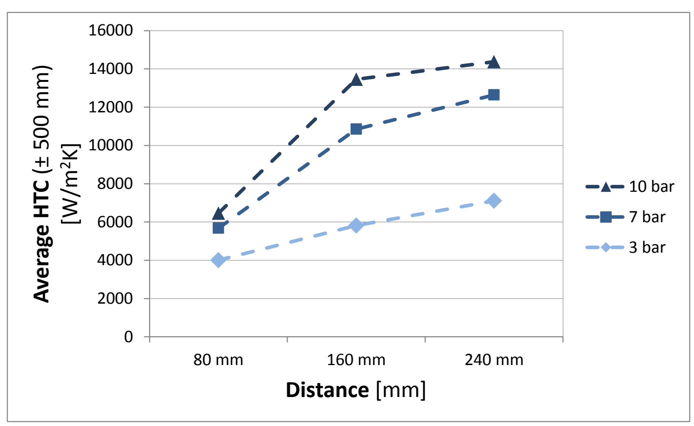


Figure 6 Dependence of cooling intensity on nozzle distance

Nozzle Pitch

Nozzle pitch should be optimized simultaneously with the nozzle distance, because it influences nozzle overlapping. This parameter influences homogeneity and intensity of cooling over the roll width. When the pitch is too big then non-homogeneity in water distribution and cooling intensity can be expected. On the other hand, when the overlapping of the impact areas is too big, cooling water is not used efficiently. The presented study was done for three different nozzle pitches, one type of nozzle at the same distance and pressure of 7 bar – constant flow-rate FR (see Figure 7, 8)

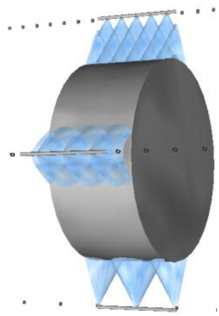


Figure 7 Configuration of experiment – influence of nozzle pitch

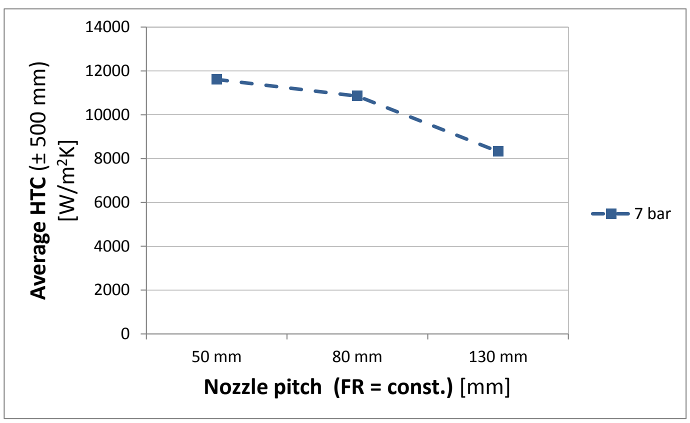


Figure 8 Dependence of cooling intensity on nozzle pitch

Inclination angle

Inclination angle means angle between horizontal level and nozzle axis in direction of rotation. Investigation was carried out for upper roll on the exit side (see Figure 9).

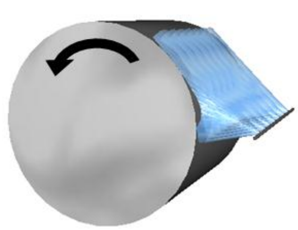


Figure 9 Configuration of experiment – Influence of inclination angle

Inclination angle influences area covered by nozzle spray and also impact pressure. Not very high sensitivity was observed in the range from 0 to 15°. Higher inclination angle caused decreasing of cooling intensity due to lower impact forces. Results are presented in Figure 10.

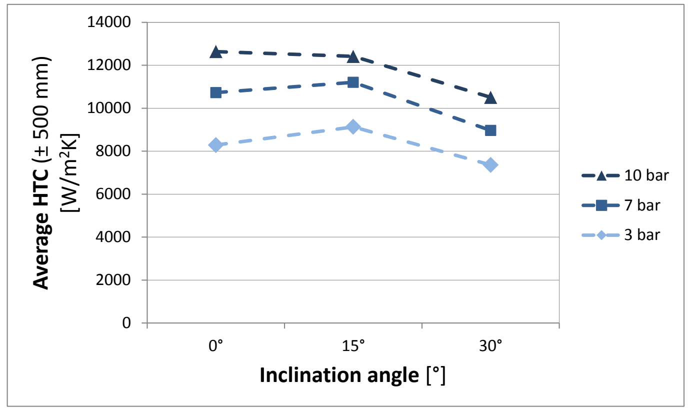


Figure 10 Dependence of cooling intensity on inclination angle

OPTIMAL CONFIGURATION

It is obvious from parametric study that there are a lot of parameters influencing intensity, homogeneity and efficiency of cooling system. Another factor, which can limit the design of optimized cooling system, is available space inside the rolling stand. Gained knowledge from laboratory investigation was successfully used for design of optimized cooling system on hot flat rolling mill in voestalpine Stahl GmbH. The aim was to remain cooling intensity and safe as much cooling water as possible. The original design was based just on usage of flat jet nozzles (see Figure 11 left). The new one is combination of full-cone nozzles (upper row) and two rows of flat jet nozzles (see Figure 11 right and Figure 12).

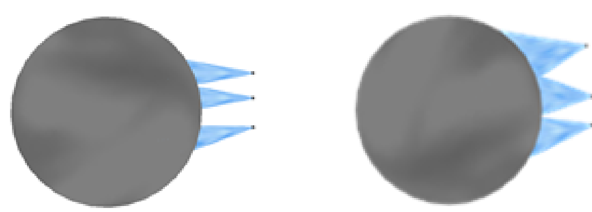


Figure 11 The original (left) and optimized (right) design

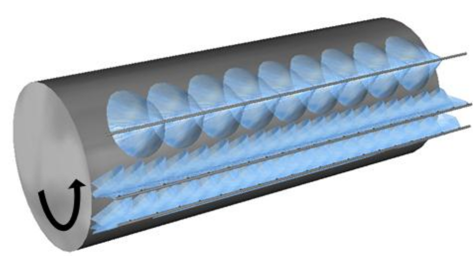


Figure 12 Optimized design – combination of full-cone and flat jet nozzles

The new, optimized system has the same cooling capacity as the original one, but save 40% of cooling water. It brings non-negligible economical effect.

NUMERICAL SIMULATION

Special software – CoolRoll - for simulation of rolling campaign was developed in HEATLAB. It enables computation of spray patterns, temperatures on the surface and inside the working roll and thermal crown during plate rolling. The main functions of the software are specified in the following bullets:

- Whole rolling campaign is stored as a project
- User-friendly environment with 3D preview
- Working roll:
  - can consist of more than one material
  - experimentally based boundary conditions
- Rolling schedule of the specimens:
  - independent speed, width, temperature and reduction
  - 3D animated preview of the rolling campaign
- Post-processing:
  - results are displayed in editable 2D and 3D charts
- Databases:
  - material database
  - nozzle database

An example of 2D output chart is plotted in Figure 13. There are temperature records in chosen points of working roll.

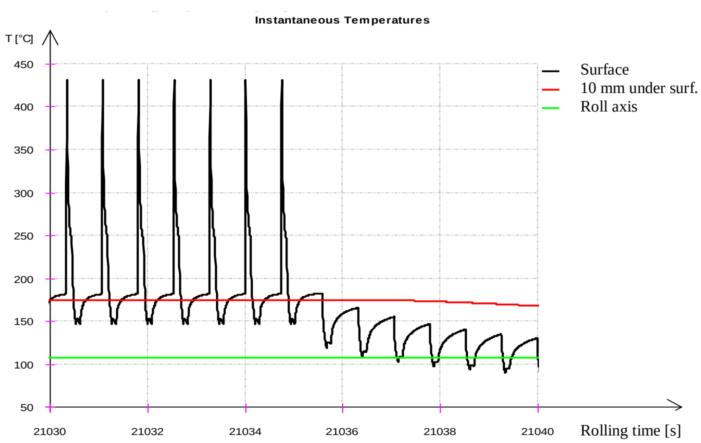


Figure 13 Example of CoolRoll output – record of surface temperature, 10 mm under the surface and in the roll axis

PLANT MEASUREMENT

The plant measurement was prepared with the aim to verify efficiency of the new cooling system and also precision of numerical model. The only chance to identify the temperature distribution inside the roll in reliable way was to measure the surface temperature of the roll after finishing of rolling campaign and withdrawing of working roll from the stand. A purpose-made measuring system was developed (see Figure 14). It consists of five magnetic sensors. The measuring element is a thin strip thermocouple. The sensors are arranged in a frame, by magnets fixed to the roll and electrically connected to a datalogger. This system enables monitoring of surface temperature development in time period after rolling.

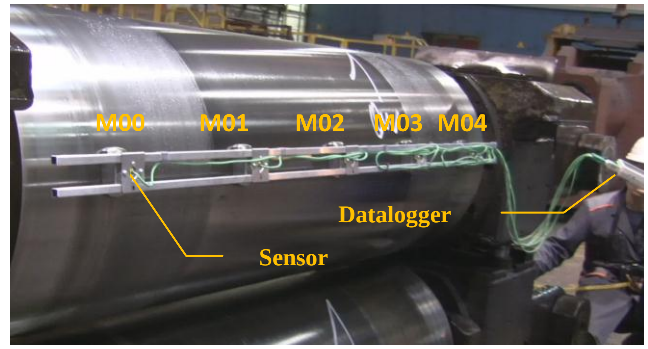


Figure 14 Measuring system for plant measurement

Comparison of measurement and numerical simulation is presented in Figure 15. Very good correspondence is observed.

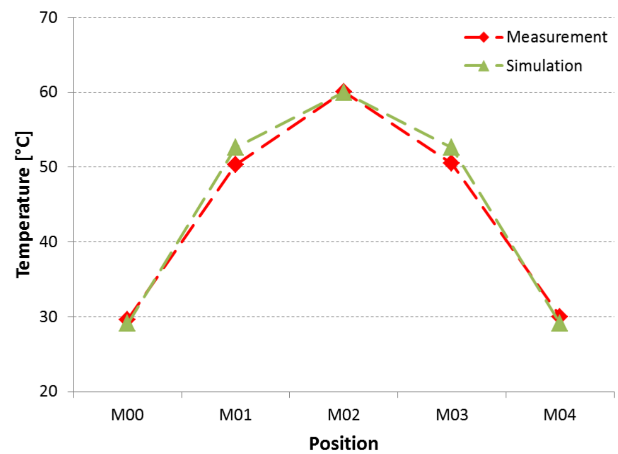


Figure 15 Comparison of measured and calculated temperature distribution

CONCLUSION

The verified methodology developed in HEATLAB was used for optimization of real working roll cooling system. The methodology consists on laboratory experiments with a preceding evaluation of results using inverse heat conduction task, numerical simulation with "taylor-made" software and verification in plant conditions. The parametric study shows the influence of dominant parameters, like nozzle type, feeding pressure, nozzle distance, position and pitch on cooling characteristics. This knowledge was used for the design of a optimized cooling system which guarantees the demanded cooling intensity and homogeneity and additionally save cooling water consumption. This optimized cooling system was applied on hot flat rolling mill in voestalpine Stahl GmbH, where about 20% of cooling water was cut down.

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