NEW SECONDARY COOLING SYSTEMS AND PRACTICES

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ABSTRACT.

In order to reduce operational costs, Plants are looking to minimise the number of operational casters by increasing the output of individual machines through increased casting speed. The ability to cast low carbon steels at ever increasing casting speeds, while still being able to cast the more critical steel grades is demanded by Steel Plants, this requires a wider control and performance of the secondary cooling system. New technologies which provide a solution to these problems are now being adopted; these include "Hard-Hard" cooling and various methods of spray width control. "Hard-Hard" cooling is the ability to apply very large quantities of spray water to the slab surface while maintaining acceptable surface temperature levels. New nozzle designs which maximise the spray footprint on the slab surface are required to provide the acceptable surface temperature levels. This new "Hard-Hard" cooling concept, combined with new air mist spray nozzle solutions, allows very intense cooling or "Soft Cooling" depending on the steel grades and formats which are to be cast. The benefits resulting from these new technologies include increased production, reduced investment and operational costs and improved caster operation and better cast quality.

KEYWORDS:

"Hard-Hard" cooling, intense cooling, soft cooling, air mist spray nozzles, spray width control, variable spray height, nozzle movement systems.

DEFINITION OF "HARD-HARD" COOLING.

"Hard-Hard" cooling is the ability to apply very large quantities of spray water to the slab surface in the upper cooling zones so as to quickly reduce the slab surface to below 700^{o}C while maintaining acceptable surface temperature levels. This practise requires a totally different nozzle design and nozzle arrangement in the top zone of a slab caster.

REASONS FOR "HARD-HARD" COOLING.

In order to reduce operational costs, Plants are looking to minimise the number of operational casters by increasing the output of individual machines through increased casting speed.

The ability to cast low carbon steels at ever increasing casting speeds, while still be able to cast the more critical steel grades, requires a wider control and performance of the secondary cooling and as such, more flexibility in nozzle turndown.

Maintaining slab bulging at increased casting speeds requires both reduced roll pitches and increased secondary cooling intensities; the latter can lead to unacceptable temperature fluctuation on the slab surface.

New technologies which provide a solution to these problems are now being adopted; these include “Hard-Hard” cooling, various methods of spray width control and new nozzle design concepts.

APPLICATION OF “HARD-HARD” COOLING.

Increasing caster output through increased casting speed for low carbon steel grades, leads to increased solidification length and longer caster support lengths. Inter roll strand bulging and mould level stability, with its associated affect on surface quality, also become more problematic.

In its self “Hard-Hard” cooling cannot totally address the issues of inter roll strand bulging, small roll pitches are also required. These roll pitches require smaller nozzle spray heights which are necessary to prevent wasteful spray collision with the support rolls and results in a multi-nozzle arrangement to provide cooling to the whole of the slab width. The number of air mist nozzles in one roll gap can be double that of a conventional cooling concept.

Normal cooling practices are usually steel grade dependant, the less critical low carbon grades can be cooled harder than the more critical grades as shown in Fig. 1, the cooling intensity is usually reduced as carbon content increases. The main reasons for this are the strand surface temperature drop which occurs within the nozzle spray footprint, together with any subsequent surface reheats.

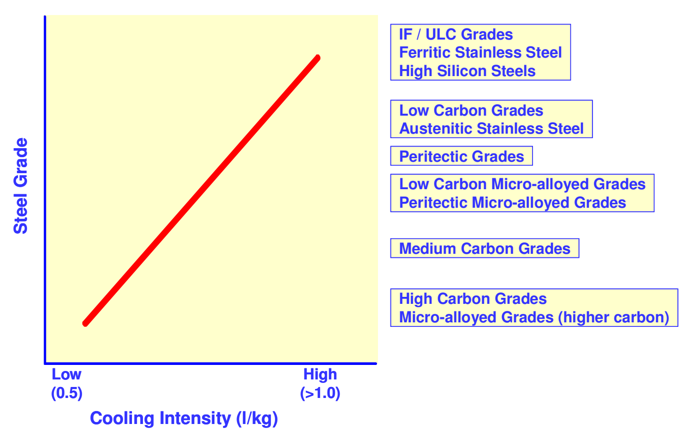

Fig. 1 – Spray cooling intensity versus steel grade.

The minor spray angle of conventional nozzles, also called the spray thickness angle, ranges between 16° and 12° for typical major spray angles of 80° to 120° (wide axis). With spray heights of 200mm to 250mm in the upper cooling zones, a relatively narrow band of footprints across the strand width exists as shown in Fig.2. The slab surface either side of this narrow band remains almost un-cooled and high temperature fluctuations within the roll gap can occur.

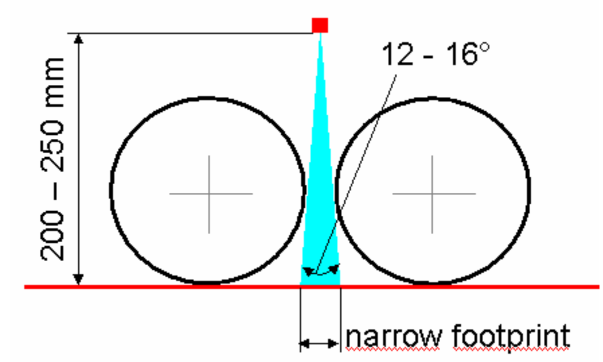

Fig. 2 – Spray footprint for conventional flat fan air mist nozzles.

These surface temperature fluctuations are normally limited by the steel grade to be cast and are typically shown in Fig. 3. Higher surface temperature drops below the spray foot print can lead to slab defects.

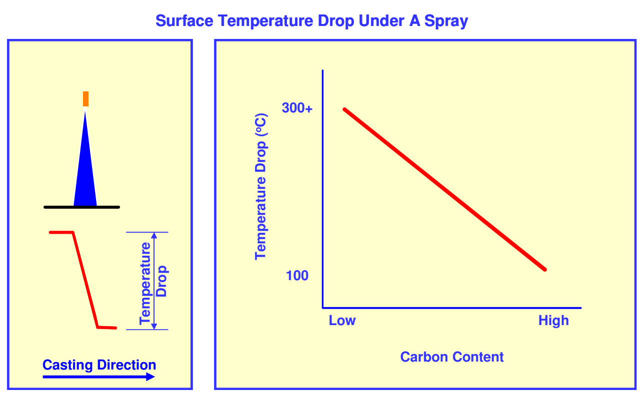

Fig. 3 – Steel grade related surface temperature fluctuations.

Slab defects attributable to secondary cooling can be minimised or avoided using the surface temperature fluctuation limits shown in Fig 3; "Hard-Hard" cooling is a technology developed to address the issues of surface temperature fluctuations and inter roll slab bulging.

"Hard-Hard" cooling technology requires that the strand surface temperature is reduced quickly to around 700°C or less in the first cooling zone after the mould sprays, this temperature is then maintained throughout the complete solidification length of the strand.

The necessary temperature profile requires high cooling intensities through high water flows. When these water flows are applied through normal flat fan nozzles, large cyclic temperature fluctuations occur on the slab surface as shown in Fig.4. These are a result of the relatively narrow bands of spray footprints across the strand width in the upper cooling zones as shown in Fig.2.

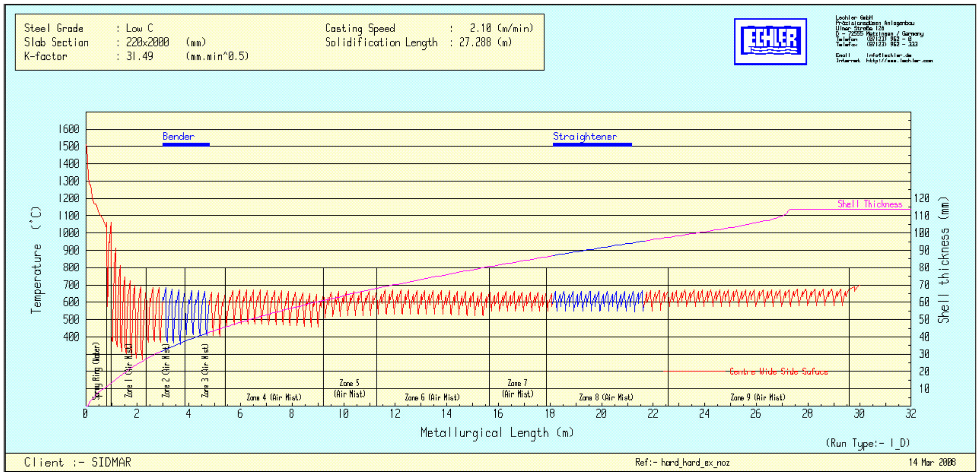

Fig. 4 – Intense cooling profile with conventional flat fan air mist nozzles.

These cyclic fluctuations can be in excess of 450°C in the upper cooling zones of the caster and can result in significant thermal stresses in the cast strand which could lead to the generation of both internal and surface defects.

Reducing the surface temperature fluctuations to acceptable levels, while still extracting the necessary heat from the slab surface, requires that the spray thickness in the casting direction is maximised within the roll gap. This is achieved with a new Lechler design concept - "Hard-Hard" cooling nozzle.

The example shown in Fig. 5 uses the same casting parameters and water flows as used for Fig. 4 with the exception of zone 1 which is equipped with the "Hard-Hard" cooling nozzles.

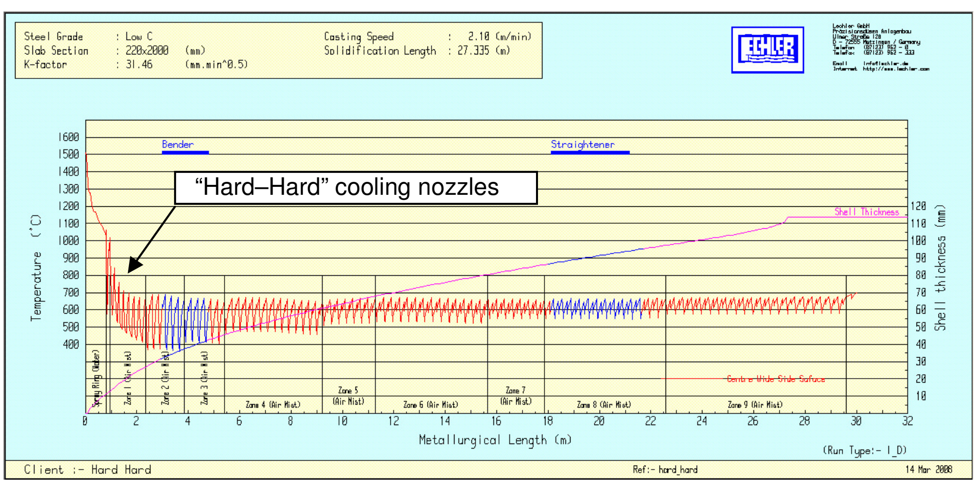

Fig. 5 - Intense cooling profile with Lechler "Hard-Hard" cooling air mist nozzles.

The main difference with respect to surface temperature between the conventional flat fan nozzles and the new “Hard-Hard” concept is shown by the reduction of the surface temperature fluctuations in zone 1, the “Hard-Hard” cooling nozzles also require less spray water to achieve the required cooling due to their increased minor spray angle which produces a larger sprayed thickness (Fig. 6) on the slab surface.

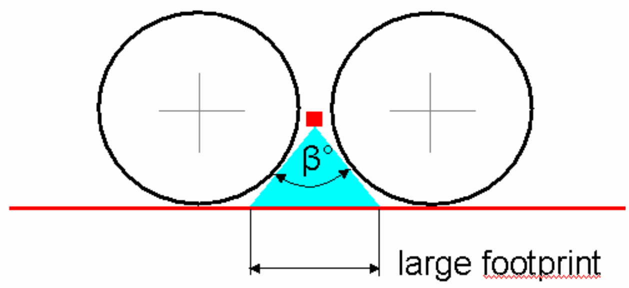

Fig. 6 – Spray footprint for “Lechler “Hard-Hard” cooling air mist nozzles.

“HARD-HARD” COOLING NOZZLE.

With the low surface temperatures associated with “Hard-Hard” cooling, the loss of cooling due to clogged nozzles will result large localised slab surface reheats. These reheats will produce large localised thermal stresses and possible defects.

When Lechler developed the “Hard-Hard” cooling air mist nozzle, one of the major design criteria was for a non clogging nozzle tip. This is why Lechler has once more concentrated on the single slot or single orifice principle (Fig. 7) so giving users the benefits of both the highest operational safety and reduced maintenance.

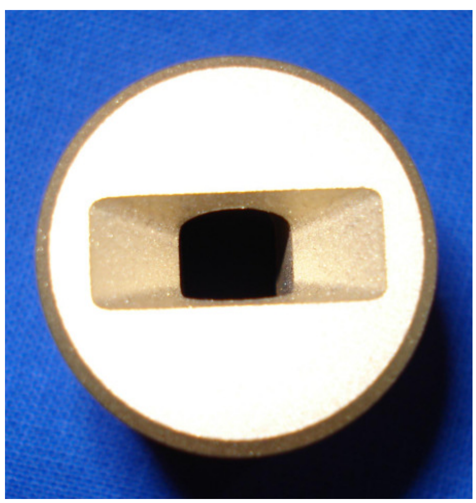

Fig. 7 – Lechler “Hard-Hard” cooling nozzle tip.

These nozzles are also mounted utilising the Lechler MasterCooler SMART method with the vertical plate connection, a system which has become an industry standard after it was successfully applied in the first caster more than ten years ago.

Because of the increased minor spray angle, the nozzles must be positioned very close to the slab surface to prevent spray collision with the support rolls. Typically a spray height of 70 – 100mm is used, in which case the nozzle tip can be below the roll centres, the nozzle tip and the nozzle pipe has therefore been designed to pass between the rolls (Fig. 8).

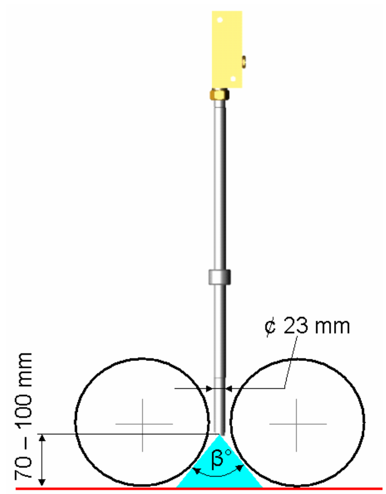

Fig.8 – Roll gap with "Hard-Hard" cooling nozzle.

Normally only zone 1 is fitted with the "Hard-Hard" cooling nozzle and subsequent cooling zones are fitted with normal flat fan air mist nozzles as these are adequate in maintaining the surface temperature at the required level. Spray width control can be incorporated into these zones to prevent overcooling of the slab corners on micro-alloyed steel grades in the case where "soft cooling" is also required.

Spray width control is where the sprayed footprint across the slab width is reduced or increased in line with the slab width and is normally used in casters that produce micro-alloyed steel grades. Various methods exist for spray width control.

SPRAY WIDTH CONTROL SYSTEMS WITH MULTI-NOZZLE ARRANGEMENTS.

Multi-nozzle arrangements can take the form of:

1) The nozzles in alternate roll gaps are staggered to prevent overcooling in the spray overlap areas as shown in Fig. 9; this layout is generally used for casters casting a wide range of steel grades which include micro-alloys.

2) The nozzles are in line in all roll gaps as shown in Fig. 10; this layout is normally associated with slab casters designed for a product mix focusing more on high quality micro-alloyed plate grades. It can also be found in casters for thin slabs.

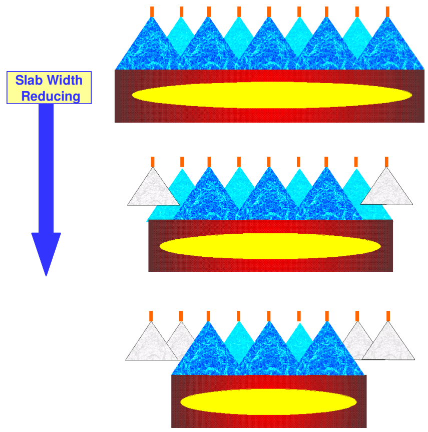

Fig. 9 – Staggered nozzle arrangement.

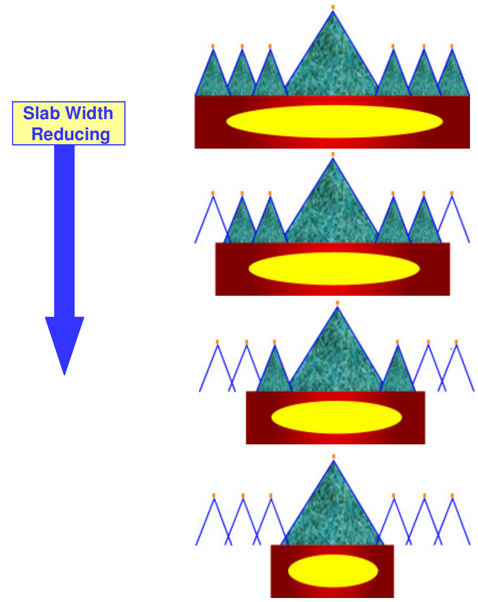

Fig.10 – In line nozzle arrangement.

WATER FLOW CONTROL CONCEPTS IN MULTI NOZZLE SPRAY WIDTH CONTROL.

In its simplest form, spray width control is achieved using one or two flow control valves to adjust the zone loop water flows together with ON/OFF valves which turn on or off the spray width control nozzles. As the slab width changes the outermost nozzles are automatically turned ON/OFF (Fig.11) and the flow control valves adjust the spray water flow accordingly.

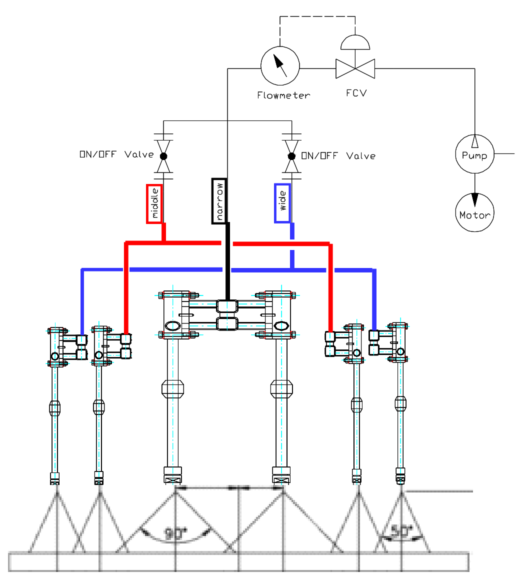

Fig.11 – Simple spray width control system.

This simple and low cost method of control can result in areas of the slab surface towards the slab edges being under cooled, this could lead to localised strand bulging and may contribute to mould level instability.

The effect can become even more severe when the ON/OFF air mist nozzles are of a smaller size than the central nozzles which are used to cover the minimum strand width. Since all the cooling zone nozzles across the strand width, regardless of their size, are being controlled by one flow control valve, it is extremely critical that all the nozzles should have the same control characteristics.

Unfortunately and frequently, not enough attention is paid to this requirement, both in the specification for new machines and also for cost reasons in the purchase of spare nozzles from questionable sources.

The example chosen for Fig. 12 shows an air mist nozzle configuration outlined in Fig.11 with two large nozzles in the centre and smaller nozzles for middle and wide slab width cooling loops. According to the solidification modelling and the cooling curves of the caster HMI level 2 system, the specified nominal flow rate for the centre nozzle is 35l/min at 3.2bar water pressure whereas the smaller nozzles for width control are being specified to spray 15l/min at an identical pressure.

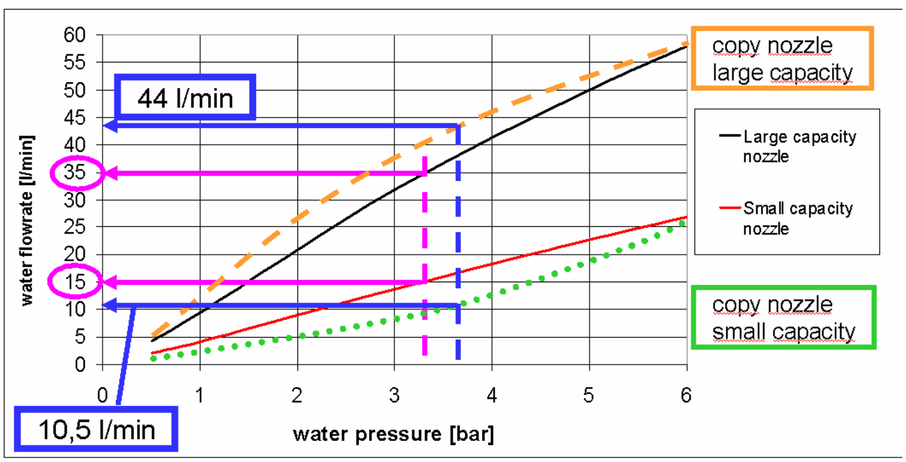

Fig.12 – Authentic and copy nozzle characteristics.

If the actual nozzles installed are not following the specified flow characteristics as described by the curves in Fig.12, heavy over cooling in the centre and under cooling at the edges of the strand can occur.

This effect can be seen in Fig. 13 which shows the cooling water density across the entire strand width based on the nozzle arrangement of Fig.11. The blue columns represent the desired water density whereas the red columns show the actual water density with 25% more water in the centre region and 30% less than specified under the spray width control nozzles.

This effect is not recognised by the secondary cooling control system since the total cooling zone water flow is correct, even though its distribution across the strand surface is incorrect.

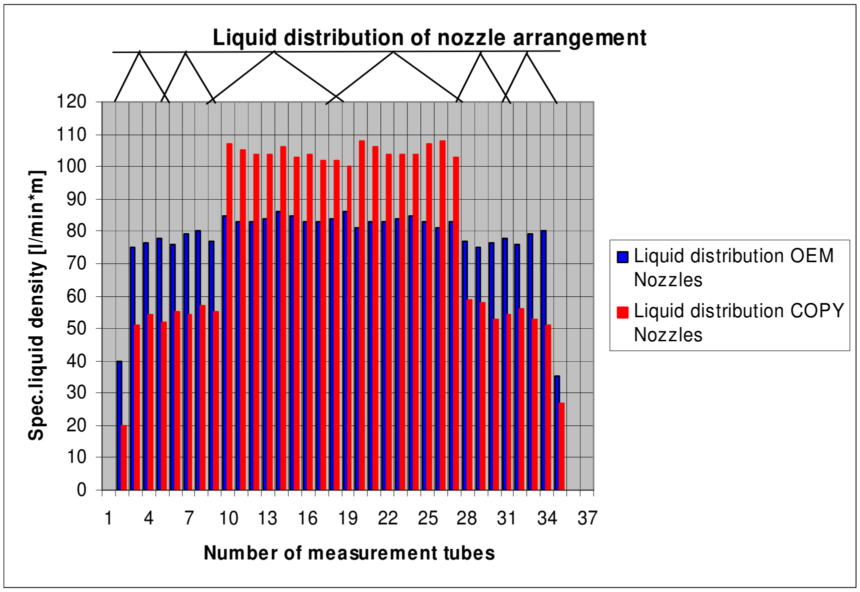

Fig. 13 – Variation in liquid distribution across the slab width.

The result of this type of cooling profile is shown on the surface temperature map in Fig. 14 where a pronounced “W-shape” final solidification profile is produced, this profile could lead to centre segregation problems even when soft reduction is applied.

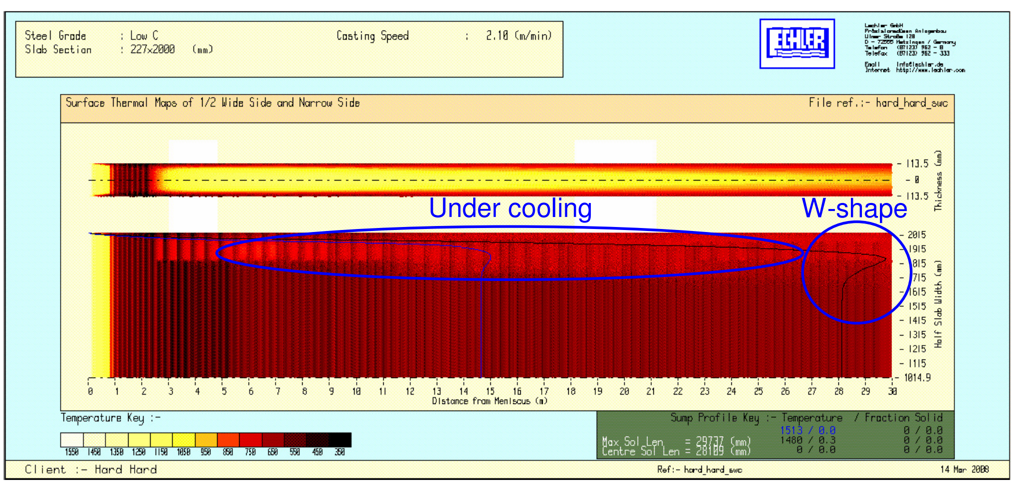

Fig. 14 – Slab surface temperature map.

In general the staggering of nozzles in alternate roll gaps is intended to provide even cooling along the total strand length. However, if staggering is not consequently and carefully applied, or totally ignored, uneven cooling across the slab width in alternate roll gaps will occur resulting in surface temperature differences. These differences can lead to distortions in the final solidification front giving the problematic final “W-shape” solidification profile.

To improve control the simple ON/OFF valves can be replaced by flow control valves, one for each strand width range (i.e. middle and wide). This enables the spray width control nozzle flows to be independently adjusted as the nozzles are turned on or off (Fig. 15) to achieve a more even surface temperature profile.

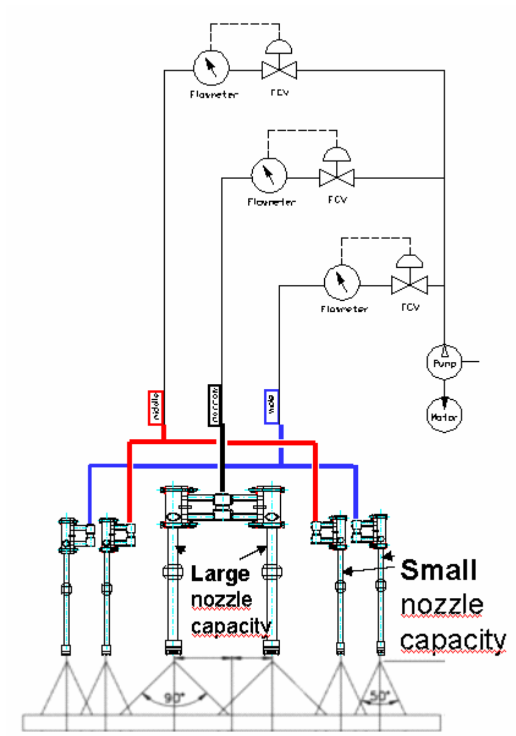

Fig. 15 – Sophisticated spray width control system.

SPRAY WIDTH CONTROL SYSTEMS WITH VARIABLE SPRAY HEIGHT.

To overcome the problems associated with uneven cooling, automatic systems have been developed which can match the spray width to the slab width consistently throughout the width range.

These systems utilise two nozzles which are moved diagonally inline with the spray pattern to maintain the correct water distribution at the spray overlap positions as shown in Fig. 16. The advantages are that the nozzles can cool the optimum width on the slab surface, without over cooling the slab corners.

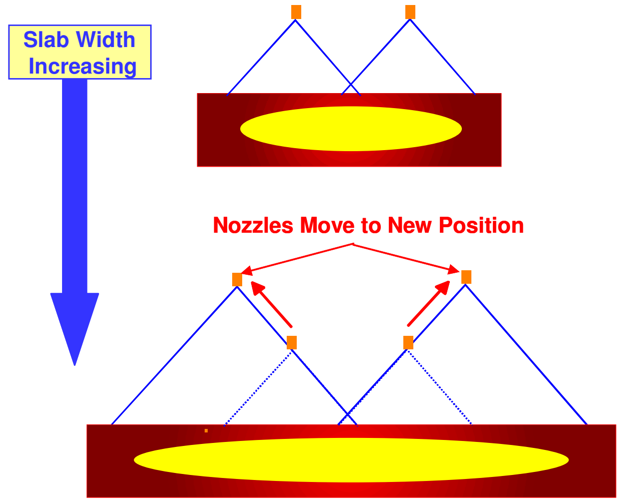

Fig. 16 – Spray width control with moving nozzles.

WATER FLOW CONTROL CONCEPT WITH VARIABLE SPRAY HEIGHT.

The secondary cooling control for the moveable nozzle systems is much more complex than for the normal ON/OFF spray width control systems in that cooling zone water flows are dependant on both the casting speed and the nozzle positions.

The spray footprint on the slab surface is directly related to the nozzle position; to enable calculation of the correct water flows which will give the correct heat extraction, the nozzle position must be known at all times. The nozzle movement systems, which can be electro-mechanical or hydraulic are controlled by the cast slab width and feature position transducers to provide the nozzle position, failure of any of these items will result in incorrect slab cooling.

Also for this concept Lechler has developed a new nozzle type, again applying the MasterCooler SMART mounting principle for safe consistent positioning and rigid mounting (Fig 17). The stiffener plate supporting the extension pipe of the air mist nozzle prevents deflection of the pipe during actuator movement.

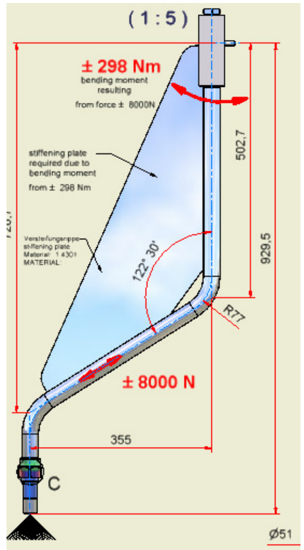

Fig. 17 – Moving nozzle design.

A spray width control system with variable spray height is an additional actuator in the already very sophisticated technology of modern slab casting. It adds to the complexity of segment design and machine control requirements. It also demands a very high degree of competence and discipline in maintenance in order to ensure consistent functionality in the harsh environment of continuous casting.

CONCLUSION.

This paper once again illustrates the importance of a carefully designed secondary cooling system within the ever increasing complexities of modern slab casting. The machine configuration and consequently the cooling system concept are determined by both the product mix of steel grades to be produced and the expected machine production output. The paper also demonstrates that various technical solutions and concepts are being made available. Whether spray width control with a multi nozzle arrangement, or with a twin nozzle variable spray height control offers the better solution can not be answered with a yes or no and needs to be addressed to the various machine builders and the steel companies producing with both concepts. With a profound competence and the experience of more that 110 strands of modern slab casters equipped with the Lechler MasterCooler air mist nozzles, Lechler offers optimum nozzle solutions for all cooling concepts.

The previous example describing the differences of nozzle flow characteristics and their effect also highlights that, frequently small details are not recognised in the entire process and these can have disastrous consequences in connection with product quality and machine productivity.

Providing and maintaining adequate cooling water and compressed air quality, combined with top class maintenance procedures, is also essential in optimum caster performance.