Parameters for effective roll cooling

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Introduction:

The correct application of coolant in a rolling mill is critical to achieving high quality strip and long roll life. Achieving control of roll temperature is increasing in importance as new and costly roll materials like HSS are used. Additionally, cooling rolls efficiently is necessary to minimize energy costs, and also, to prevent overcooling of thin slabs being delivered to the hot mill by the latest generation of thin slab casters. On top of that it helps to improve the quality of the rolled product and to increase the production capacity of the plant.

Optimal application of coolant requires an understanding of both efficient application and balanced application of coolant as well as the spray nozzle technology (Fig.3). Spray nozzles are the tools to achieve these important tasks of roll cooling. Coolant should be applied to achieve the most efficient heat transfer between the rolls and the coolant. Temperature control between the top and bottom rolls and across the face of the rolls must be achieved to accomplish effective cooling of the rolls. This paper investigates all these aspects.

The control and limitation of temperature is essentially for:

- Good strip profile control
- Minimizing work roll cracking.

A good strip profile can be achieved by:

- Restricting the thermal expansion difference between the middle of the work roll length and the work roll edge. This thermal expansion difference is called "thermal crown" (TC1), see Fig. 4.
- A nearly flat thermal profile on the work roll within the strip width (TC2), see Fig. 4

Achieving a Maximum Heat Transfer Coefficient

The starting point for designing the new work roll cooling is the choice to cool with nozzles. So the first step is the selection of the most suitable nozzle type, then after the nozzle type selection, experiments can be carried out to find the right spray conditions for this nozzle type to maximise the heat transfer coefficient at the work roll surface.

Measurement of the Heat Transfer Coefficient

In a Heat Transfer Laboratory the heat transfer coefficients can be measured as described below (Fig. 5). A steel plate is heated up to a required temperature and cooled down to the temperature of the coolant by applying sprayed water on the hot surface. The plate, or at least a part of it, is equipped with thermocouples, which are arranged 3 mm under the surface to be cooled. When cooling down the plate, the signals of these thermocouples are recorded continuously on a data-logger. After the test the temperature data allow to compute the heat transfer coefficient as well as the removed heat.

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Fig 1. *Author and presenter information.*

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- Reasons for roll cooling
- Heat transfer
- Nozzle arrangement
- Nozzle types
- Liquid distribution

Fig 2. *Parameters for effective roll cooling*

Why Roll Cooling ? LECHLER

- Heat transfer into the rolls
- Rolls need to be cooled uniformly, otherwise surface defects on rolls
- Rolls are subject to thermal expansion, influence on material profile
- Friction between rolls and material requires lubricant

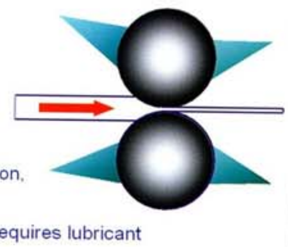

Fig 3. *Why roll cooling?*

Roll Test Bench

The basic principle of the dynamic test as described above can also be used on a roll test bench (Fig. 6). A steel plate of 60 x 450 x 19,2 mm is equipped with 7 thermo sensors and welded into a steel roll of 600 mm diameter and 600 mm length. The roll is driven by an electric motor and the data-logger, which is battery powered, is assembled in the inside of the roll. At the beginning of the test, the roll is heated up to a temperature of 300°C with an electric heater. When the final temperature has been reached, the heater is removed, the roll starts rotating with the pre-set number of revolutions and the spray nozzles are switched on.

The area of spray on the roll can be subdivided into two regions. The first one is in the area with relatively homogeneous cooling, where the sprays overlap. The second area are the sides of the spray, where the cooling drops down significantly with increasing distance from the nozzle position. For the homogenous area the HTC is – more or less – constant in the longitudinal direction but decreases in the direction of roll movement with increasing distance from the axis of the spray bar. Surprisingly the area, where the heat transfer is acting, is much larger than the area of direct impingement of the spray. The heat transfer covers an angle of revolution from 60 to 180 degrees, measured from the position of the pulse sensor, i.e. approximately one third of the roll surface is involved in the heat transfer.

Selection of nozzle type

To make the right selection of the nozzle type, basic knowledge is needed of the heat transfer coefficient during spray cooling with the nozzle on a work roll.

Flat jet nozzles achieve a perfect coverage of the rolls with coolant. The spray nozzles do not interfere when correctly arranged on the headers, and allow exact sprays in the required zonings (Fig. 7). To achieve this we select the suitable nozzle spray angle and determine the required inclination angle of the nozzle on the header.

In practice roll cooling is often accomplished by means of a simple header that is drilled and tapped to accommodate nozzles with threaded connections. The header is fit into at the mill where there is room and the sprays directed toward the area intended to be cooled. This often results in sporadic and inconsistent cooling across the width of the roll (Fig. 8), between the bottom and top work rolls. Therefore, self aligning flat jet nozzles with a metallic sealing dove tail are recommended (Fig. 9). The welding nipples are once welded onto the header in the correct position. The fitters can later not make any mistakes during maintenance. High operation safety and cost savings are guaranteed.

With full cone nozzles or oval cone the sprays can not be as exact. Furthermore flat jet nozzles offer the best constant flow density at their impact area, resulting in a higher heat transfer coefficient compared to oval and full cone nozzles (Figs. 10, 11 and 12).

The water sprays from two nozzles should also not overlap as mentioned above. If they spray into each other the penetration power and therefore, the heat transfer coefficient in the overlap region of the impact areas is reduced (Fig. 13).

The heat transfer coefficient is related to the penetrating power of the water spray through the water layer on the work roll surface.

The main parameters are:

- Water pressure
- Spray height (distance nozzle to work roll)

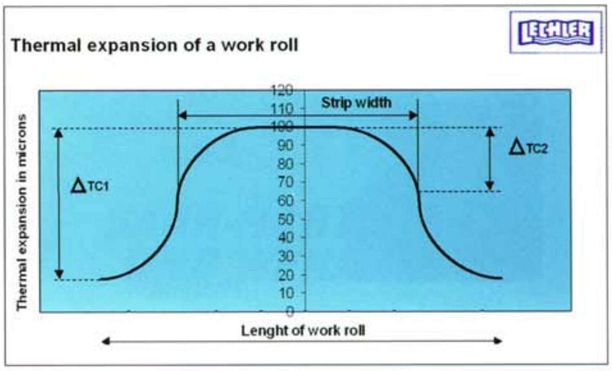

Fig 4. *Thermal expansion of a work roll*

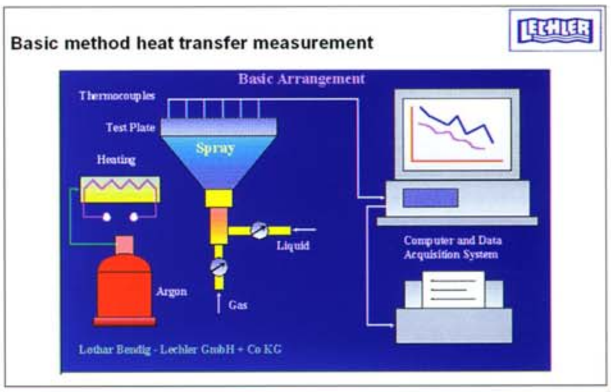

Fig 5. *Basic method heat transfer measurement*

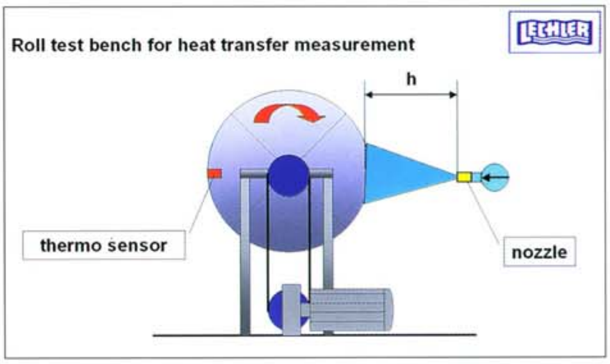

Fig 6. *Roll test bench for heat transfer measurement*

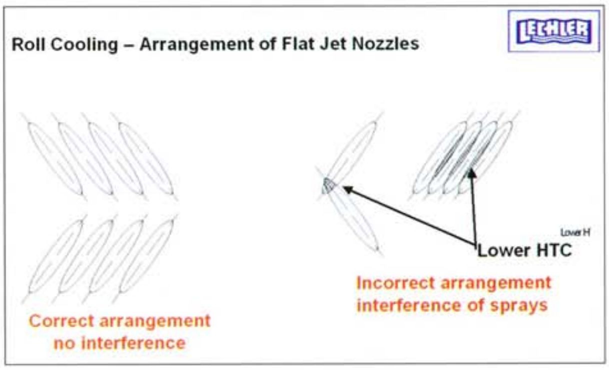

Fig 7. *Roll Cooling – Arrangement of flat jet nozzles*

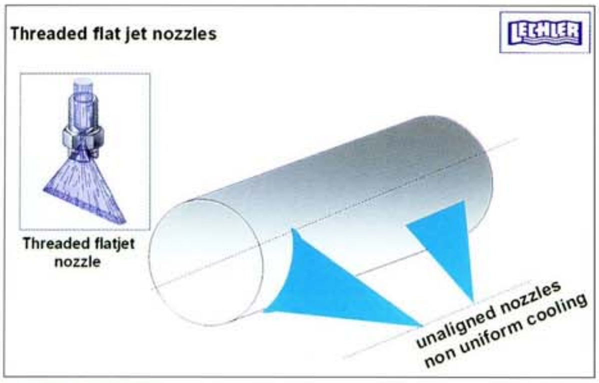

Fig 8. *Threaded flat net nozzles*

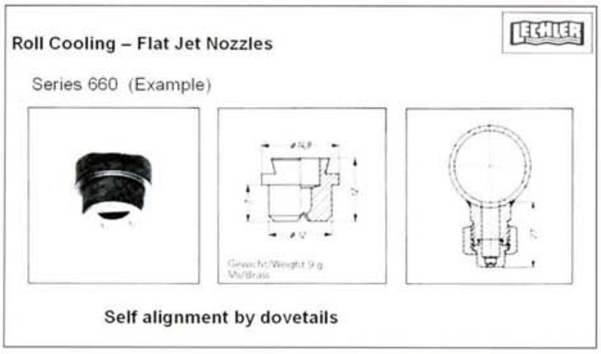

Fig 9. *Roll Cooling – Flat jet nozzles*

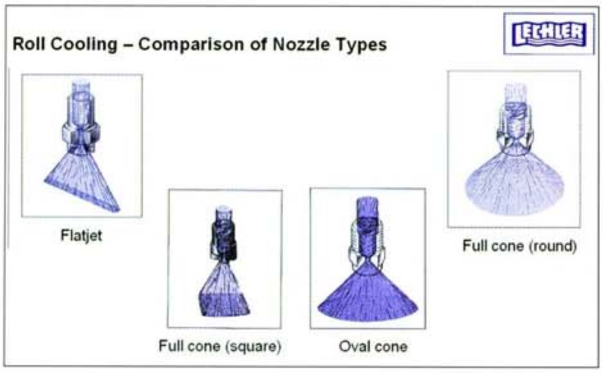

Fig 10. *Roll Cooling – Comparison of nozzle types*

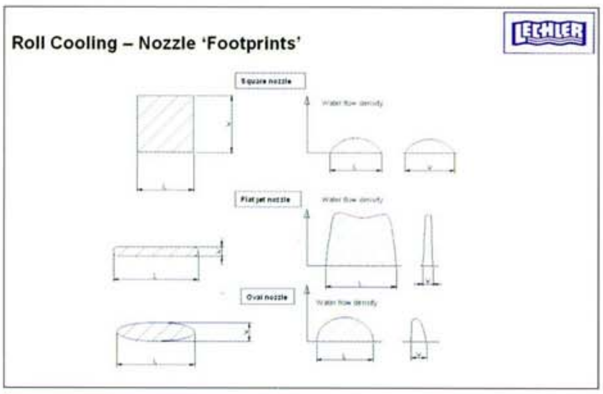

Fig 11. *Roll Cooling – Nozzle "Footprints"*

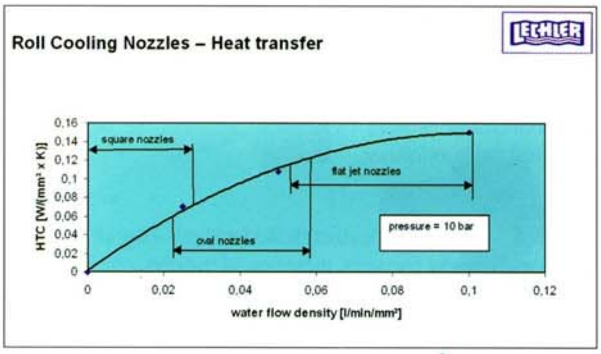

Fig 12. *Roll Cooling Nozzles – Heat transfer*

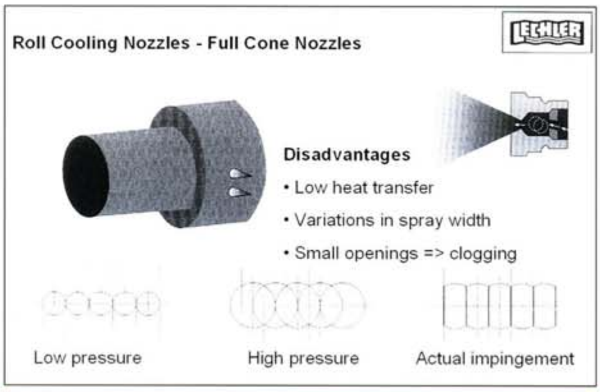

Fig 13. *Roll Cooing Nozzles – Full cone nozzles*

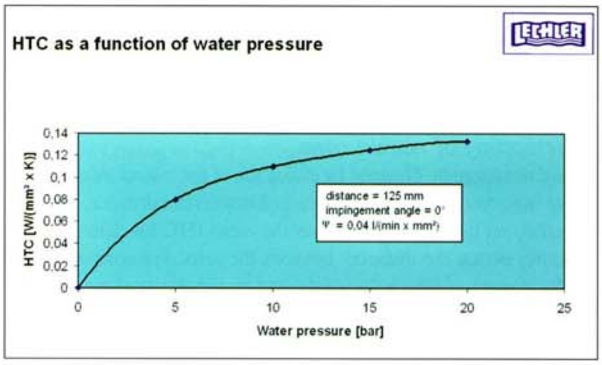

Fig 14. *HTC as a function of water pressure*

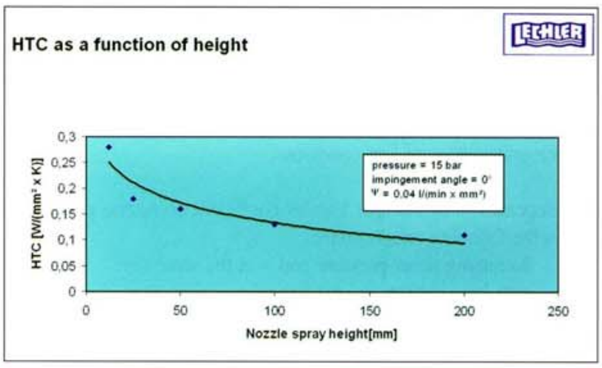

Fig 15. *HTC as a function of height*

- Inclination angle (angle between the water spray and the work roll surface)
- Overlapping of nozzle rows

The relationship between these parameters and the heat transfer coefficient (a) is as follows:

Pressure

Comparing different nozzle sizes, however all providing an equivalent flow rate at different pressures, it can be said that above 15 bar there is only a small increase in (a), reaching a maximum at approximately 20 bar. For other spray parameters the results vary little from the above (Fig. 14).

Spray height

The spray height also has an important influence on the heat transfer. With an increase in spray height the water flow density and the kinetic energy of the spray are reduced, hence the heat transfer coefficient also drops, as shown in Fig. 15. Therefore, spray heights of more than 200mm should be avoided.

Inclination angle

The direction of the water spray should be perpendicular to the roll surface. If the deviation (b) is more than 15 degrees, an increasing disturbance of the water flow at the impact area takes place, and hence cooling efficiency decreases (Fig. 16).

Spray angle

There is a clear influence of the water pressure at a given water flow rate and the water flow rate itself on the heat transfer coefficient. But the effect of the water flow rate is superimposed by the influence of the nozzle arrangements and the spray angle. Large spray angle nozzles (90°) show a lower HTC compared to those with 30° and 45° or 60°. Obviously the lower impact caused by a larger impingement angle (vertically to the roll surface), diminishes the cooling efficiency of the nozzles, too (Fig. 17).

Overlapping of nozzle rows

A third result can be obtained by evaluation of the mutual influence set, where two rows of nozzle were arranged in a certain distance, one after the other, on the roll. Fig. 7 shows the mean HTC for different water pressures versus the distance between the rows. For comparison the results of one row (which do not depend on the distance) are shown as reference lines. HTC values do not depend very much on the distance between the rows and the heat transfer coefficients of two rows are not twice that of one row, but approximately Ö2 times that of one. The reason can be found in the fact that the HTC acts in an area of approximately 0,7 m and a small distance between the spray bars is negligible, i.e. the HTC is like that of overlapping nozzles (Fig.18).

Results of HTC measurements

Comparison of all tests show, that differences in the results are obtained, which can be explained by the behaviour of the sprayed water on the surface under different test conditions.

The dependence of the heat transfer coefficient on nozzle parameters shows the following relationships:

- Increasing water pressure and – at the same time – water flow rate increase the heat transfer coefficient, but nozzle configuration also have an influence. Especially the 90° nozzles seem to be less efficient.
- Lower spray heights are preferable for an increase of the heat transfer coefficient.

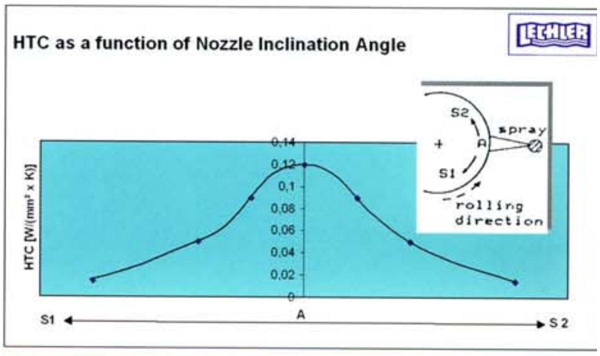

Fig 16. *HTC as a function of nozzle inclination angle*

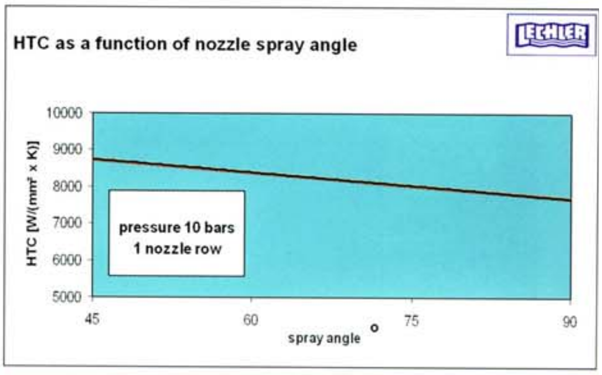

Fig 17. *HTC as a function of nozzle spray angle*

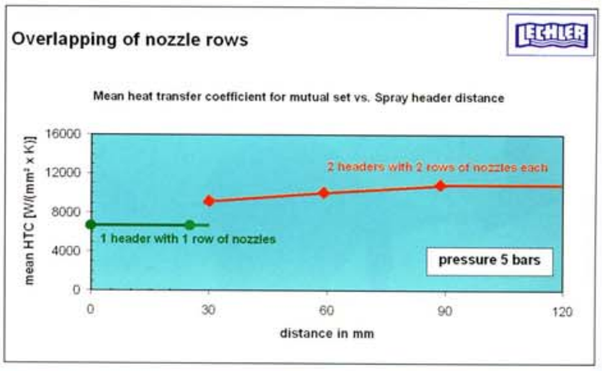

Fig 18. *Overlapping of nozzle rows*

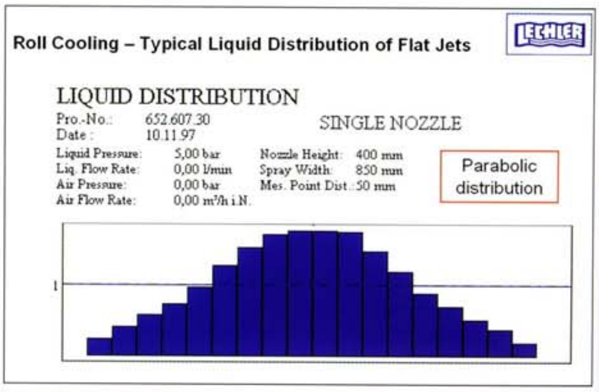

Fig 19. *Roll Cooling – Typical liquid distribution of flat jets*

- Increasing speed of the roll causes lower heat transfer coefficients, but the total heat, which is removed, does not depend significantly on the roll velocity.
- Overlapping of nozzles does not result in an increase in the heat transfer coefficient.

The preferred flat net nozzles have parabolic water distribution. Fig.19 shows that the parabolic water distribution is "bell-shaped" with heavy volumes of spray in the center and tapering to the edge of the footprint. The parabolic distribution is designed for use in headers. By overlapping the spray patterns the volume of water and more importantly the impact densities along the entire header can be equalized. Correct nozzle overlap can only be calculated by knowing the change in spray impact density along the entire length of the nozzle footprint. Furthermore, to properly overlap nozzles, the patterns must be offset such that the sprays do not interfere. To keep the offset uniform, a dovetail or other fixed orientation nozzle connection should be used. With a fixed offset the correct overlap is set and the sprays will never interfere on each other. Correct nozzle spacing and fixed alignment ensure balanced heat removal across the face of the roll (Fig. 20).

Conclusion

Good design in roll cooling systems and the use of precision spray nozzles benefit operations, maintenance and engineering. Personnel in these areas find:

- Improved roll life
- Consumption of fluids is reduced
- A reduced number of reject coils
- Roll crown is easily controlled
- The mill is easier to set and control
- Start-ups are easier and faster
- Reduced downtime
- Improved strip quality and cleanliness
- A cleaner mill environment
- Easier and less frequent maintenance
- Coolant temperature stability
- Lower energy costs

All of these benefits result in higher quality and increased production.

Summary:

Like the rolls themselves, the cooling system is an integral part of the rolling process. Well designed roll cooling headers and spray nozzles are precision instruments which apply coolant to the rolls in an efficient and effective manner. If designed well, they become a known quantity and help eliminate the thermal profile of the roll as an uncontrolled variable in the mill.

Lechler offers the right nozzles and application know-how. The basis for this are the ability to measure all parameters and to design and simulate installations with special facilities and software.

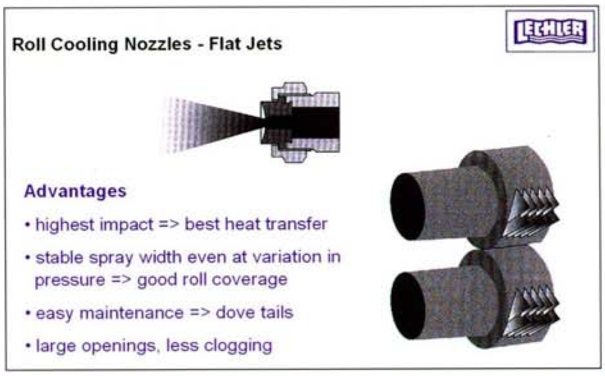

Fig 20. *Roll Cooling Nozzles – Flat jets*

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