4th generation of thin slab casting technology – present and future

In January 2010, only six months from start of industrial operation, the thin slab casting plant at Posco consolidated the practice of casting speeds of 7 m/min during sequence operations. Productivity is at a level of 145,000 t/month with an average slab thickness of only 110 mm. However, with two new casters at Tangshan Iron & Steel the era of 4th generation thin slab casting has been officially entered. This generation is not only capable of guaranteeing the highest production level but also a variety of high added-value steel grades that until a few years ago could be produced only with traditional thick slab technology.

Figure 1. The new thin slab caster at Posco started industrial production in mid-2009, achieving in a short time casting speeds exceeding 7 m/min.

Danieli's thin slab caster development started in the 1980s. This was a pioneering period when different ideas were under evolution and a clear idea of what might be final configuration of a thin slab caster was still under discussion. This debate not only involved the caster configuration itself but also the configuration of the downstream hot strip mill.

Danieli worked in two directions. The first was the development of a specific solution related to thin slab casting and high-speed operation. The second was to design the caster by adopting certain important advantages of the best existing thick slab casters in operation with the aim to overcome the quality and productivity limitations of the first generation thin slab casting plants.

This approach materialized in the vertical curved "flexible Thin Slab Caster" (fTSC) concept, where "flexibility" means capacity to ensure top quality slabs in the full operative range of casting conditions requested by the mill, over an extremely diversified product mix of steel grades and slab thicknesses.

The evolution of the caster during the last 20 years has demonstrated the superiority of the vertical curved design over pure vertical and curved designs. The vertical curved design was considered as a necessary requirement for different reasons:

- The vertical design has the great disadvantages of a limited metallurgical length, i.e. low productivity, and the issue of bending/unbending in solid core condition and the associated problem of controlling the temperature, resulting in a surface quality problem.
- The curved design has the disadvantages of accumulated inclusions at the inner side, compromising the quality for automotive grades.

The vertical curved design eliminates all these problems and allows a design that is completely free from any limitation related to slab thickness and casting speed. At present the

Andrea Carboni, Executive Vice President; Gabriele Paulon, Executive Manager, Process and Technology, **Danieli Davy Distington**, Buttrio, Italy

Contact: www.danieli.com
E-mail: a.carboni@danieli.it

Danieli thin slab caster technology is capable to process slab thicknesses from 40 mm up to 110 mm within a speed range from 2.5 m/min up to 8.0 m/min.

The Posco CEM project

General. On September 20, 2007, Korean steel producer Posco and Danieli reached the agreement for the joint development of a new generation of plant based on the thin slab casting and rolling process for the production of flat products. The plant was to be installed at Posco's Gwangyang site, Korea. After revamping, the plant was to produce 1.8 million t/year of quality coils in a single strand caster, concentrating the complete production on narrow and medium widths (max. width of about 1.3 m).

In place of the original two thin slab casters, a single "new generation high-speed Danieli thin slab caster" was installed, designed to cast 80 mm thick slabs, at a speed of up to 8.0 m/min.

Caster configuration. The caster has a vertical curved design characterized by a long vertical section and a long horizontal section **(figure 1)**. The long vertical section is necessary to consolidate the solidified slab thickness before starting bending and to guarantee an inclusions floating time long enough to avoid subsurface non-metallic cluster formation that may compromise the surface quality.

The horizontal section consists of five segments. In total the metallurgical length is 20 m. Such a long containment allows a slab 80 mm thick to be cast at 8.0 m/min.

Particular care was dedicated to minimizing downtime. A top feeding dummy bar allows re-stranding in just few minutes. Operational exchange of segments in the bow and horizontal parts is performed fast and easily thanks to a segment manipulator.

The top part of the caster is designed to enable quick exchange by removing the mould, top zone and bender in a single operation. The top zone and bender, as well as the other segments, feature dynamic soft reduction capability. The hydraulic and the electrical systems are off-board, located on the static frame of the casting tower for quick exchange. No connection or disconnection is required for a segment exchange. The extremely user-friendly design together with the reliability of the process resulted in a steel-in-mould time of 79%.

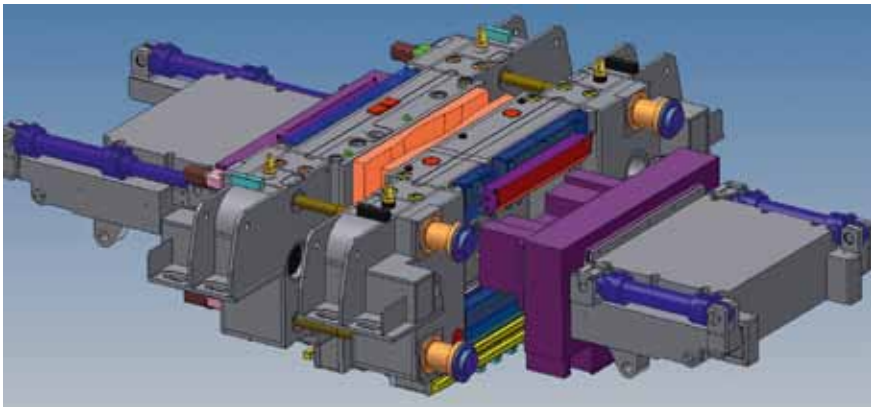

Figure 2. Design of the electromagnetic brake system

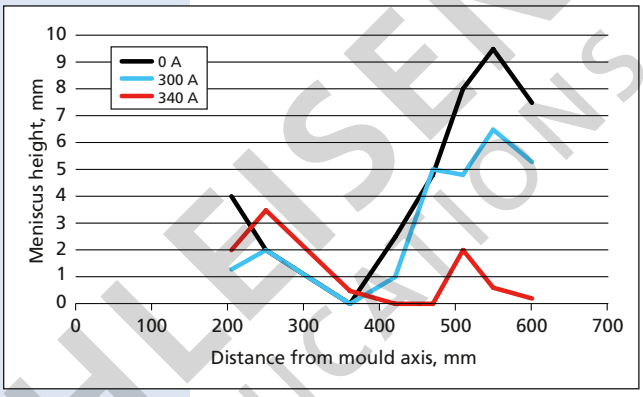

Figure 3. The meniscus wave shape proves effectiveness of the electromagnetic brake

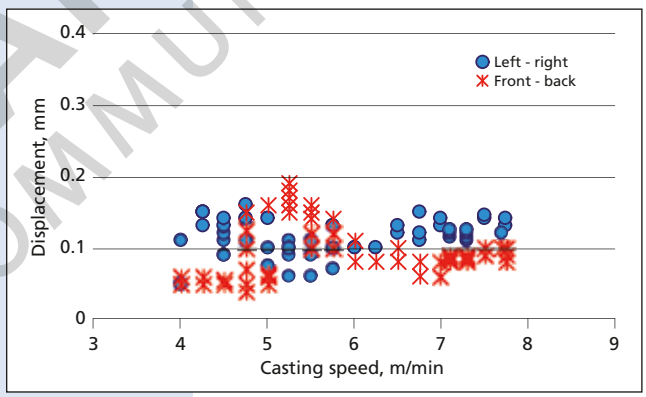

Figure 4. Oscillator displacement

Casting floor is designed to operate with two 130 t ladles at the same time. A 60 t tundish is arranged in a T-shape that makes possible simultaneous pouring of the ladles. A ladle change will never lead to a drop in tundish level, and stability of fluid dynamics in the tundish/SEN/mould system will not be compromised. An automatic powder feeding system guarantees stable powder feeding.

Fluid dynamics concept. For the SEN/mould system, the following solutions were considered:

- advanced H2 mould (high quality, high speed), with patented long funnel concept; the large volume of the funnel allows use of large-size SEN.
- new design 4 ports SEN for high liquid steel flows, approaching 7 t/min.

Soft liquid steel distribution allows operation of the caster at up to 6.0 m/min without using any electromagnetic braking device. Dimensions of the SEN are suitable for sequences up to 12 h (sequence index).

Electromagnetic brake. An electromagnetic device was added to extend

the good performance of the SEN within a casting speed range above 6.0 m/min and up to 8.0 m/min. The system is a DC brake with external yoke and retractable poles. A manipulator inserts the poles into and removes them from the mould. The handling of the mould is not affected by the presence of the electromagnetic brake, since it is off board. The weight of the electromagnetic brake does not overload the oscillating mass thus minimizing the workload of the oscillator.

The electromagnetic poles are designed in such a way that by adding or removing elements the shape of the magnetic flux can be adapted to the

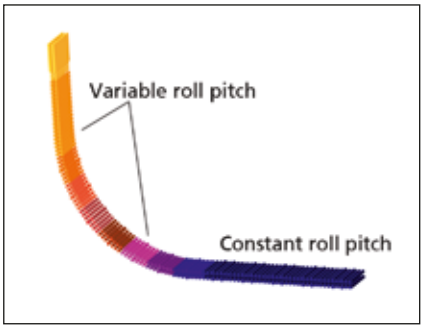

Figure 5. Vertical length and main radius have been increased

SEN design and fluidynamic pattern **(figure 2)**. Effectiveness of the electromagnetic brake has been proven by analyzing the meniscus wave shape with different current. A flatness of less than 3.0 mm has been achieved **(figure 3)**.

Mould breakout prevention system. A new concept for mould breakout prevention with advanced features and for high casting speeds was introduced. New algorithms were developed for faster detection of possible abnormalities that may lead to breakouts and for complete thermal mapping. Aside the complete thermal mapping of the mould, the system also implements monitoring of heat flux extraction.

The ratio between narrow side and broad side heat transfer is continuously monitored and the taper of the narrow side is adjusted accordingly. This control system together with a multi-taper profile of the narrow side keeps the contact between the solidifying shell and the copper plates stable. Longitudinal facial cracks are avoided. A rate of 0.2% breakout has been achieved even with speed constantly over 6.5 m/min.

Mould level control is based on LQG control principles instead of traditional PID systems. These algorithms are specifically conceived to identify recurrent phenomena, such as dynamic bulging instability, and to effectively counteract these phenomena.

Online mould level Fourier analyzer (real time FFT) functions are carried out for these purposes. Occurrence of sinusoidal disturbances due to dynamic bulging are detected by analyzing the roll pitch spacing versus the frequency of level disturbance. In this case a feed forward action in the liquid steel flow is activated to control dynamic bulging and dump it down.

A dedicated algorithm identifies the disturbances (steady and unstable weaving) that may be generated at the meniscus and it filters the signal to avoid occurrence of a resonance situation on the level fluctuation. As a result a stable level oscillation within ± 2 mm is possible at a speed of 7.0 – 8.0 m/min.

Inmo oscillator. The hydraulic oscillator is of the Inmo design. The Inmo technology is utilized for the very first time in thin slab casting. The distinctive feature of this patented technology, originally developed by Danieli and Posco for tight guidance of vertical oscillation in thick slab casters, is the stability of the oscillations parameters, as well the absence of parasite movements that might be detrimental at the highest frequency and asymmetric-sinusoidal curves. Accuracy of movements is continuously monitored with online sensors. Performances have been verified at 500 strokes per minutes showing horizontal displacements of less than 0.2 mm **(figure 4)**.

Roll geometry. Danieli employed its vertical curved design concept. The vertical length was increased by about 65% to ensure flotation of inclusions even at ultra-high casting speeds. Also main casting radius was increased to 5.5 m **(figure 5)**.

A new concept for a multiple split roll diagram was developed with specific features to avoid dynamic bulging and with gradually variable diameter on the vertical and the bow sections. Non-repeatable roll spacing avoids triggering of dynamic bulging. In order to evenly distribute the withdrawal force, driven rolls were distributed along the segments, already starting from segment 1, while in traditional solutions driven rolls are only adopted at the exit of the caster.

Secondary cooling. New generation high-efficiency air-mist secondary cooling, including a new secondary cooling design, provides innovative cooling strategies for temperature edge control. High-efficiency spray nozzles with large impinging areas were adopted in order to cope with hard cooling practice on the top part of the caster, due to the amount of heat to be extracted **(figure 6)**. The wide wet area allows reaching a specific water rate of up to 3.2 l/kg and a fast solidification rate together with a low surface temperature capable of suppressing dynamic bulging.

Edge temperature control is very critical for high-speed casting and possible direct rolling. The utilization of a spray width control with proportional valves allows adjustment of slab surface cooling with different intensities from the centre to the slab corner according to the metallurgical needs and for avoiding corner cracking **(figure 7)**.

Air mist cooling provides a very high water adjustment range. Both very hard and soft cooling is possible according to the steel grades. Production on this caster varies largely, including low carbon grades at 8.0 m/min, high carbon grades at 5.0 m/min and HSLA at 6.5 m/

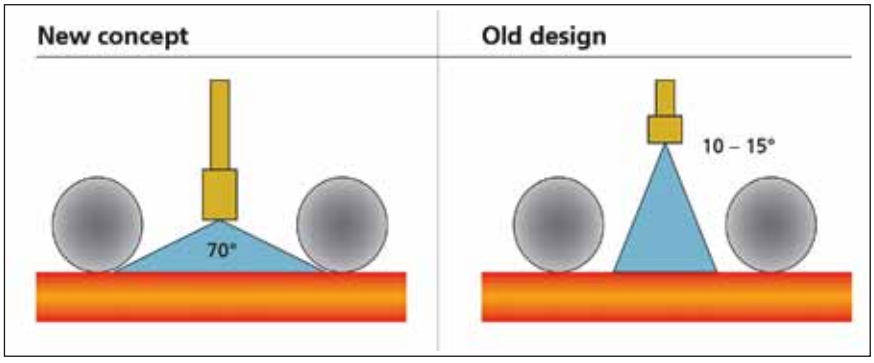

Figure 6. The new spray nozzle design can cope with hard cooling practice

min. Each of these steel grades requires very different cooling practice both in terms of intensity and temperature control across the width. The combination of air mist together with the independent flow control of lateral nozzles is the right answer here.

Overall secondary cooling design enables a temperature level high enough to perform direct rolling in a speed range of 5.0 – 8.0 m/min, requiring an endless configuration. In case of traditional batch production this will result in a big energy saving potential.

Performances and conclusion. Already in January 2010 (only 6 months from the start of industrial operation), the plant reached the intended quality and casting speed, consolidating the practice of casting speeds of 7.0 m/min during sequence operations. Productivity is at a level of 145,000 t/month with an average slab thickness of only 110 mm.

Casting speeds over 7.0 m/min are nowadays standard. The average casting speed is around 6.5 m/min. Distribution of typical speed per steel grades is as follows:

- max. casting speed for low/medium carbon grades: 7.7 m/min (8.0 m/min tested)
- average speed for low carbon grades: 7.2 m/min
- HSLA grades average speed: 6.0 m/min
- HSLA grades max. speed: 6.5 m/min
- high carbon grades average speed: 5.0 m/min
- average speed of all steel grades: 6.5 m/min.

The evolution of the casting speed has been impressive. Within a few months the contractual speed of 7.0 m/min was achieved **(figure 8)**. The ramp-up curve shows the reliability of this technology **(figure 9)**.

Quality. The production is focused mainly on four steel grade families:

- low carbon grades (0.02 – 0.04% C)
- medium carbon grades (0.17 – 0.19% C)
- HSLA grades (C + Nb)
- high carbon grades (0.23 – 0.55% C).

Thanks to soft reduction the internal quality is of centreline soundness class 1 **(figure 10)**. The surface quality is at a level comparable with a standard HSM and thick slab caster process.

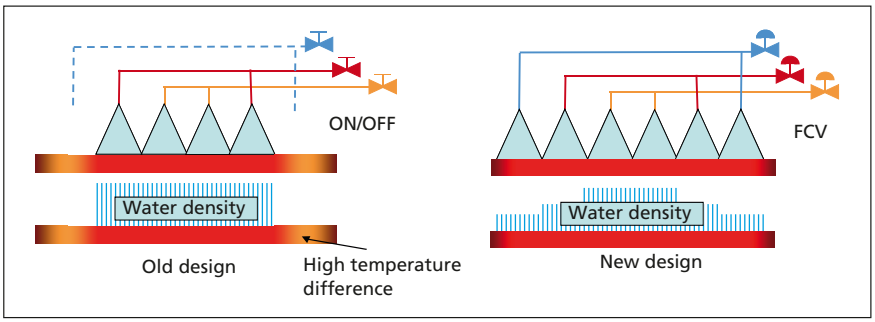

Figure 7. Spray width control to avoid corner cracking

In total, the most typical defects related to a thin slab caster, such as longitudinal cracks and edge/corner cracks, are lower than 1.0% **(figure 11)**. It is worth highlighting that this level was reached even with the speed being above 7.0 m/min.

The Tangshan 4th generation TSC

In June 2011, Chinese steel producer Tangshan Iron & Steel awarded Danieli an order for two single-strand slab casters to be installed in their production site of Tangshan, located in the Hebei province, P.R. China. In 2001, Tangshan Iron & Steel had already awarded Danieli a first order for two fTSC. The follow-up order was awarded among others due to the positively evaluated superiority and flexibility of the original vertical curved design of the fTSC caster and its technological packages. These advantages became very clear from the very beginning during the design stage because the equipment, originally built for 70 mm slab thickness, was – upon request of the customer – easily adapted to a new configuration for slab thicknesses in the 65 mm and 85 mm range without incurring any limitation because of the caster length.

This trust was immediately rewarded by reaching the world record of 3.2 million t/year of production of quality coils shortly after the start-up. This performance was achieved thanks also to the possibility of adapting the slab

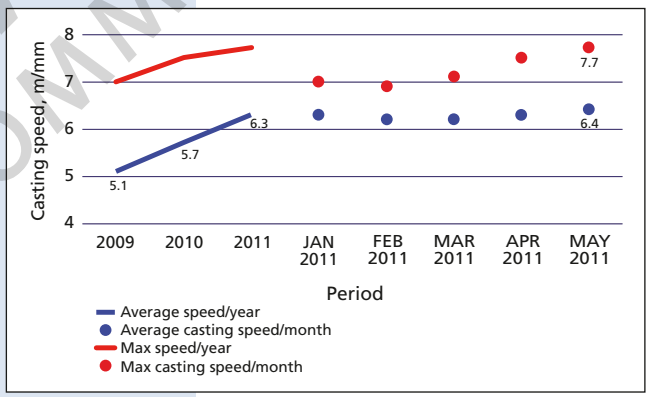

Figure 8. Evolution of casting speed

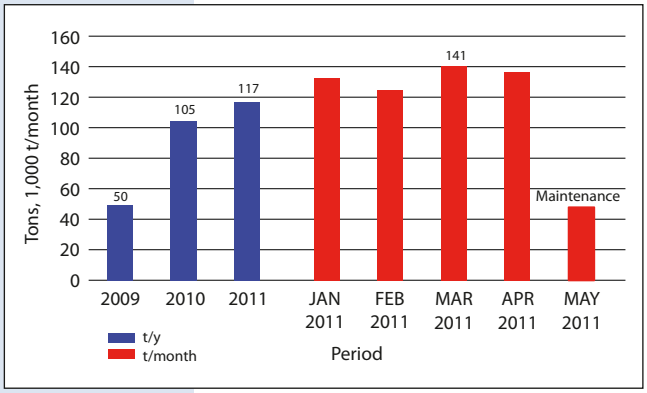

Figure 9. Within a few months the caster achieved its contractual speed

thickness according to final strip requirement. Casting conditions were optimized with the target of reaching – at the same time – best levels of productivity and quality.

The two new single-strand vertical curved casters will replace the old ones in the existing plant. Most of the applied technologies take advantages of the experience in two Danieli plants – first, at Posco where a casting speed of 8.0 m/min has been achieved with a quality level superior to any other caster in the world. The other one is at OMK in Russia where premium pipe grades, including the highest grade API 5L X 70-80 for arctic application and sour gas application, are produced.

Total productivity will be more than 3.2 million t/year of qualified slabs (maximum productivity is limited by the availability of liquid steel). The product mix in terms of variety of high added-value grades will be dramatically expanded to a level similar to the best performing thick casters worldwide.

The new casters are scheduled to be in operation by October 2012 and are designed to process a wide range of steel grades for quality slabs:
- ULC & IF for DDQ,
- low carbon for DDQ (exposed and unexposed),
- low carbon, microalloyed (formable) for structural automotive applications,
- peritectic for automotive wheel rims and pipe applications,
- medium carbon, high manganese (1.6%) and microalloyed for pipeline applications,
- medium carbon for structural and pipes,
- HSLA (700 MPa YS, 770 MPa UTS) for automotive (DSP 700B, 700T grades),
- HSLA for structural and API (X-70 to -60°C),
- V-N alloy (N= 200 – 250 ppm; 80 KSI),
- boron, low carbon (formable; hot forming),
- weather-resistant – Corten,
- high carbon (0.40 - 0.70%),
- dual phase (DP 600),
- silicon steel NGO (50BW800, 50BW400, 50BW330).

Figure 10.
The internal quality is showing centreline soundness of class 1

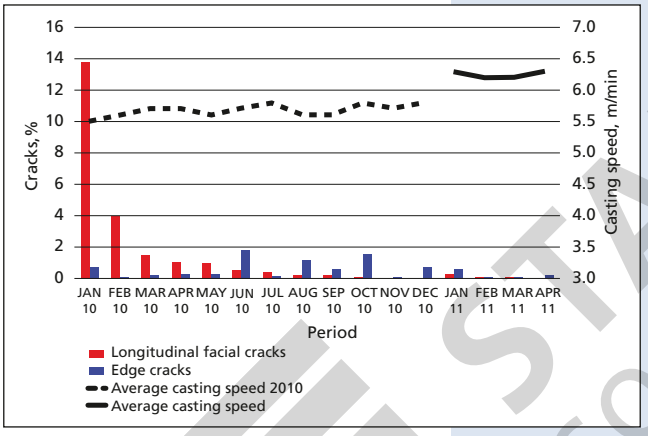

Figure 11.
Production quality vs. casting speed

Moreover, this product mix will be further expanded by the API family, production of which has already proven successful in the Danieli TSC at OMK. Slab sizes produced by the new caster will be in a range from 900 to 1,680 mm in width, from 65 to 85 mm thickness and casting speeds up to 7.0 m/min.

Considering all these factors, Danieli proposed a specific roll geometry and machine design to meet the demanding requirements of the existing business plan at Tangshan Iron & Steel. It was paramount that this design would not compromise on the latest state-of-the-art technology available from Danieli, guaranteeing achievement of best internal and external quality. The main target to be achieved by the new roll design was to increase the casting speed to above 6.0 m/min for crack sensitive grades. This makes it possible to maintain the actual production in excess of 3.0 million t/year with high added-value steel grades. Such state-of-the-art-technology includes:
- new vertical curved roll diagram with 5.0 m main radius and new progressive unbending,
- Inmo mould with remote width adjustment system,
- hydraulic oscillation system with rolling elements,
- breakout prevention system with mould thermal mapping,
- tight roll pitch design for suppression of dynamic bulging at the highest casting speeds,
- application of dynamic soft reduction process for the whole machine length,
- air-mist secondary cooling, with dynamic spray width control,
- continuous spray width adjustment for slab edge temperature control,
- high-efficiency spray nozzle with wide foot print for intensive cooling suitable for high-speed operation.

Danieli Automation will install a new L1 and L2 advanced control system with client/server architecture and a complete set of functions and models for casting process control, including:
- advanced mould level control with anti bulging algorithm and gravitational wave control,
- automatic slab width control in mould and taper adjustment,
- dynamic control of hydraulic oscillation parameters,
- new breakout prevention system software, with complete mould thermal mapping,
- element life time model for dynamic secondary cooling,
- spray width continuous adjustment,
- liquid pool model for dynamic soft reduction control,
- QUART real-time quality control system.

With these new casters, Tangshan Iron & Steel and Danieli have officially entered the era of 4th generation thin slab casting. This generation of technology is not only capable of guaranteeing the highest production level but also production of a variety of high added-value steel grades that until few years ago could only be produced with traditional thick slab technology. ■