Metallurgical, Operational and Economic Benefits of SMART®/ASTC Technology in Continuous Casting (1)

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ABSTRACT

The development and implementation of automatic strand taper control (ASTC) used in combination with SMART® segment technology leads to considerable improvements in the internal strand quality of continuously cast steel through the reduction of center segregation. The roll-gap taper is remotely adjusted and with the application of dynamic soft reduction the special demands for transient casting conditions can also met.

As of January 2004 sixteen slab casters and one bloom caster are operating with SMART®/ASTC technology worldwide. Additional orders have been placed for the installation of this technology in numerous other casters. SMART®/ASTC technology is ideal for the casting of all steel grades in both slab and bloom casters—the latter exemplified by the start-up of the six-strand bloom caster at PANZHIHUA Iron & Steel Group in China in September 2003.

Key words: continuous casting, SMART® segment, ASTC - automatic strand taper control

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INTRODUCTION

Optimization of the center quality of continuously cast products is an important target in continuous casting. One method of improving center quality is to compensate for thermal contraction by reducing the casting thickness near the final solidification point. This process is referred to as soft reduction.

VAI has developed a soft-reduction technology termed automatic strand taper control (**ASTC**) which is used in combination with hydraulically adjustable **SMART®** segments. The technology enables the dynamic adjustment of the desired roll-gap profile based on the position of strand solidification which is calculated online. SMART®/ASTC technology is capable of optimizing the internal strand quality at any casting speed as well as under transient (non-steady state) casting conditions.

The **SMART®/ASTC** technology package developed by VAI rapidly and reliably alters the roll-gap settings to achieve different casting thicknesses without any manual work required. In the following, aspects of metallurgy, segment design, set-point calculations, automation, visualization, operational results and project status are discussed.

METALLURGICAL BACKGROUND

Center Segregation

Because steel does not solidify at a fixed temperature but over a temperature interval, there is a mushy region in which the steel is neither completely liquid nor completely solid (**Figure 1**). In this mushy region segregation occurs depending on various parameters, such as the content of the alloying elements, the solidification rate and the superheat temperature. Near the final solidification point the temperature gradient in the casting direction at the center of the strand is much larger than the temperature gradient at the slab surface [1]. This causes the residual melt to flow towards the end of the internal strand crater where it solidifies with elevated concentration of alloying elements such as C, Mn, P or S. This is referred to as center segregation.

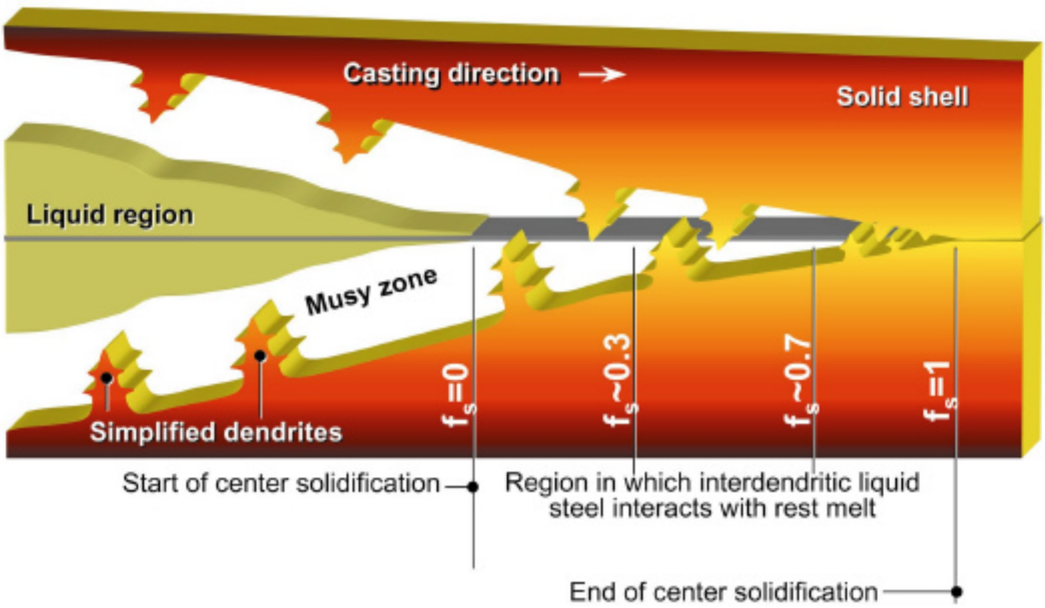


Figure 1: Dendrite Growth in the Strand "Mushy Zone" During Steel Solidification

One method of reducing center segregation is by means of soft-reduction whereby the strand thickness towards the end of the internal strand crater is mechanically reduced through an adjustment of the roll-gap taper. The most important influential parameters which determine the zone of soft reduction are strand format, casting speed, steel chemistry and superheat and strand secondary cooling. Because casting parameters typically vary during the casting procedure, a dynamic roll-gap adjustment system offers significant advantages over the simple mechanical adjustment of the roll gap.[10]

A unique solution developed by VAI features hydraulically adjustable SMART® segments [2] used in combination with a process control package, referred to **A**utomatic **S**trand **T**aper **C**ontrol (**ASTC**), for the online calculation of the optimum roll-gap taper.

SMART® SEGMENT DESIGN

Only static soft reduction has been only previously applied on a limited scale because of the highly demanding boundary conditions that must be met for casting operations. On the basis of advanced numerical simulations in combination with extensive testing, VAI has developed a technological package which enables the dynamic positioning of the inner frame of the segment[11]. The system is not only extremely reliable, but well suited to the harsh conditions of a steel works. The main features of the SMART® dynamic roll-gap adjustment segment are as follows (**Figure 2**):

- Robust and fail-safe hydraulic system (with position locking of the inner frame)
- Achievement of ± 0.1 mm positioning accuracy using standard valves
- Simple and wear-free electronic-stroke sensors integrated within the cylinders

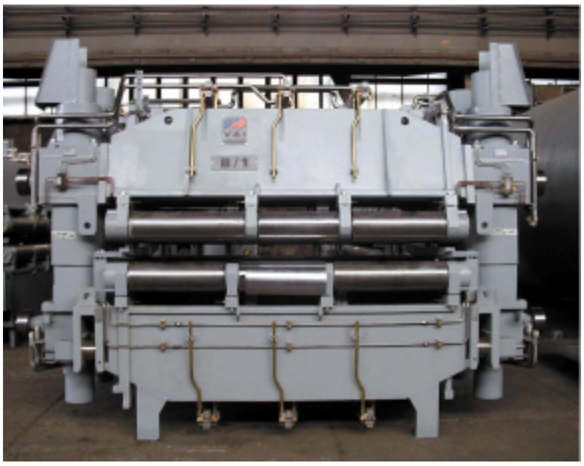


Fig. 2: The VAI SMART® Segment

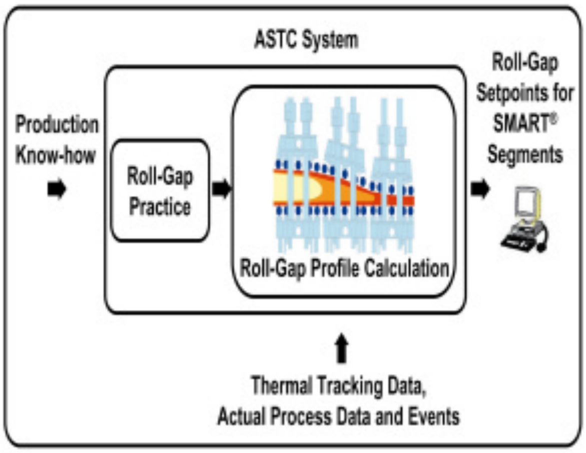


Fig. 3: Overview of the ASTC System

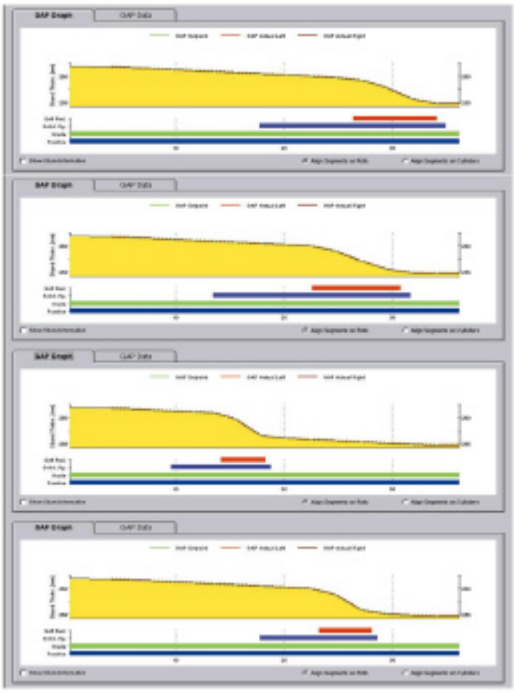
CALCULATION OF ROLL-GAP SETPOINTS

Calculation of the setpoints for the roll-gap settings with ASTC is based on a thermal-tracking model and a defined roll-gap practice (**Figure 3**).

The **thermal-tracking model** calculates the temperature field in the strand on the basis of the actual casting conditions. This thermal tracking system is also a part of the highly successful **DYNACS®** cooling system of VAI, which is installed in over 50 slab casters worldwide [3] [4] [7] [8] [9].

The steel-grade-dependent **roll-gap practices** incorporate metallurgical know-how which can be expanded upon.

Dynamic roll-gap practices are applied to achieve the foreseen thickness reduction within a predefined zone near the point of final solidification (dynamic soft reduction—**Figure 4**). The gap profile in the soft reduction area is determined by the metallurgist in accordance with the demands of the respective steel grades. The start and end point of soft reduction is a function of the solid fraction content ($0 \leq f_s \leq 1$) of the strand. As a consequence of this definition, the soft reduction area is dynamically readjusted at the correct position even during transient casting conditions.



Casting speed 1.3 m/min
Grade A; thickness 254 mm;
at steady-state casting conditions

Casting speed change from 1.3 to 0.7 m/min
Grade A; thickness 254 mm;
after 7 min transient casting conditions

Casting speed 0.7 m/min
Grade A; thickness 254 mm;
after 20 min steady-state casting conditions

Casting speed change from 0.7 to 1.3 m/min
Grade A; thickness 254 mm;
after 14 min transient casting conditions

Figure 4: Dynamic Roll-Gap Profile During Transient Casting Conditions

Static roll-gap practices are the basis for the adjustment of a fixed gap profile in the slab caster (**Figure 5**). Determination of the taper setpoints is a function of the expected steel grade in addition to the casting speed. At the start of casting a static gap practice is always applied to guarantee safe passage of the dummy bar through the machine. During tail-out of the strand a static gap practice is again employed to assure safe passage of the "cold" end of the strand through the caster. Static gap practices have to be applied whenever the required operating parameters are not available from the Level 2 automation system, prohibiting the correct application of the thermal tracking model.

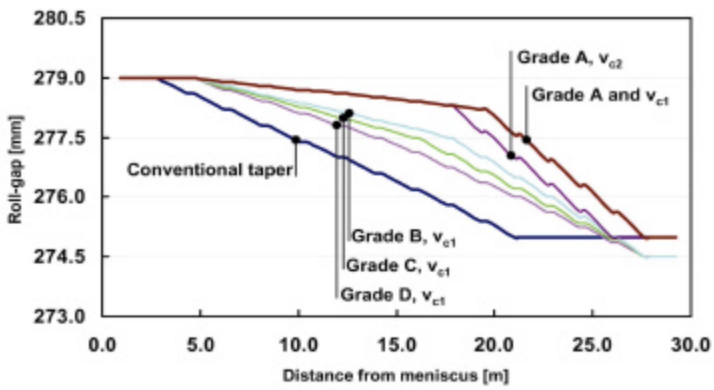
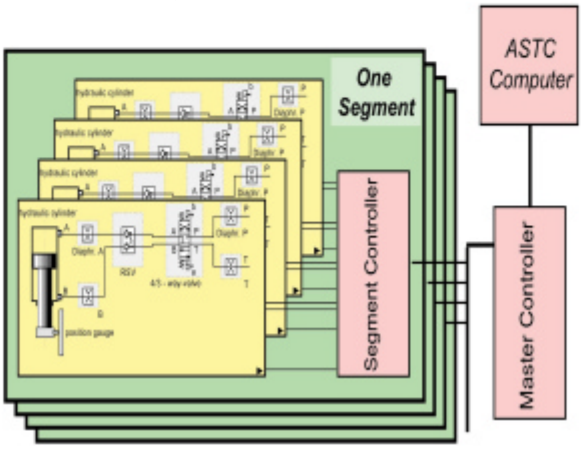


Figure 5: Static Roll-Gap Profiles for Different Casting Speeds and Steel Grades

AUTOMATION SYSTEM

The SMART®/ASTC system is designed as a hierarchical process-control system[13], as shown in **Figure 6**.



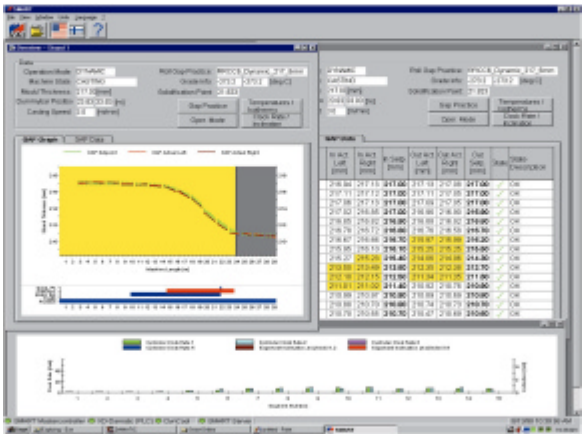


Fig. 6: Levels of Automation

Fig. 7: Operator Visualization Screen

Segment Controller

SMART® segments are designed with four hydraulic cylinders—one on each segment corner—for position adjustments together with a segment controller for precise position control. A set of rules is included in the controller software which assures overall machine protection under all operating conditions. Furthermore, the segment controller periodically reports all current segment data, such as the actual positions and the state of each cylinder, to the strand master controller.

Prior to delivery, the full functionality of each segment can be tested in the workshop to ensure rapid and problem-free installation and start-up.

Master Controller

The master controller is an abstract interface for all segment controllers. The task of the interface is to encapsulate the segment controller code from customer-specific interfaces. Whereas the code of the segment controller remains identical for all installations, only the code of the master controller has to be adapted to correspond to the changes in communication topology from one project to the next.

Process Computer

The process computer is the general interface to the caster automation system. On the basis of the data supplied from either Level 1 or 2 caster automation as well as from steel-grade-dependent roll-gap practices—both static and dynamic—the roll-gap profiles are calculated and made available to the Master Controller.

Safety Aspects in the ASTC Process Model

As cited above, the segment controller maintains a setpoint for each cylinder. If the segment controller does not receive valid setpoints, it maintains the last given setpoint until a new setpoint is received.

VISUALIZATION

The VAI client server visualizes all essential process parameters such as roll-gap practice, casting speed, casting thickness and the soft reduction zone. The setpoints and the actual values of the roll-gap profile are displayed both graphically and in text form (**Figure 7**). Deviations exceeding the positioning tolerance and thus causing a position correction movement are marked. A text description is also provided for each segment.

The integrated cylinder leakage detection is an important part of preventive maintenance. Whenever a cylinder moves beyond its foreseen positioning range, it is correctly repositioned by means of the segment controller through the opening of the respective on/off valve. Cylinder leakage is assumed if the number of control actions on one cylinder is excessively high.

With the visualization display the operator is also provided with the necessary support to correctly respond to critical situations. An emergency "to do" list with the recommended actions is displayed at the push of a button.

OPERATIONAL RESULTS

Experience with SMART®/ASTC technology in combination with static and dynamic roll-gap control practices has shown that this system significantly improves the inner strand quality with respect to center segregation.

The results of applying SMART®/ASTC technology on the segregation area ratios (S.A.R.) at the strand center were investigated under different casting conditions. Soft reduction was applied at different solid-fraction values for each heat as indicated in **Figure 8**. As can be inferred from the results, when the solid fraction was either too low (roll-gap practice 1) or too high (roll-gap practice 4), the application of soft reduction did not result in the desired beneficial effects. However, the S.A.R. was close to zero when the roll-gap profile parameters were correctly selected (roll-gap practices 2 and 3).

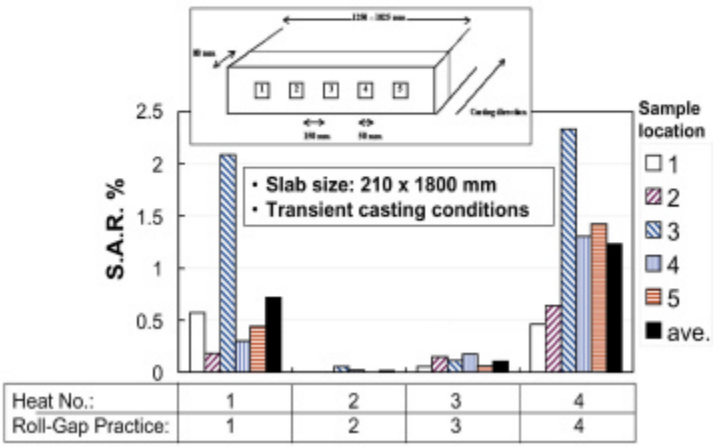


Figure 8: Segregation Area Ratios in Heavy Plates with Different Roll-Gap Practices

Figure 9 illustrates the effectiveness of soft-reduction technology for improved internal slab quality. A comparison was made between two slabs simultaneously cast on a 2-strand slab caster with identical casting speeds and cooling patterns, however, with and without soft reduction. On the left-hand side of the figure a sulfur print of the slab cast without tapering is shown. Although the quality result is acceptable, a slight center segregation can be seen. In comparison to this, a sample from a tapered strand is shown on the right-hand side of Figure 9. The notable quality improvement achieved with soft reduction is clearly seen.

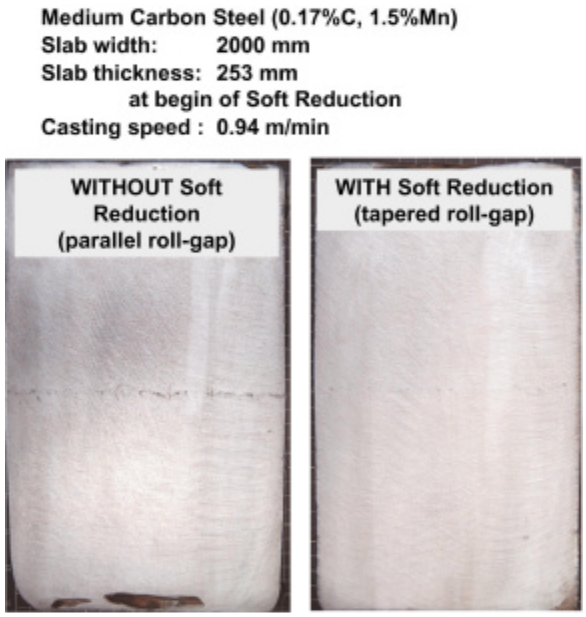


Fig. 9: Comparison of Internal Quality with and without Soft Reduction

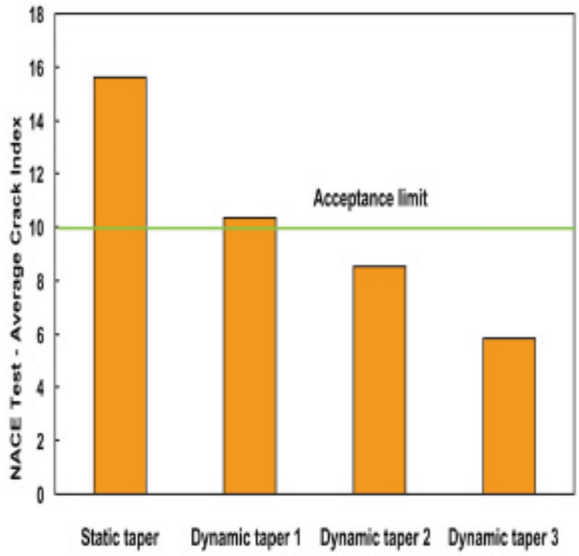


Fig 10:NACE Test Results Comparison

Figure 10 demonstrates NACE test results of HIC-resistant (**h**ydrogen-**i**nduced **c**racking) steel grades before and after application of soft reduction using SMART®/ASTC technology. In three successive phases a 50% improvement in the crack index could be achieved.

CURRENT STATUS

To date (May 2003) SMART®/ASTC technology has been installed in nine slab casters. Three were for slab-caster upgrading projects (ILVA/Italy, POSCO/Korea, voestalpine Stahl/Austria) and four were for new casters (Rautaruukki/Finland, Bethlehem Steel/USA, WUHAN I&S/China, Jinan I&S/China, Meishan/China and AvestaPolarit/Finland).

The wide range of application possibilities with SMART®/ASTC is underlined by the following examples:

The focus of **Rautaruukki** [5] [6] [12] was to enable rapid thickness changes in accordance with their just-in-time supply philosophy.

The focus at **Bethlehem Steel** [14] was to ensure excellent center quality with consideration to the fact that a large percentage of their cast slabs are longitudinally slit.

The focus at **ILVA**, **POSCO** and **voest**alpine was to increase the yield when producing HIC-resistant steel plates.

AvestaPolarit is the world's first producer of stainless steel to benefit from the application of SMART®/ASTC technology.

WUHAN I&S was the first steel producer in the world which applied dynamic soft reduction right from the first cast!

WUHAN Steelmaking Plant No. 3 (two-strand wide-slab caster), China

POSCO Gwangyang Works CCP 1-3, Korea (two-strand slab caster)

PANZHIHUA Iron & Steel Group (6-strand bloom caster), China

FUTURE SMART®/ASTC START-UPS

As a result of the excellent quality, reliability and economical results achieved with SMART®/ASTC, this technology can today be considered as state-of-the-art. The following start-ups are scheduled in the near future:

- NANJING Iron & Steel Works (wide-slab, medium-thick slab caster) China
- ZHANGJIAGANG Hongchang Plate, China (2x two-strand slab casters)
- Nishnij Tagil, Russia (single/twin slab caster)
- ANGANG I&S, China (2 two-strand medium-thickness slab casters)
- WUHAN Steelmaking Plant No. 2 CC 1 & CC 2
- POSCO Gwangyang Works CCP 2-4, Korea (two-strand slab caster)
- OA AMK, Alchevsk, Ukraine
- Iljitsch Met. Combine, Mariupol, Ukraine
- Hunan Valin ISCO, Xiangtan, P.R. China

SUMMARY OF BENEFITS

The benefits **of SMART®/ASTC technology** can be summarized as follows:

- **Improved inner quality** of the strand through a major reduction in center segregation

- **Reduction** in the number of **NACE test rejections of HIC-sensitive** steel grades

- **Minimized centerline cracking** of phosphor and boron steel grades, particularly **important with slit slabs**

- **Flexible adjustment** of any slab thickness and roll-gap profile within the strand guidance design range

- **Fast and remote slab-thickness changes** leading to

  - **Increased productivity**

  - **Increased caster availability**

  - **Higher product yields**