# FUTURE-ORIENTED MODERNIZATION CONCEPTS WITH PROVEN TECHNOLOGY FOR CONTINUOUS CASTING PLANTS*

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**Abstract**

A comprehensive modernization concept of SMS group includes the mold oscillation and the mold itself. For the mold, SMS group developed the Delta speed narrow face adjustment during casting and the HD mold with breakout prevention system and longitudinal facial crack detection via thermocouples or fiber optics.

For extending the strand guide or widening the slab format SMS group has the appropriate solution for production increase or amplified product range in order to make the plant fit for the future.

A strand guide system teaming up with the dynamic solidification model DSC® enables Dynamic Soft Reduction®. Applied with the suitable rate at the optimum position it contributes significantly to a homogeneous and crack-free slab microstructure.

Perfect alignment of the strand guide is crucial for maintaining an optimum quality. HD LASr aligning assistant with three-dimensional laser measuring system and intuitive operating concept is SMS group's answer.

SMS group's air-mist secondary cooling system which is characterized by a fine-adjustable, width-dependent breakdown of the cooling zones ensures crack-free slab surfaces.

Thanks to the Eco-Mode allowing on-demand addition of utility systems, the continuous casting plant will meet the increased requirements with regard to environmental protection.

**Keywords:** Modernization; HD mold; HD LASr; Eco-Mode.

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## 1 INTRODUCTION

Following comprehensive modernization by SMS group, the continuous caster No. 1 at the works of thyssenkrupp Steel Europe in Duisburg-Beeckerwerth, Germany, was successfully put into operation again in October 2014 [1]. The two-strand casting plant had been built in 1974 by SMS group as bow type designed for a production of originally 1.2 Mio tons of slabs per year at that time.
The modernized plant will enable thyssenkrupp to provide the market and particularly the automotive industry with high-quality products for a long time. The new caster is a significant contribution for the production of TWIP, TRIP, higher strain and crack sensitive grades as well as pipes and plates.
With the completed acceptance test in July 2015, the challenging goals set for the conversion have been achieved. The production could be increased to more than 2.6 Mio tons per year offering slabs with an enlarged width range of 1,000 up to 2,150 millimeters at a thickness of 257 millimeters [2].
Some 500 revamps worldwide proof SMS group's modernization competence with a wide range of packages addressing the aims of thyssenkrupp regarding the improvement of the slab quality, the expansion of the product range, the enhancement of process reliability and the environmental protection by energy efficiency.
We thank thyssenkrupp for the friendly support and cooperation during creating this paper.

## 2 PLANT DESCRIPTION AND MODERNIZATION CONCEPT

The aim of this project has been the complete revamp of the two-strand bow type continuous casting plant no. 1 of thyssenkrupp Steel Europe in Duisburg Beecker-werth.
The new plant is designed for slab widths between 1,000 and 2,150 millimeters, covering a width range that has been increased by 290 millimeters. The thickness of the slabs remains unchanged at 257 millimeters; however, the plant is designed and prepared for a slab thickness of 350 millimeters.

**Figure 1**. The new ladle turret and casting platform

For the conversion of the caster SMS group engineers carefully planned in cooperation with thyssenkrupp the most adequate, convenient, time- and money saving concept.

Starting with fact-finding at the existing plant we recorded actual geometries with 3D laser scanning of the existing equipment focusing on saving most of it by introducing tailored modules fitting in ideally. The designing was in 3D basing on the plant layout resulting from the scan, mutually agreed in planning and design meetings. (Figure 2)
For the thyssenkrupp caster modernization SMS group prepared the technical planning for the conversion of the two-strand bow-type caster and supplied all X-Cast® mechanical components from the mold down to the exit and the complete X-Pact® electrics and automation systems basing on a holistic unified concept with integrated safety technology. So thyssenkrupp received all equipment and technology from a single source ensuring process reliability. Beneath that also the erection and commissioning of the complete scope as well as the training of the personnel has been covered by SMS group.

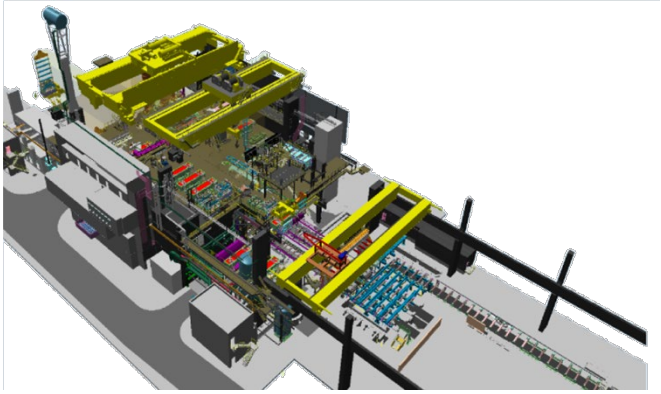

**Figure 2**. 3D model of the complete casting plant

thyssenkrupp focused with this revamp realized by SMS group on having a continuous casting plant easy to handle, maintenance-friendly and above all offering highest availability.
General assignments to SMS group covered the increase of tundish content from 50 to 75 tons. The strand guide has been again realized as bow type with two independent strand guides. The design minimizes bending stress by extending the straightening zone to ten points. For further quality improvement the segment rollers are split and aligned with optimized distances. The secondary cooling philosophy changed from water to air-mist medium enabling width-dependent media distribution including the related media supply.

The overall levels of the casting platform and the roller tables in the run-out area have been kept. Also the maintenance equipment has been adapted for the new molds, oscillation and segments in the workshop including HD LASr.

New electrical components and substations, automation and control systems have been realized as well as a new process control system for the complete continuous caster No. 1 implementing all new technological functions and the existing thyssenkrupp systems.

**Table 1.** Main technical data

| Caster no. 1 | before revamp | after revamp |
|---|---|---|
| Plant type | bow | bow |
| Casting radius | 12 m | 12 m |
| Mold length | 800 mm | 900 mm |
| Control points Breakout prediction | 30 | 130 |
| Metallurgical length | 33 m | 32.4 m (37 m) |
| No. of segments | 0 - 18 | 0 – 13 (15) |
| Straightening points | 5 | 10 |
| Slab width | 1,180 mm to 2,040 mm | 1,000 mm to 2,150 mm |
| Slab thickness | 257 mm (cold) | 257 mm (cold) (350 mm) |
| Spray cooling | Water | Air mist |
| Max. casting speed | 1.35 m/min | 1.35 (1.5) m/min |
| Tundish weight | 50 t | 75 t |
| Nominal capacity | 220,000 monthly tons | 235.000 monthly tons |

On the revamped continuous caster, high-quality basic material for high-strength steel grades such as AHSS (advanced high strength steel: high-strength, unalloyed steel grades), ULC and IF steel grades as well as tinplate, sheet, pipe and tube strip, and quarto plate steel is cast.

## 2.1 Improvement of product quality and introduction of value-add products

### 2.1.1 Liquid steel handling

Clean steel practice starts in the preparation of the liquid steel and extends to the continuous caster. The level of cleanliness has been improved by increasing the tundish content by 25 tons up to 75 tons. Beneath that the new tundish design increases also the buffering capacity during ladle change. Consequently also the ladle turret and the tundish car have been exchanged. A new S-type ladle turret with integrated ladle inclination and independent lifting of the ladles containing up to 290 tons has been installed. For rotation electromechanical drives are foreseen as for the tundish car travel drive. The hydraulic shroud manipulator and the pneumatic multifunction manipulator for sampling or temperature measuring serve for more safety on the casting platform.

### 2.1.2 Strand guide

Main focus for eliminating cracking has to be on internal strain during bending as well as during straightening. A bow type curved mold caster design lacks the bending zone. For further decreasing the bending stress level the straightening zone features 10 unbending points. Main reasons for thyssenkrupp to stay with an optimized bow-type caster design for caster no. 1.

With both caster types available, as caster no. 2 is built in vertical bending design, the plant in Beeckerwerth is able to address a wider market segment of steel grades.

For placing the mold and segment 1 in the right position centering bolts are fixed to one center of reference, the oscillator frame. This new machine head design has been realized focusing on smooth and stress-free transition of the just formed and yet weak strand shell from the mold to segment 1. During insertion the mold and segment 1 are self-positioning and self-connecting to the water supply by stainless steel water connection plates. Mold and segment 1 can be removed together in one step for maintenance.

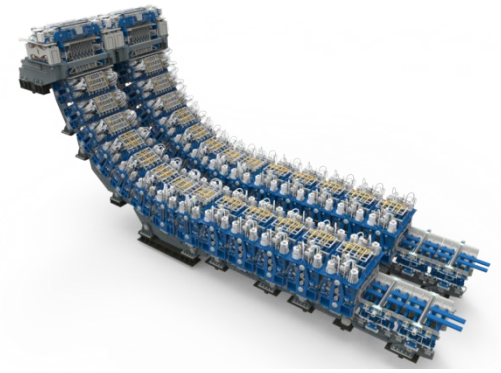

**Figure 3**. 3D model of the 2-strand guide

### 2.1.3 Intelligent secondary cooling solutions

Efficient and homogenous cooling is essential to ensure both big production and high quality. SMS group cooling systems focus on precisely adjusting the cooling intensity according to the slab widths providing for crack-free slab surfaces.

Starting in segment 1 the secondary cooling media is changed from water to air-mist supply basing on new compressor stations each per strand. The loose and fixed sides of segment 1 to segment 8 are equipped each with five control zones for most flexible adaptation of cooling medium distribution over the slab width.

High internal and surface quality is promoted through the width-dependent cooling system, fully controlled by the new X-Pact® Solid Control (formerly Dynamic solidification control model DSC®) with widened functionality, e.g. 3D calculation, observation of solidification length, grade tracker, strain monitor, bulging monitor, solid-front controller, maximization of slab exit temperature, generators for cooling curves and temperature curves, calculation of grade based thermal conductivity or scale thickness, solid fraction and ductility diagrams, calculation of segment gap and K-factor, temperature control or live time control and replay-function.

Keeping in mind minimum consumption of air or water, dry casting can be applied for thick slab casters as soon as the solidified strand shell becomes thicker than approx. 100 millimeters. Accordingly the horizontal Cyberlink® segments are realized without secondary cooling. However the rollers are designed as internally cooled revolver rollers for protection against overheating and it would even be possible to start dry casting in segment 2.

The results are a maximum cooling efficiency for a maximum format spectrum at maximum casting speeds for all steel grades, but especially for micro-alloyed peritectics and micro-alloyed medium carbons.

### 2.1.4 Hydraulic segment adjustment with X-Pact® Gap Control

The most modern strand guide system features position-controlled segments in the bow and horizontal area for fast thickness changes enabling dynamic hydraulic strand taper adjustment. With Dynamic soft reduction® the macro-segregation and

solidification structure in the strand center is controlled to achieve a uniform and crack-free slab microstructure.
The segments are built in thick sheet design with high stiffness for high life time and consequently increased plant availability. Furthermore the complete bow of the strand guide is realized in tunnel cooling chamber design, offering direct access to the segments for repair, protecting instruments (e.g. hydraulic cylinders) as these are outside the wet area and finally decreasing the corrosion of steel structure aside.
The significantly increased rate of directly charged slabs has led to a marked improvement of the production processes at thyssenkrupp Steel Europe.

### 2.2 Increase of plant yield, increase of plant capacity and flexibly scheduling of the production

With additional segment rollers or segments, with support frame and retracting rails the strand guide can be extended (Figure 4). The caster no.1 has been prepared for the extension of the containment zone by two segments.
You increase the casting speed and get directly a rise in output: By adding one segment the casting speed can be increased by approx. 0.1 meters per minute you can boost the production up by 80,000 tons per year. New steel grades might then be possible and with higher casting speed the strand reaches the straightening zone at a higher temperature. For many steel grades this leads to a distinctly decreased amount of surface cracks and to better slab quality.

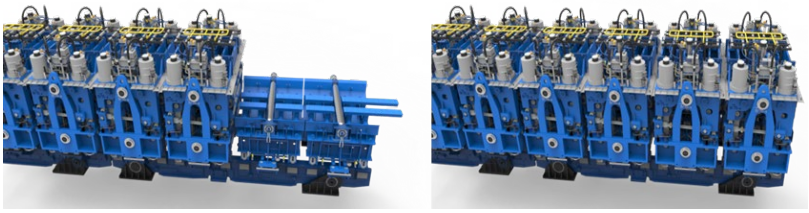

**Figure 4.** Prepared for strand guide extension

SMS group concepts are focused on keeping slab format flexibility to serve a wide market thus staying independent of market changes. With new slab thicknesses new market segments can be addressed.
The possible retrofitting of hydraulic adjustment for slab thicknesses of 257 to 350 millimeters enables the supply of heavy plates or slabs for tubes and pipes production. So a small change in the dimensional range can widen the product spread and improve the productivity.

#### 2.2.1 Mold

The mold length has been increased from 800 to 900 millimeters enabling casting at higher production speed when extending the strand guide length. The mold is also prepared for thickness changes up to 350 millimeters (Figure 5).
The exact adjustment of stable narrow sides is essential and easily possible with the new mold. To prevent backlash and dynamic bending the mold narrow sides feature high-precision spindles and optimized back-up plates. Thus stable heat transfer at the narrow faces is enabled and the risk of longitudinal or transverse corner cracking is minimized. High casting speed can be realized while the risk of breakouts is significantly reduced.

X-Pact® Level Control serves for a stable mold level enabling auto start and reacting automatically on steel grade or width changes.

**Figure 5.** The built-in mold

The bow-type mold features X-Pact® Width Adjust. Any width adjustment and automatic setting of the mold taper can be performed during running production without having to reduce the casting speed (Figure 6). The narrow face adjustment is fast and achieves shortest transition lengths thus increasing the yield.
In doing so, the system takes into account the steel grade and the current casting speed. Optimized for crack-sensitive grades the strand shell will be very softly compressed during decrease. For width increase the gap in-between mold narrow face and strand shell is kept very small. Thus any breakout risk is minimized.

**Figure 6.** Slab width reduction by 200 millimeters
– from 1,300 to 1,100 millimeters over a short length of only 6.3 meters

### 2.2.2 HD mold

The mold monitoring system HD mold$^{TC}$ basing on thermocouple technology is implemented into the mold. With 130 control points the system helps for breakout prevention - also longitudinal facial cracks can be detected.
A captivating experience however is the real-time view deep into the liquid and just solidifying steel, into the process that determines mostly the steel quality.
With four times more measuring points, distributed across the entire height of the mold, HD mold$^{FO}$ (fiber optical)(Figure 7) displays a comprehensive picture of the solidification process thus achieving higher process security. It provides even more information relevant for breakout prediction with more reliable detection of stickers and longitudinal cracks and maps the heat flux density in much more.
The different types HD mold$^{TC}$ and HD mold$^{FO}$ are used in alternating manner.
The HD mold$^{FO}$ with its fiber optical sensors are configured to coexist with thermocouples too in a highly flexible way. In doing so we are able to e.g. mix the thermocouple signals of broad sides together with fiber optical sensor signals from narrow sides.

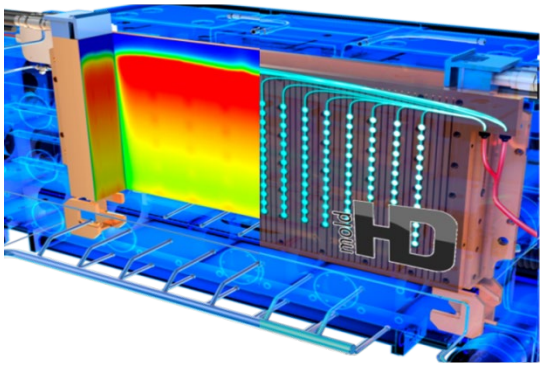


**Figure 7. HD mold principle**

Several assistants support the operator in precarious situations, which convinced thyssenkrupp to decide for HD mold[FO].
Breakout Prevention Assist reliably prevents break-outs resulting from stickers in the mold and in this way ensures effective protection and high availability of the plant. Mold Temperature Assist provides two- and three-dimensional information on distribution of the heat dissipation, alignment of the submerged entry nozzle, stirring effect and the contact between strand shell and copper plates.
Direct visualization of the local strand shell thickness and the respective thickness of the liquid and solid layers of mold powder is only possible using HD mold[FO]. This provides for a deeper understanding of the solidification process. The reduction of production faults and the improvement of quality serve again for increased plant availability.

### 2.2.3 Dummy bar system

The dummy bar chain is realized as top feeding type with the dummy bar car and the related winch to move the dummy bar into position (Figure 8).
The maintenance-intensive decoupling system with a hydraulic device has been replaced by the solution with a self-decoupling dummy bar head. For continuous inspection of the strand guide geometry an online passline and roll gap checker is integrated in the dummy bar.

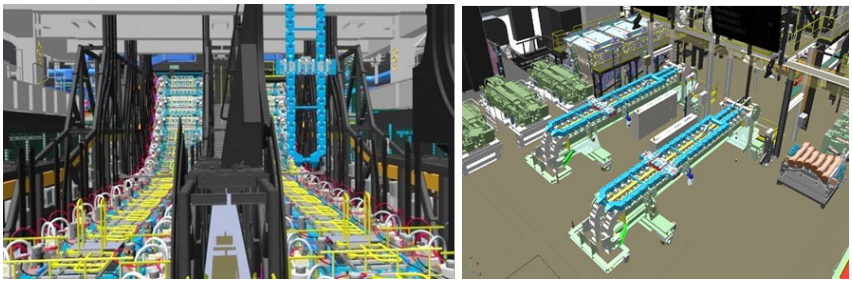

**Figure 8.** Top feeding dummy bar and dummy bar car on casting platform

## 2.3 Reduction of operational costs

### 2.3.1 Mold oscillation

The hydraulically actuated resonance oscillation system developed by SMS group combines two key elements (Figure 9). First a leaf-spring suspension cares for precise guidance and second a hydraulic drive provides complete flexibility with the online dynamic control of oscillation stroke, frequency and wave form.

The maintenance-friendly system features reliable control of the operation mode with short stroke and high frequency leading to decreased oscillation mark depths and thus to reliable surface quality improvement. The output signals are continuously compared; any deviation from the synchronized movement of the cylinders is detected.

**Figure 9.** Resonance oscillation system, hydraulically actuated

### 2.3.2 Eco-Mode

Thanks to the Eco-Mode feature, which activates the media systems only to the extent necessary in each situation, the modernized caster also satisfies the requirements of the ever stricter environmental standards. Depending on the status of the plant, the operator can set the energy saving system into the modes MAX for switch-off all devices. OFF for no energy savings or ON for stand-by of un-used devices.

By the customized connection of plant cooling systems, pressurized air for secondary cooling, natural gas and the hydraulic systems, minimized energy input for process control and for plant cooling is realized for the protection of our environment.

## 2.4 Industrie 4.0. Intelligent machines, components and systems for holistic product and process control

### 2.4.1 HD LASr

As part of SMS group‘s strategy to promote the digitization in the steel industry we develop different approaches for digital maintenance, one supporting solution thyssenkrupp is relying on is the aligning assistant HD LASr.

Precise aligning of the strand guide is an important key for producing high-quality slabs.

The obvious solution is the most precise measuring of aligning-relevant objects with today’s best available measuring tool, the lasertracker.

SMS group developed a measuring concept enabling maintenance operators to apply easily the lasertracker: the aligning assistant HD LASr. Its decisive component is the customized software excelling in its practicality – the operator is guided by the software and realizes intuitively the measuring process in short time.

The need for many different types of templates with indefinite actual condition and relatively low accuracy for aligning are things of the past.

HD LASr registers the measuring information automatically and issues digitalized measuring protocols. The measuring data and the resulting strand guide alignment will be evaluated on a much higher level. Slab quality issues can be analyzed and potentially retraced to their reason. Predictions on the measured components’ life time are simplified. Relevant change or spare parts can be ordered just-in-time thus decreasing the stock-keeping. The digital integration of maintenance data makes it possible.

The central feature of HD LASr is the comparison of the laser-measured actual position of the measuring object with its nominal position and this is realized in three dimensions. The operator gets immediately the information on the necessary mechanical measures (shim value) for aligning the object to the optimum position. Any aligning relevant point, line or area whether in horizontal, vertical or sloped orientation will be registered. The high quality of measurement with HD LASr, the zero-fault-strategy with redundant measuring, the precise and reliable logging and the authoritative evaluation of the measured objects generating automatically a measuring protocol just cannot be compared with other systems.


**Figure 10.** Few measuring components including the multi-device-able software

### 2.4.2 Process control system

A homogeneous and integrated automation scenery and innovative operation concept is installed in the new process control system. With high grade of automation the new central control pulpit, caster control unit and local operator panels are all based on PCS7 with integrated safety functions. All sub-systems also from sub-suppliers are fully integrated. Interfaces enable the communication also with existing thyssenkrupp systems.

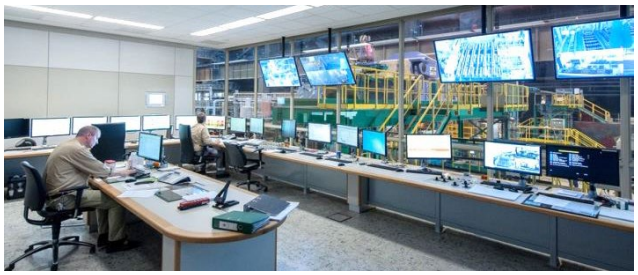

**Figure 11.** Central control pulpit

### 2.5 All assignments realized

For training the thyssenkrupp operation and maintenance personal and minimizing the commissioning period we started an integration test well in advance before the commissioning start, involving thyssenkrupp intensively. thyssenkrupp was able to get familiar with the automation concept and its software design right from the start.

The proven SMS group integration test comprised the implementation of the mechanical construction drawings and the animation of the equipment. A simulation program monitored in real-time movements (kinematic) incl. mass inertia (dynamic) and material tracking (animated strand) including all IOs. The application software including control and functional operations has been tested by 100 per cent.
The erection could be realized implementing all new equipment in pre-assembled and tested condition thus minimizing the installation time. Equipment as new

buildings for electrics and automation, water pumps or compressors, the new emergency water tank and new drive motors of energy efficiency class 2 IE2 could even be installed before the main shutdown.
The tested automation systems equipped with a user-friendly HMI containing advanced analysis options, interlocking and bypass functions were installed in the PLC-rooms on site and immediately started up. When new installed equipment or devices have then been installed in the field, they were directly connected to the automation system and the commissioning was started in the particular area.
Only a few casting simulations with the new equipment and with thyssenkrupp production personnel were sufficient to prepare the first cast.
To ensure a steep start up curve, the highly sophisticated automation system was set up, tested and pre-optimized by realistic simulations prior to commissioning.

## 3 CONCLUSION

For many years SMS group modernizes various continuous casters and equips them with future-oriented technology. The scope ranges from small optimizations right up to far-reaching changes of the continuous casters as particularly the recent modernization of thyssenkrupp caster no. 1 in Duisburg Beeckerwerth (Figure 12).
The concrete measures have been defined according to the thyssenkrupp's objectives: the improvement of the slab quality, the introduction of value-add products, the increase of plant yield and plant capacity, the reduction of operational costs and the promotion of digitization of the steel plant.

**Figure 12.** Running slab production at thyssenkrupp

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