Advanced continuous casting technology

Near-net-shape beam blank casting, soft reduction of blooms and use of vertical casting instead of bow casting for high alloy steels are three examples of Siemens VAI design and technology being used to advantage to improve output, improve quality and reduce costs in the production of high grade products for special applications. Technological features and plant data from three plants in China are presented.

Authors: Olaf Schwarze, Franz Wimmer, Gerald Hrazdera, Franz Leingruber, Hans-Peter Kogler and Markus Burgholzer
Siemens VAI Metals Technologies

NEAR-NET-SHAPE BEAM BLANK CASTING

A beam blank continuous casting machine (CCM) has many similarities in technology and equipment to traditional continuous casters. However, because the cross-section of a beam blank is irregular, the cooling intensity and shell growth are not equal throughout the profile and the shrinkage and the strength of the solidified shell are not homogenous. These factors mean that surface and inner quality problems can be problematic, and thus the production difficulty of the beam blank CCM is greater than on other types of caster. The design of a beam blank CCM therefore requires some specific technological features in order to address these issues. These are illustrated by reference to the caster at Laiwu Steel Group, China.

Laiwu beam blank caster

Prior to 2005, Laiwu Steel Group was a producer of small and medium size H-beams. This restricted size range was considered to be insufficiently competitive so Siemens VAI was contracted to design and build a high capacity, large size beam blank caster which was a key component of increasing product output and size capability. This was commissioned in 2005 (see Figure 1).

In order to simplify the rolling procedure and to optimise production benefits, three near-net-shape formats were adopted. These are: BB1: 1,024 x 390 x 90 mm, BB2: 750 x 370 x 90 mm and BB3: 555 x 440 x 90 mm. (90 mm is the web thickness). At the time of implementation, 1024 x 390 x 90 mm was the largest near-net-shape beam blank in the world.

Key features of the caster are shown below:

Caster type 3-strand curved machine of 12m radius and with continuous straightening and ladle turret.

Tundish T-shaped with an impact zone and special dam system to aid metal flow. There are two metering nozzles.

Fig 1 Beam blanks at Laiwu
per strand. One tundish is used for the three sizes. Casting speed is 0.7-1.5m/min.

**Oscillation type** Dynaflex hydraulic oscillator, with variable stroke 0-12mm (± 6mm) and variable frequency range 40-300/min. Sinusoidal or non-sinusoidal operation are available.

**Mould** Copper plate type, length 800mm, CuAg, coated Cr/FeNi – 0.1mm Optimised tapers in different areas of the mould.

**Secondary cooling system** Secondary cooling is divided into five zones. Zone 1 uses water nozzles; zones 2 to 5 air-mist nozzles. The nozzles are specially aligned and designed for easy exchange and there is a water blow-off device on the inner side of segment 2 to remove the secondary cooling water from the inner bow of the beam blank.

**Casting operation** Open stream, out of tundish, then into a funnel through the mould powder into the mould. Dummy bar uses a prefabricated packing system. There is an automatic start mode and emergency swivelling chute to divert steel away in the case of an emergency.

**Plant performance** Commissioning of the caster was extremely smooth such that in August 2005, only five days after start-up, the design’s daily production capability was reached, followed by the design’s monthly production capability in November 2005. From January to November 2007, the average monthly production output was more than 100,000t (see Figure 2), with an average qualification rate of more than 99.6% (see Figure 3), a break-out rate of less than 0.02% and a defect rate of less than 0.4%. In 2007 production reached 2.42Mt and Laiwu became the largest H-beam producer in China. Typical steel grades cast are low carbon, medium carbon and low alloyed steel grades. Even peritectic steel grades are cast without problems. Figure 4 shows cast products ready for despatch.

**DYNAGAP SOFT REDUCTION**

Because steel solidifies over a temperature range rather than at a specific temperature, there is a mushy region between the liquid core and the solid shell in which the steel is neither completely liquid nor completely solid (see Figure 5). In this region segregation occurs due to the enrichment of alloying elements in the remaining liquid between the growing dendrites (interdendritic zone).

Centre macro segregation is then generated by interdendritic fluid flow of this highly segregated liquid towards the area of final solidification, where the temperature gradient is much less than at the bloom surface. In other words, the lower cooling rate in the center area of the strand results in increased feeding flow, which
in turn leads to increased macro segregation compared to the strand shell.

To prevent excessive centre segregation formation during final solidification, the area of equiaxed solidification has to be extended. This can be achieved by low superheat casting, electromagnetic stirring or by adding external nuclei. As a consequence, the segregation and shrinkage porosity is more evenly distributed and centre bridging is prevented.

A further method to reduce the centre segregation is to mechanically reduce the strand thickness. The chemically enriched liquid is then squeezed in the opposite direction to the casting direction and the thermal shrinkage is compensated by external deformation. The process takes place by applying small thickness reductions in the area where the liquid core is close to the final point of solidification. The most relevant parameters which determine the zone of soft reduction are:

- Strand format
- Casting speed
- Steel analysis
- Superheat
- Secondary cooling

Figure 6 shows how much one individual parameter – C content – can influence the solidification point. All other casting parameters are kept constant. By choosing the right soft reduction parameters, not only is centre segregation reduced, but so is the formation of shrinkage porosity along the cast product centre line. With static taper, static pinch roll drive adjustment and a static soft reduction location, the operating window becomes very small to achieve good centre segregation and centre porosity results. The challenge, however, is to apply soft reduction in the optimum position (see Figure 7). In reality, the casting parameters such as steel composition, superheat and casting speed change during sequence casting, hence the solidification range also alters.

**Bloom DynaGap soft reduction technology** To address the above challenges, a control system has to continually adjust the soft reduction position and reduction amount by considering process parameters like steel analysis, section size, history of casting speed, secondary cooling water and changes in the superheat of the steel. Siemens VAI has developed a fully automated DynaGap roll gap taper adjustment system in connection with a 3D thermal tracking system which calculates the thermal profile of the strand online.

The bloom thickness reduction for each pinch roll and the calculated temperatures and isotherms in the casting direction can be followed online. If all pinch roll stands are equipped with the necessary hardware and software...
for force measurement, the trends of the reduction amounts and the applied soft reduction forces for each pinch roll stand can be displayed during the process (see Figure 8).

Each strand has a so-called DynaGap strand controller, which controls all pinch rolls using one of the following strategies:

- Strand position thickness based on the actual measured roller gap and the thickness set point given by the DynaGap model
- Screw down with a certain predefined force

The first pinch roll before the soft reduction range is used as a measuring roll for the strand thickness. The DynaGap software deals with position control in the soft reduction range. Outside of this range, all pinch rolls are clamped with a fixed pre-defined force, which is called screw down control. This is the normal mode of operation as used at most bloom casters. Once the strand thickness is known, a reduction function relative to this thickness is applied to the strand until the end of the soft reduction range.

To understand reduction function, consider the scenario where the strand thickness before the soft reduction area is 205mm and the soft reduction area starts at 13.4m and is 6.5m long. If the metallurgist wants to reduce the thickness in the soft reduction range by 5mm, this is done by defining linear reduction functions one by one in an offline maintenance system. This function is the heart of the DynaGap practice, which is applied depending on the steel grade.
The technology also includes an online thermal tracking system for the calculation of solid fraction, taking into consideration the actual casting parameters.

**Caster retrofit at WUHAN Iron & Steel Co** The existing Siemens VAI 5-strand bloom caster at Wuhan (see Table 1) was upgraded with this technology in 2004.

To implement soft reduction it was necessary to add two new withdrawal stands without drives, and to modify all four existing driven pinch roll stands, which comprised the relocation of the first three existing stands (see Figure 9). The chosen solution not only had the advantage of the highest production flexibility, but could also be applied within a very short time schedule. With these six pinch roll stands, soft reduction is performed in the range between 13.4m and 19.9m from the meniscus.

Due to the fact that an excessive deformation of the solid shell can create internal cracks, the thickness reduction has to be done in small steps. Therefore, a staggered arrangement of the reduction stands is required and must also allow for variations of the casting speed. As the optimum location for soft reduction has to coincide with the straightening process, the pinch roll stands or pinch roll segments are adapted to provide the necessary reduction forces and positioning control.

After successful modification of the caster, optimisation trials were carried out on high carbon steel grades (cord and bearing type steel) for 200 x 200mm blooms. Test samples were taken to investigate the influence of various parameters on internal quality and their reproducibility.
The casting of a broad range of high alloy steels for critical applications is extremely difficult in a conventional bow-type caster. This is because these types of materials are exceptionally rigid and sensitive to cracking, thus they cannot easily be bent from the vertical to the horizontal direction in the bending and straightening zones of a caster. A vertical caster, on the other hand, does not need to bend or straighten the cast product so it does not suffer from these problems. A disadvantage is the extra height needed when compared to a bow-type caster.

**Baosteel Shanghai caster** In order to ensure fulfillment of strict quality demands and to continuously cast new steel grades, Baosteel decided to install a new single-strand vertical Siemens VAI-designed slab caster with a nominal casting capacity of 270,000t/y (see Figure 10). Baosteel is now able to continuously cast a broad and highly specialised product mix comprising high- and ultra-high-alloyed carbon, special and stainless steels. The key plant details are shown in Table 2 and Figure 11.

For this unique continuous casting machine, the following sophisticated technological packages and special design features were required to assure reliable plant operations and highest slab quality:
- Butterfly ladle turret with independently liftable arms and ladle weighing
- Semi-gantry type tundish car with trough type tundish and SEN stopper rod system
- Smart Mold with Mold Expert system, LevCon mold level control and soft clamping
- DiaFace Mold Narrow Face for small friction and uniform heat removal in the mould
- DynaFlex hydraulic oscillator with online stroke, frequency and wave pattern adjustment such that both sinusoidal and non-sinusoidal oscillation can be achieved. The system avoids wear as well as generation of resonances at high frequencies without the requirement of lever arms or bushings.
- Segment 0 has been equipped with an electromagnetic stirrer for casting ferritic and silicon steel grades.
- All segments supplied are Smart Segments which, in combination with the DynaCap Soft Reduction® technology package and input data from the Dynacs secondary-cooling system, enable dynamic soft reduction to be carried out to minimise centreline segregation for highest internal strand quality.
- Considering the highest surface and internal quality demands of the critical steel grades produced at Baosteel, as well as improving casting flexibility, “dry casting” is practised in the lower strand section to prevent strand formation.
overcooling. This is made possible by employing internal peripherally cooled rollers of the so-called ‘revolver type’.

- DynaJet spray nozzles
- Rigid type dummy bar with bottom feeding system
- Dynacs dynamic secondary cooling model incl. centre/margin mode
- Torch cutting machine
- Level 1 and level 2 systems
- Segment exchange system
- Tilting roller table
- Withdrawal unit
- Hook cars

With this caster the company is able to cast almost every steel grade, which improves plant flexibility and is the ideal solution to serve certain niche markets.

**Machine safety concept** In a caster of 40m height it is essential that everything is secure to prevent a slab or machine parts from falling. Siemens VAI engineers developed a machine safety concept, including a machine protection program for all automatic routines, which are started when the strand, slab or dummy bar stops for longer than five minutes. Furthermore, a novel withdrawal unit was installed in addition to a completely new slab discharge system. During slab cutting, the slabs are clamped by a second withdrawal unit and transferred through the casting pit by a system of hook cars and tilting roller tables. Another part of the concept was the secondary cooling water deflection system which had to be implemented in order to fully remove water from the caster area and to keep the casting pit dry.

**Results** Because of changing mould flux properties during casting of high Al, low C steel grades, the sticking tendency of the strand shell increases. However, with Mold Expert, which provides online detection of strand shell sticker during casting, these extreme sticking-sensitive grades are castable without breakouts. Mold Expert provides additional information like friction forces, heat flux removal and thermal (temperature) condition of the mould, which increases the overview of process conditions.

In **Figure 12** a typical snapshot of the Mold Expert display shows the uniform temperature distribution and the very stable temperature and friction conditions during the casting of a high carbon steel grade. Red indicates high and yellow low temperature. **Figure 13** is a snapshot of a low magnetic steel grade with very high Al content. The temperature pattern is much less uniform, indicating the risk of poor strand lubrication.

Because of the need for low casting temperatures of certain steel grades, special care had to be taken in...
order to ensure the steel at the meniscus was not too cold. Fluid flow analyses was carried out to help design a suitable SEN, defining the parameters for immersion depth and SEN opening dimensions. This and the DynaFlex oscillator has a major influence on the surface quality. Figure 14 shows an example of the surface of a 310S austenitic stainless steel from the caster. There is a smooth surface with shallow oscillation marks and no depressions.

Due to the sophisticated Machine design and DynaGap Soft Reduction® technology the internal quality of the cast products is also very good and does not show any cracks and centre segregation.

CONCLUSIONS

Near-net-shape beam blank casting, soft reduction and vertical casting of special alloy grades are three examples of Siemens VAI design and technology being used to advantage to improve output and quality and to reduce costs. The economic benefits of beam blank casting are primarily in the rolling mill and include fewer crop ends, higher yield, lower energy consumption in the re-heating furnace and rolling deformation, fewer passes in the roughing stand, less maintenance and lower investment cost.

DynaGap Soft Reduction® technology improves internal quality (segregation, porosity) and is of value, particularly in the high quality bloom market.

The vertical caster concept enables casting of almost any steel grade, particularly those which cannot be cast on a bow-type machine. Restrictions in grade castability relate only to the availability of suitable casting powders for the low casting (liquidus) temperatures, other unique physical properties or compositions of certain special steel grades.

Olaf Schwarze, Franz Wimmer, Gerald Hrazdera, Franz Leingruber, Hans-Peter Kogler and Markus Burgholzer are with Siemens VAI Metals Technologies, Germany

CONTACT: rainer.schulze@siemens.com

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