



THE EVOLUTION OF THE THIN SLAB CASTER CONCEPT: FROM “FIRST GENERATION PLANTS “TO THE LATEST PRODUCTION AND QUALITY WORD RECORD BREAKING APPLICATIONS¹

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Abstract

Since the first pioneering applications of thin slab casting in late eighties, Danieli developed his own peculiar thin slab caster design aimed to overcome the quality and productivity limitations of the first generation plants. This approach has been materialized in the “flexible Thin Slab Caster” (FTSC) concept, where “flexibility” stands for his peculiar 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 thickness. After about 20 years from the first pioneering applications, this strategic approach in innovating consolidated solutions allows Danieli to proudly include as his references some of the world record breaking plants such as Tangshan Iron and Steel in P.R.China that positively proved the possibility to overcome the threshold productivity of 3 million tons per year of hot rolled coils (with two casting slabs in operation) strands since 2005. As for Quality, since the first industrial application of its FTSC caster in 1997, Danieli Essar Algoma plant (Canada), consistently proved the possibility to cast sensitive grades, such as peritectic, which are still today excluded, as a role, from the product mix of “ first generation “ thin slab casters. This process of targeting more demanding grades continued over the years, allowing at present to practically cover all the steel grades for flat products application, even API X60 and X70 used for artice pipe applications, successfully first produced in Danieli Ezz Flat Steel plant in 2005 and high Silicon grades (Si content exceeding 3,2 %) as in Danieli Benxi Iron and Steel plant in China, since 2005. This paper describes the defining features of Danieli FTSC, including the most recent developments conceived to target record breaking casting speeds of 8 meters per minute, that allow Danieli plants to aim at plant productivities of 1.8 / 2 million tons per stand, as in the new POSCO plant in Korea.

Keywords: Flexible thin slab caster; Extremely diversified product mix.

A EVOLUÇÃO DO CONCEITO DE LINGOTAMENTO DE PLACA FINA: DAS PRIMEIRAS GERAÇÕES ATÉ A ÚLTIMA PALAVRA EM APLICAÇÃO DE PRODUÇÃO E QUALIDADE EM APLICAÇÃO DE RECORDE DE NÃO PERFURAÇÃO

Resumo

Desde as primeiras aplicações pioneiras de lingotamento em placas finas, no final dos anos oitenta, Danieli desenvolveu sua própria concepção peculiar de lingotamento de placas finas destinadas a superar as limitações de qualidade e produtividade das primeiras plantas. Esta abordagem se materializou no “flexível *Thin Slab Caster*” (conceito FTSC), onde “flexibilidade”, destaca por sua capacidade peculiar para assegurar placas de alta qualidade em toda a gama , condições de lingotamento solicitadas pela usina em cima de mix de produtos extremamente diversificado de tipos de aço e espessuras. Cerca de 20 anos após a primeira e pioneira aplicação esta abordagem estratégica em soluções inovadoras consolidadas, permitiu à Danieli orgulhosamente a se incluir em referências de quebra de recorde mundial de *breakout* , como nas plantas de Tangshan Iron and Steel em PRChina positivamente revelaram que a possibilidade de ultrapassar o limite de produtividade de 3 milhões de toneladas ano de bobinas a quente (com duas máquinas de lingotamento de placas em operação) desde 2005. Também em qualidade , desde a primeira aplicação industrial de seus lingotamentos FTSC em 1997, o Danieli planta Essar Algoma (Canadá), mostrou de forma consistente a possibilidade de lingotar especiais ligas , como peritéticas, que ainda hoje são excluídos, como um papel, a partir da combinação de produtos de “primeira geração” de lingotamentos de placas finas. Este processo de segmentação de maior demanda de mix continuaram ao longo dos anos, permitindo atualmente a abranger praticamente todos os tipos de aço para aplicação de produtos longos, mesmo API X60 e X70 utilizado para aplicações de tubo no ártico, sucesso produzido na planta Danieli Ezz Steel Flat em 2005 e em graus elevados de silício (teor de Sisuperior a 3,2%) como em Danieli Benxi usina siderúrgica na China, desde 2005. Este paper descreve as características definidoras da FTSC Danieli, incluindo os mais recentes desenvolvimentos concebido para atingir recorde de velocidade de lingotamento de 8 metros por minuto, que permitem que as plantas Danieli chegar a produtividade de 1,8 / 2 milhões de toneladas por veio , como na POSCO em sua nova fábrica na Coreia.

Palavras-chave: Flexibilidade em lingotamento de placas finas; Extrema diversificação de mix de produtos.

¹ *Technical contribution to the 41th Steelmaking Seminar – International, May, 23^h-26th 2010, Resende, RJ, Brazil.*

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1 INTRODUCTION

Since the first developments of the thin slab casting process in the late eighties, Danieli developed his own peculiar design of caster starting from his extended activity of R&D, consolidated from experience of his first industrial scale pilot plants and confirmed over the last twenty years in close co operation with our customers that are an irreplaceable source of operational feedback, essential for the continuous improvement of the proposed solutions.

Thanks to this partnership relations, Danieli has been able to develop dedicated solutions to fulfil the specific needs of each application, all including the defining technological packages that identify the Danieli concept of flexible thin slab caster.

Most of the limitations of the first generations of thin slab casting and rolling plants installed in the world were related to limitations imposed by casting process, mainly due to the not optimal handling of the fluid dynamics in the mould, in secondary cooling and soft reduction process.

These limitations impose that the caster produces “at his best” in a limited operational “window”: this operational rigidity is in contradiction with the needs of a fully integrated plant (i.e a single production line made up by the caster , the tunnel furnace and the mill).As a consequence plant productivity and product mix were mainly limited to commercial grades.

In contraposition of these “rigid” operational strategy, Danieli developed his concept of “flexible” caster with a remarkably wider range of application.

Danieli defined since the first applications his own approach in successfully solving these limitations, as widely recognized by the achievements of our reference plants at present in operation.

The main areas of concern have been analysed and solved as follows:

Roll diagram concept

Since the beginning, Danieli promoted its vertical curved design, compared to vertical caster design.

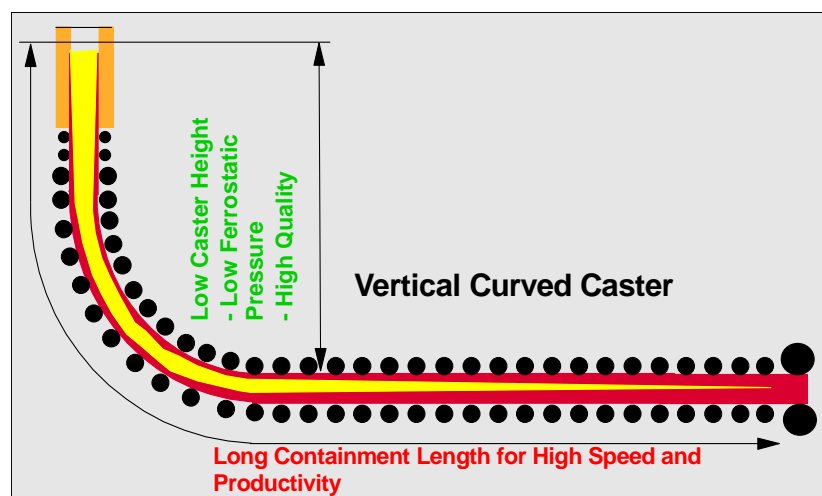


Figure 1 : Vertical Curved Caster

The advantage of this design is that it combines the advantage of the internal cleanliness given by the vertical portion , with a remarkably lower height of the casting



platform compared to the level of the discharging roller way. In his way the ferro static pressure inside the solidifying slab is lower and gives a slab that is much less prone to all well known detrimental bulging phenomena. Moreover, this design of caster allows the possibility in future to easily add further segments, hence increase metallurgical length.

Fluido dynamics in mould

Danieli developed the concept of his long funnel mould that, taking into account the well known benefits of the funnel design, brilliantly solved the problems on surface quality on the slab, due to an optimised distribution of the area along the slab where the shape of the early solidified slab is flattened.

This is the defining feature of the Danieli patented H2 mould (High speed, High quality) and is the key factor that allowed the casting of sensitive grades, including truly peritectic grades.

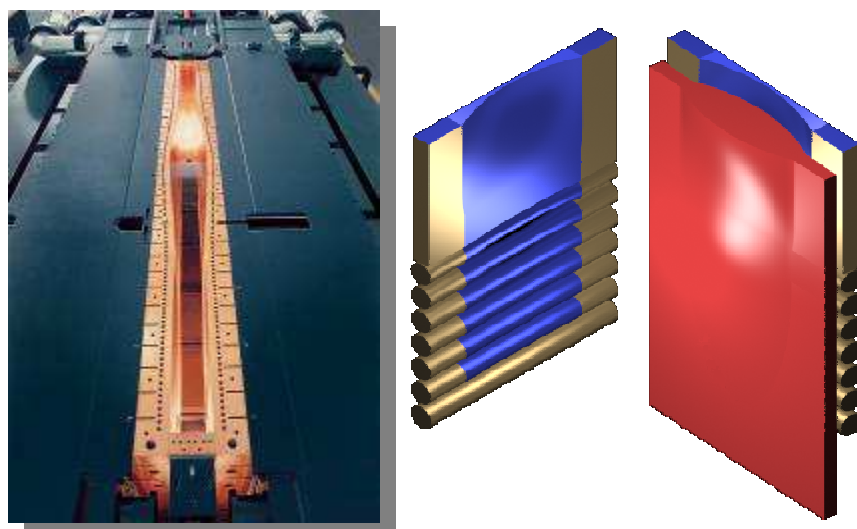


Figure 2: the Danieli H2 long funnel design mould concept

Also the increased volume of the liquid steel in the mould as well as the multiple port patented SEN ensures that the correct flow pattern is obtained in the mould, without risks of meniscus instability, temperatures non uniform distribution and “wash away effect “ on the just solidified steel skin.

Prove of the efficiency of the combination of long funnel mould and patented multi port SEN is that even if almost all the Danieli thin slab casters at present in operation are designed to accommodate the electromagnetic stirrer, no one of Danieli casters felt the need to install such an expansive device to control the liquid steel pattern flow, being it already controlled by caster design itself.

Secondary cooling

All Danieli Thin slab casters are equipped with air mist cooling, in order to allow the fine tuning of the temperature profile, instead of more traditional water cooling only strategies.



Figure 3 : Danieli segments with split roll design and air mist secondary cooling

Soft reduction process

Also the application of Dynamic soft reduction is a key factor.

The Danieli way of applications considers the following key principles:

a) The soft reduction must be applied according to the principles of a dynamic process, hence applied in a variable position along the strand, where and only where the optimal metallurgical conditions are found (in terms of correct ratio between solid and liquid fraction).

These conditions are not fixed but migrate along the length of the containment according to the specific casting conditions considered (i.e. casting speed, superheat, secondary cooling flows adopted....).

As a consequence, the position of application of the Soft Reduction MUST be variable.

Only in this way the well known benefits in internal quality are achieved: if the process is not applied in the correct position, the results could be either null or even resulting in a worsening of internal quality of the slab.

Danieli

Dynamic Soft Reduction

U.S. Patent No. 5,601,138

Soft Reduction accords to:

- ⚡ Actual casting speed
- ⚡ Superheat
- ⚡ Steel grade
- ⚡ Cooling pattern

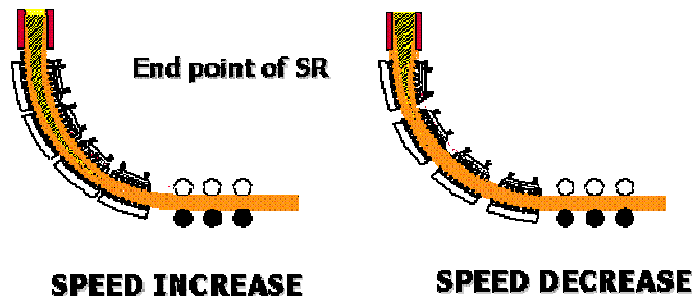


Figure 4 : Danieli soft reduction

b) The application of slab thickness control from mould to caster exit imposed by soft reduction is not limited to the few millimetres only requested by the soft reduction itself, but is applied also to significantly increase the thickness of the slab in the



mould area, hence creating casting conditions similar to the ones experienced in traditional

Due to this concept, it is typical Danieli solution to adopt about 20 mm of soft reduction.

A visible result is the dramatic reduction of breakout rate at the same levels of a traditional caster, even if the casting speeds are remarkably higher.

These concepts, together with more specific maintenance relates issues, such as the internal cooling of caster rolls, in order to ensure a proper cooling of rolls and bearings under all load conditions, allowed in recent years the users of Danieli casters to reach world records in terms of diversification of steel grades produced and productivity levels.

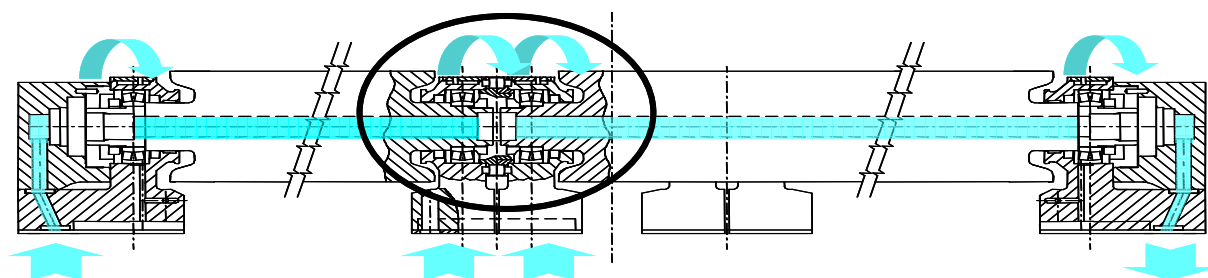


Figure 5 : Roll bearing supports and caster rolls internally water cooled

The “State of the art”.

Up to date, Tangshan Iron and Steel in P.R.China is the first and only plant in the world that positively proved the possibility to overcome the threshold productivity of 3 million tons per year of hot rolled coils with two Danieli thin casting slabs in operation since 2005.

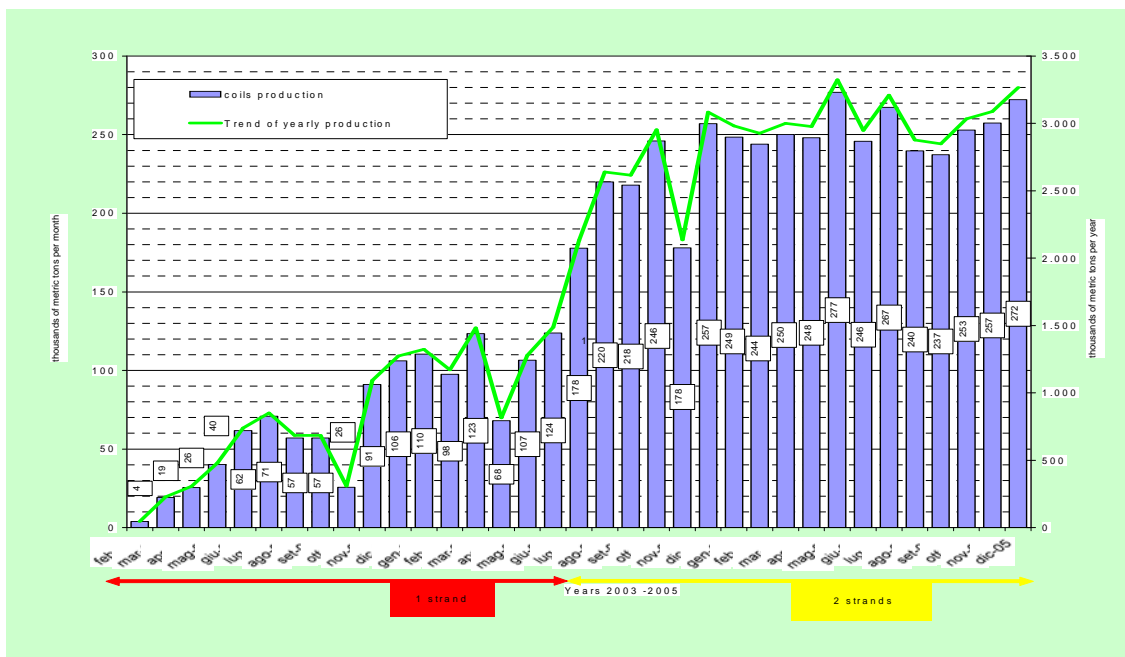


Figure 6 : Tangshan Iron and Steel in P.R.China production

As for Quality, since the first industrial application of its FTSC caster in 1997, Danieli EssarAlgoima plant (Canada), consistently proved the possibility to cast sensitive



grades, such as peritectic, which are still today excluded, as a role, from the product mix of “ first generation “ thin slab casters.

This process of targeting more demanding grades continued over the years, allowing at present to practically cover all the steel grades for flat products application, even API X60 and X70 used for artice pipe applications, successfully first produced in Danieli Ezz Flat Steel plant in 2005 and high Silicon grades (Si content exceeding 3,2 %) as in Danieli Benxi Iron and Steel plant in China, since 2005.

The “ next best thing”.

In order to further expand the boundaries of the application of thin slab process, Danieli is further developing his design concepts and thanks to the co operation with his Customers has the ambitious target to propose new solutions that already allows to target plant productivities of about 2 million tons per year per strand, with the latest pioneering experiences at Ultra High Casting speeds, approaching normal cruising speeds of 8 meters per minute, as in the new revolutionary thin slab caster in POSCO, just commissioned in may 2009.

Overall lay out solutions previously adopted in thin slab casters and design of each single component of the machine needs to be re-considered to verify if it is adequate or not to bear a productivity increase of approximately 50 % compared to consolidated casters of previous generations.

The POSCO CEM project

On September 20, 2007 POSCO and Danieli reached the agreement for the joint development of a new generation of plant for the production of flat products, to be installed in POSCO Gwangyang site, Korea.

As known, POSCO installed in 1996 in Gwangyang an ISP minimill ,based on thin slab casting and rolling process.

After many years of trials and developments, POSCO finally decided to completely revamp the existing casting and rolling facilities in order to both overcome the limitations of the original plant and develop a new revolutionary technology in flat products production.

In order to reach this ambitious goal, POSCO selected Danieli as technological partner, thanks to his recognized experience in design high speed thin slab casters and Hot strip mill facilities, as well as in process automation.

The original plant was composed by two single strand thin slab casters, originally supplied by SMS DEMAG.

Due to process limitations of original plant, afferent both to insufficient quality and limited plant productivity, POSCO was not satisfied of the results and decided to completely change the plant lay out.

The target of the new plant after revamping is to produce 1,8 Mtpy of quality coils in a single strand caster, concentrating all the production in narrow and medium widths (max 1,3 meters about).

In place of the original two thin slab casters, a single “new generation high speed Danieli thin slab caster” has been installed, conceived to cast 80 mm thick slabs, up to 8 meters per min casting speed.

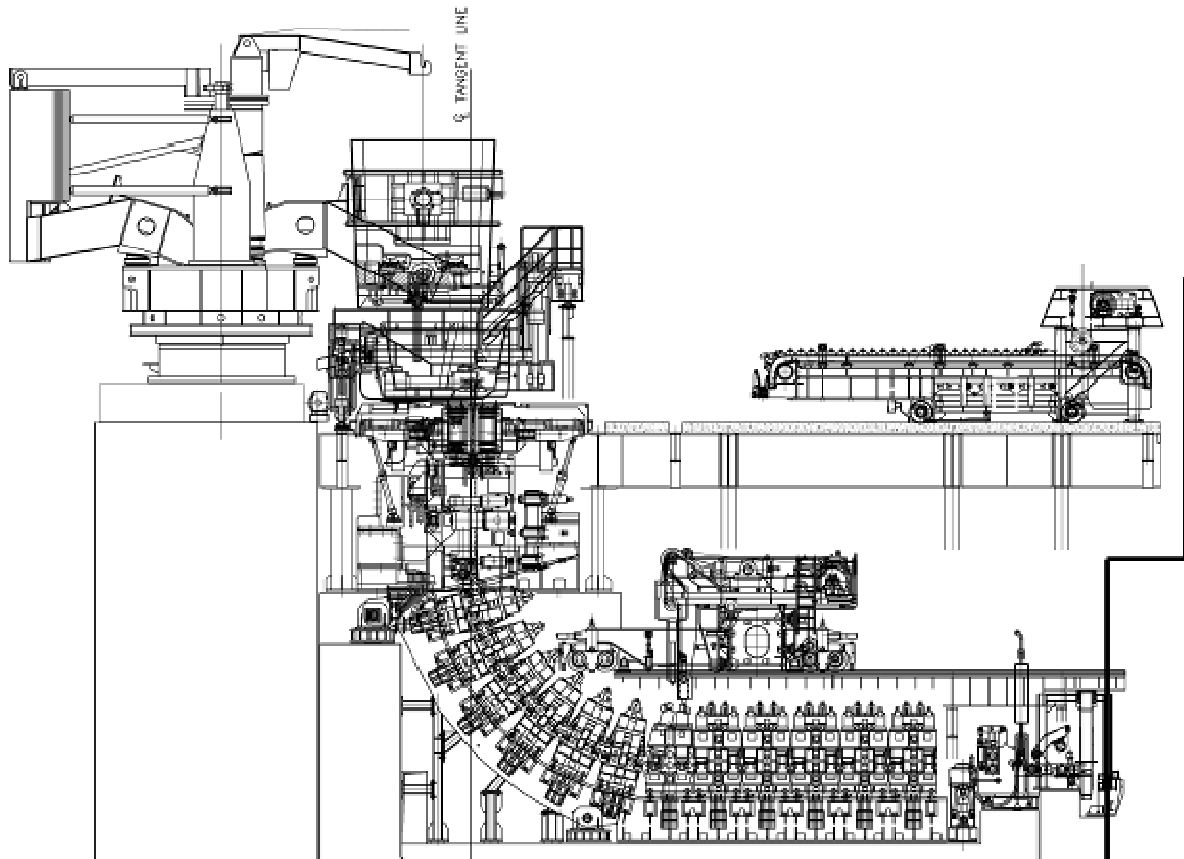


Figure 7 : The new Danieli Ultra High Casting Speed thin slab caster in POSCO

Key points for the success, are the enhanced solutions considered to prevent the most harmful phenomena occurring at high speed such as:

Unsteady bulging

Mould level fluctuation

Insufficient efficiency in spray cooling

Higher wearing for the consumable components

Tighter automation control needed for the faster production process

Advanced caster lay out solutions for efficient maintenance.

In order to cope with the new challenges, that are not a simple enhancement of previous performances but a real “quantum leap” in technology, a comprehensive review of all the design has been carried out.

The following areas of concern and related new solutions have been adopted:

Issue: master liquids steel fluido dynamics IN the mould.

The following solutions are considered:

- Advanced H2 “high quality high speed” Danieli mould, with patented long funnel concept. The Danieli funnel mould is proven to be the only one capable to guarantee the production and quality for HSLA steel grades. Now a new long funnel mould geometry has been specially designed for high casting speed;
- New design SEN for high speed casting;

Worth to be underlined, mould and SEN are designed to handle extremely high liquid steel flows, approaching the 7 tons per minute.

- New concept for Mould Breakout Prevention System (MBPS) with advanced features for high casting speed. New algorithms have been developed for faster detection of



the possible abnormalities that could lead to breakouts and for complete thermal mapping.

Aside the complete thermal mapping of the mould, the system implements also monitoring of the heat flux extraction.

- Advanced mould level control system in order to master and stabilize liquid steel level in mould.

Based on LQG control principles instead of traditional PID systems, these algorithms are specifically conceived to identify recurrent phenomena, such as the dynamic bulging instability and properly counteract. Online mold level Fourier analyzer (Real time FFT) functions are carried on for these purposes.

- Instead of traditional Eddy current sensors that “read” a limited area of the meniscus, a dedicated scanning device is considered to identify the disturbances (steady and unstable weaving) that could be generated at the meniscus surface.

Moreover, dedicated sensors have been installed along the caster to closely monitor the slab solidification process and populate the caster technological database in order to properly investigate the dynamic bulging incurrence.

Issue: Monitoring of oscillation process at high casting frequencies and ensure slab surface quality.

Innovative INMO design for the hydraulic oscillator is applied.

The INMO technology is utilized for the very first time in Thin Slab Casting.

The defining feature of this patented technology, originally developed by DANIELI and POSCO for tight guidance for vertical oscillation in thick slab casters , is the stability of the oscillations parameters, as well the absence of parasite movements that could be detrimental at the highest frequency and asymmetric-sinusoidal curves

Issue: minimize internal inclusions and master slab stress/strain

- While keeping the defining Danieli vertical curved design concept, vertical length has been increased of about 65% to ensure flotation of inclusions even at ultra high casting speeds. Also caster main radius has been increased.

- New concept for multiple split roll diagram with specific features to avoid dynamic bulging and with gradually variable diameter on the vertical portion and bow.

- order to evenly distribute the withdrawal force, driven rolls have been distributed along the segments, already starting from segment 1, while in traditional solutions driven rolls are adopted at the exit of the caster only.

Secondary cooling

New generation high efficiency air mist secondary cooling, including new secondary cooling design and innovative cooling strategies for temperature edges control

High efficiency spray nozzles with high wet footprint have been adopted in order to cope with hard cooling practice on the top part of the caster, due to the heat to be extracted.

Issue: innovate plant lay out solutions to reduce caster non productive time and maintenance

For the first time, some advanced solutions already consolidated in traditional casters have been adopted in thin slab casters, in order to ensure the maximum reliability of the plant as well as maximum availability (i.e. reduction of non production time), namely:

- Robot type segment change manipulator has been considered to minimize the



maintenance down-times and to have at the same time an enhanced tool for segment maintenance operations. In this way the segment exchange is practical a fully automatic operation.

- Dummy bar top feeding for fast restranding between sequences
- Tunnel type” cooling chamber, in order to allow full access to segment components to allow and improve both easy inspection and preventive maintenance practices

CONCLUSION

The order awarded by POSCO to Danieli for the development of the new generation of thin slab caster consolidates the already established Danieli technological leadership in thin domain, as demonstrated by the outstanding quality and productivity performances of our reference plants.

The plant, at present under commissioning phase, already confirmed the premises of the project overcoming, since the first heat, the max casting speed ever reached by the old casters.

Already during the first heats, the plant demonstrated production and quality performances in line with the expectations : casting speeds exceeding 7 meters per minute have already been achieved, as shown in the following picture.



Figure 8: Production and quality performances in line with the expectations

The results in terms of slab quality are satisfactory since both the slab internal and surface quality is at top level for the steel grades cast up to now (low carbon with 0.035 % C, medium carbon with 0.170 % C), better than the best achievement for similar plants.

● 08/05/02, Low carbon, 4.0 m/min

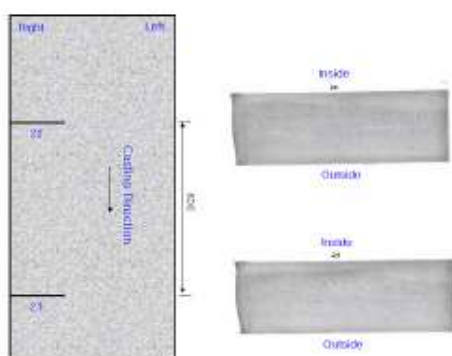


Figure 9: Quality sampling on POSCO thin slabs, showing defect free top quality



- 07/05/30, Medium carbon, 4.5 m/min
- Casting direction : C1 ~ C5
- Logitudinal direction : L2 - ¼ width, L3 - ½ width, L4 - ¾ width, L1/L5 - Tiple points

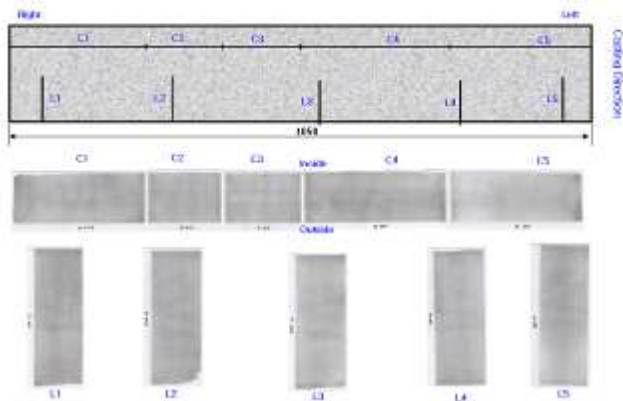


Figure 10: Quality sampling on POSCO thin slabs, showing defect free top quality

Some of the pioneering applications described in this paper are already part of the new generation of Danieli slab casters at present under engineering stage with Severstal Lucchini plant in Italy and Baosteel Meishan plant in China.

Worth to be underlined: as abovementioned the Ultra Ugh casting Speed caster I osco is decised to produce 1,8 Mtpy considering a max coil with of about 1.300 mm:

Should this technolugu be applied to more traditional coil widths, such as 1600 mm, a caster productivity exceeding 2 Mtpy per strand can be already archieved.

In case this innovative caster design is applied to a two strand thin slab casting and rolling plant lay out, an overall plant productivity exceeding 4 Mtpy can be reached: in line with most of the high productive conventional mills at present in production.