Danieli QSP® – Quality Strip Production – at Nucor Steel Gallatin

*Nucor Steel Gallatin has contracted Danieli to upgrade its hot strip plant in Ghent, Kentucky, USA. The new plant configuration – from compact thin slab casting and rolling plant to ultra-modern QSP® (Quality Strip Production) – will allow the plant to improve thermomechanical rolling capabilities and increase product range. This will be the first time that a classical compact thin slab casting and rolling plant has been fully reconfigured into an ultra-modern QSP®.*

Authors: Mateo Bulfone, Christian Bilgen, Mike Knights, Mathias Knigge, Alessandro Stenico, Paula Da Costa and Luca Faralli

In order to extend the range of steel grades being produced, Nucor Steel Gallatin has contracted Danieli to upgrade its hot strip plant in Ghent, Kentucky, USA. The new plant configuration will allow the plant to improve thermomechanical rolling capabilities and so expand the production of advanced high strength steels (AHSS) grades, API line pipe grades and a number of other added-value grades. The current capabilities of the steel plant are mostly structural steel, micro-alloyed grades and thin line pipe grades. The current and proposed product range are shown in Figure 1, along with world market trend information.

This will be the first time that a classical compact thin slab casting and rolling plant has been fully reconfigured into an ultra-modern (Quality Strip Production) QSP®, and this investment is a major component of Nucor’s strategy for long-term profitable growth in flat-rolled products. Nucor and Danieli are determined to establish a new world-beating benchmark casting and rolling plant. It will also further strengthen the partnership between Nucor and Danieli in the flat product segment.

This capability expansion will increase the company’s presence in the Midwest market, specifically in the automotive, agriculture, heavy equipment and energy pipe and tube sectors.

**NUCOR STEEL GALLATIN**

Formerly known as the Gallatin Steel Company, the Ghent thin slab rolling plant has a capacity of 1.6M short t/yr of hot rolled coils having a thickness range of 1.4-12.7mm, widths up to 1,625mm and maximum coil weight of 35 short tons.

The plant operates a 185t twin shell DC EAF, a single LMF, a vertical caster producing slabs 65mm thick by 1,625mm wide, a 206m tunnel furnace, a six-stand tandem rolling mill with traditional laminar cooling and one down coiler. A schematic plant layout is shown in Figure 2a.

Like similar compact mini-mills, Gallatin was originally designed with the capability for doubling the annual capacity by means of a second steel melt shop and second vertical casting strand, with a tunnel furnace connected by a swivel ferry system to the in-line hot strip mill. The

### Fig 1 Evolution of Gallatin product mix and market trend

<table>
<thead>
<tr>
<th>Worldwide Market Trend Mix</th>
<th>Nucor Gallatin Product Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>More Advanced Grades</strong>&lt;br&gt; AHSS &amp; API X70/80</td>
<td>Future Current 50% 0%</td>
</tr>
<tr>
<td><strong>Advanced Grades</strong>&lt;br&gt; HSLA, MC, API X60</td>
<td>Future Current 39% 20%</td>
</tr>
<tr>
<td><strong>Commercial Grades</strong>&lt;br&gt; Low Carbon (e.g. DD11)</td>
<td>Future Current 61% 30%</td>
</tr>
</tbody>
</table>
the steel grades used for flat product applications, including the most demanding ones, such as AHSS, micro-alloyed and silicon steels for the most sophisticated applications, such as automotive and pipe manufacturing, including arctic applications.

Extending the range of final strip thicknesses to include ultra-thin gauges below 1.0mm.

The Danieli QSP® is a technology for thin slab casting and rolling plants designed according to the specific needs of the product mix and production capacity.

Soon after the first pioneering applications of thin slab casting and rolling technologies in the late 1980s, Danieli recognised the necessity to develop its own design concept to overcome the limitations of first generation plants in terms of quality and productivity. The two main areas in which Danieli introduced its innovative approach are the thin slab caster design and the configuration of the rolling mill.

Since its first pioneering applications in 1985, the vertical curved caster design has been adopted, with application of the patented dynamic soft reduction process. This design allows both superior slab quality and the maximum...
flexibility in selecting the slab thickness, according to both productivity and quality requested by the mill.

The separation of the roughing stands from the finishing stands and the use of a vertical curved caster with thicker slabs are the distinctive concepts of Danieli’s QSP®.

**QSP® PLANT CONFIGURATIONS**

**Standard design** Compared with other rolling mill configurations, where all rolling stands are arranged together and operate as a single finishing mill, Danieli identified several mill stand arrangements with separate roughing and finishing stands in order to apply advanced rolling practices typically adopted in conventional hot strip mills, such as thermomechanical rolling. The number of stands is selected according to targeted slab thickness and final coil gauge.

The QSP® layout is recommended for very demanding customers who want to produce the top range of commercial steel grades and is designed to work with thicker slabs (up to about 130mm) than other thin slab technologies. This makes it possible to increase production levels up to 3.0Mt/yr with only one casting strand, and to produce the highest range of grades using controlled metallurgical technology, with ‘two-step rolling’, thermomechanical rolling in particular. An example of the thermomechanical temperature profile through a QSP® line is shown in Figure 3.

The thicker slabs and the superior temperature control of the QSP® layout mean that eight rolling stands can be installed (2 RM + 6 FM) to produce a complete range of products, including light gauge strip down to 1.0mm thickness in coil-to-coil rolling mode. The investment required to implement the QSP® configuration is fully repaid by the possibility of mass producing products with high added value, which means that the plant is very profitable even with only one casting strand, without the need for future expansion.

The QSP® layout provides several advantages that lead to superior strip quality:

- Vertical edger attached to the roughing mill for accurate strip width control
- Separated roughing mill and finishing mill to increase the overall flexibility of the plant and the steel grade production range
- Transfer bar furnace (TBF) to homogenise transfer bar temperature, with consistent benefits in terms of rolling stability in the finishing mill
- Possibility of installing an intermediate cooling system before the TBF when API grades are produced
- Three high-pressure descalers positioned throughout the mill to ensure a superior quality strip surface
- Drum crop shear at FM entry for safe and stable threading during thin and ultra-thin gauge rolling

**Compact design** An alternative QSP® layout, but not proposed for Gallatin, is a compromise between investment cost and product range capability. This layout is shorter, due to the fact that there is no HTT and the RM and the FM are coupled. This configuration has most of the advantages of the QSP® (eg, three descaling points, vertical edger at RM, crop shear before FM, intermediate cooling and advanced run out table cooling system) in a shorter layout.

The product mix can cover most market requirements. The absence of two-step rolling only creates a limitation in special grades to be produced with true thermomechanical processes, such as thicker pipeline grades API X70-X80 for arctic applications. The nominal slab thickness in this configuration is usually 70mm (with the possibility of reaching 85mm).

The compact layout and the tandem rolling of RM and FM make the plant suitable for semi-endless rolling technology to produce ultra-light gauges below 1.0mm on seven stands (2 RM + 5 FM), with the addition of special machines such as a high-speed shear, threading device and high-speed coilers equipped with four wrapper rolls.
RE-ENGINEERING GALLATIN WITH QSP®

Steelmaking The new melt shop, to be built adjacent to the existing shop, will be the most modern in the USA, utilising the latest steelmaking technologies and plant automation systems. The plant will comprise a high performance 188t DC EAF, twin ladle furnaces and provision for a vacuum degasser in the future. It will make use of the most recent process management tools, and Industry 4.0 is a key aspect in terms of process control, either by applying adaptive process control for the EAF, where the new Q-MELT technology package will dynamically alter the EAF profiles for the best cost and operational practices, or by using mechatronic technologies that make it possible to conduct the majority of the operations remotely from the main pulpitis. Safety and productivity are key pillars that will guarantee the success of this project.

Casting The new caster represents the fifth generation of Danieli high-production slab casting machines. The vertical curved caster will be equipped with a complete suite of advanced technological packages, including Danieli’s latest design of multi-mode electromagnetic brake (MM-EMB) to help control the control of fluid dynamics within the mould, enabling high throughput of quality thin slabs (see Figure 4). Slabs will be 100-123mm thick and 900-1,870mm wide.

If in the future increased production capability is required, a new production unit will be installed with slabs delivered by a single-strand vertical curved caster having a total capacity of up to 3.0M short t/yr.

Reheating and rolling The slab will be delivered to the rolling mill by a new tunnel furnace via a swivel-type ferry system. The new layout shown in Figures 2b and 5 will allow for the installation of the new caster and first portion of the tunnel furnace and swivel system without affecting the mill’s production. Furthermore, two new roughing mills will be added to expand rolling capabilities.

The independent high speed roughing, intermediate transfer bar cooling and final finishing rolling introduces the ability to perform a thermomechanical rolling process, as is typical for conventional hot strip mills.

There will be complete replacement of the existing tunnel furnace, a new run-out table with advanced combined intensive and laminar cooling and two new down coilers with coil handling. The tunnel furnace and the transfer bar furnace installed between the roughing stands and finishing stands will be supplied by Danieli Centro Combustion.

The six-stand finishing mill will be retained but will be widened and upgraded with new interstand guides, loopers and a new bending and shifting system. This will allow rolling of strip up to 1,870mm wide (73.5in). To further enhance the performance of the finishing mill, the first three rolling stands will be reinforced to withstand higher rolling forces.

Two new powerful roughing stands and a vertical edger will be installed ahead of the finishing mill. With a total draft of 100mm, a powerful edger allows the full recrystallisation of the slab edges and makes it possible
to expand the capacity of the plant when producing narrow products.

**Installation** The project will be implemented over three carefully planned mill shutdowns after 9, 15 and 23 months. The strategy will take maximum advantage of the annual maintenance outages already planned by the plant. The layout is conceived in such a way that large parts of the new equipment can be installed and tested off-line. The new layout shown will allow for the installation of the new caster and first portion of the tunnel furnace and swivel system without affecting mill production.

During the final shutdown, the complete roughing mill group, pre-assembled off-line, will be moved in-line via a lift-shift system. The foundations of the mills will be prepared under the existing tunnel furnace without interfering with production.

**Control and automation** The complete process control from melting to finished hot rolled coils will be developed by Danieli Automation. The challenge is to optimise the operation between the existing and the new melt shop, while controlling the quality of the caster and QSP®. As part of the implementation strategy, the new system will shadow and parallel the current automation systems to allow seamless switchover to the new automation. The automation system will be designed for integrating the Industry 4.0 concept.

An additional aim is to create a highly reliable plant, targeting zero downtime because it will be based on the predictive concept for items such as maintenance events and order management. It will have Q LIVE real-time simulation to collect plant data and implement continuous improvement on models, able to dynamically simulate the material rolling forces and deformation with a response time of 0.1 sec. Moreover, quality levels will be visible in all phases of the process. Energy and utilities will be continuously adjusted to run at the lowest possible OpEx without compromising the output material quality and delivery time.

**QSP® PLANTS AND PRODUCTS**
The first production QSP® plant was installed at North Star BlueScope at Delta, Ohio (USA) in 1997, followed, in the same year, by Essar Steel Algoma (Canada). Other plants subsequently built include Ezz Flat Steel (Egypt), OMK (Russia), MMK (Turkey), NMDC (India), SGJT (China), Hoa Phat (Vietnam), Tangshan Iron & Steel (China) and Benxi Iron & Steel (China). Highlights of some of these plants are described below.

OMK Vyksa is a single-strand plant with a plant layout similar the one planned for Nucor Gallatin. It has a casting machine producing 90mm slabs, a 200m tunnel furnace, etc.
two powerful high-reduction stands, a transfer bar area with intermediate transfer bar cooling and HTT, and six finishing stands. Due to this flexible plant layout, OMK is able to cover a wide range of products from 1.0mm to 12.7mm thick of API grades for special applications in a width range of 800-1,800mm. Photos of the plant are shown in Figures 6 to 11 to illustrate what the Gallatin plant may look like.

In 2015 the product mix at OMK consisted of more than 50% API grades (up to API X80), with the balance being more general products. Surface quality was excellent with 98.6% prime coils. In 2017, 99% of the products were used in their own pipe shops to produce final pipes for the oil and gas market. Approximately 50% of output is to API or similar specifications. The mill is operated consistently above its rated capacity of 1.2Mt/yr.

An imminent installation of a new intensive cooling unit in the ROT cooling section will help OMK increase the mechanical properties of the produced steel grades (strength and impact toughness) and opens up the possibility of decreasing high-cost alloying elements, such as manganese, silicon and niobium.

Tangshan Iron & Steel in China was the first thin slab plant in the world to exceed 3.0Mt/yr after adopting the thin slab casting and rolling process in 2005.

In 1997 Essar Steel Algoma in Canada became the first thin slab casting and rolling plant in the world to produce peritectic steel grades, as well as HSLA grades like DSPC 700 with a yield strength exceeding 700MPa. These are used, for example, in the automotive sector, including all the major North American OEMs, primary suppliers to the auto industry, major service centres in the Midwest, as well as tier 1 manufacturers (among whom are the largest car manufacturers in North America).

In the electrical applications market, like silicon steel laminations for the transformer cores and the stators and rotors of motors, Benxi Iron & Steel (China) is a pioneer in the production of silicon steel using its thin slab casting technology using a casting speed of more than 4.0m/min to produce electrical steels with a Si content of up to 3.2%.

CONCLUDING REMARKS
The proposed installation at Nucor Gallatin of an ultra-modern Danieli QSP® will allow the plant to significantly improve thermomechanical rolling capabilities and increase product range. This will be the first time a classical compact thin slab casting and rolling plant has been fully reconfigured into a QSP®. MS

The authors are with Danieli SpA, Italy and Danieli Germany GmbH.

CONTACT: m.knigge@germany.danieli.com