The new benchmark heavy-plate mill project at Nucor Steel Brandenburg

The Danielli 175in wide (4,450mm) heavy plate/Steckel allows for flexible production of heavy and light plates, and jumbo coils. The consolidated global tendency toward green power generation investments, especially hydro power and wind power, offers new development opportunities for the steel plate market. Heavy plates of 3in to 14in (76.2mm to 355.8mm) final rolled thickness, are interesting products for plate mills to remain innovative and competitive.

The new 175in (4.450mm) Nucor Steel Brandenburg plate mill, based on an energy efficient EAF melt shop, combines in a single mill the advantages of plate/Steckel rolling for medium thin plates, as well as 60 short tons (54.4t) jumbo coiled plates with 36in (914mm) ingot rolling. Innovative Extream II cooling technology and EVO/6 levelling technology, supported with advanced process control and automation systems, with Industry 4.0 technologies, are the key tools for matching the required production flexibility, with superior plate quality and energy efficiency.

Authors: Enrico Zambon, Danielli Germany; Paulo da Costa and Lorenzo Lusina, Danielli & C. Officine Meccaniche S.p.A.; and Marco Mossutti Mossutti Danielli Automation

INTRODUCTION

Nucor Corporation is the largest steel producer in the USA with a total steel production of over 22.4 million short tons in 2020 [1]. Headquartered in Charlotte, North Carolina, Nucor is also North America’s largest recycler, with more than 20 million short tons of scrap melted in its electric furnaces every year. The company employs over 27,000 people at different plant and facilities primarily in North America [2].

As part of the strategy to establish itself as a steel plate market leader, on October 23rd, 2020, Nucor broke ground for the single largest investment in the history of the company. A $1.7bn plate mill will be located at the Buttermilk Falls Industrial Park, along the Ohio River in Brandenburg, Kentucky, the core of America’s largest plate consuming region (Figure 1). The 1.5 million square foot operation will provide Nucor with 1.2 million short tons of annual capacity for steel plate production [3] and allow it to produce 97% of the grades commercially available in US market [4].

Building on an established relationship (Figure 2), Nucor contracted Danielli for the new hot rolling plate mill, as well as the new steel melt shop. Danielli is also Nucor’s partner in the massive expansion project at its Gallatin mill in Ghent, Kentucky. The new plate mill will start up in 2022. There will be 400 new full-time jobs that will strengthen Nucor’s relationship with the local community.

PRODUCTION FLEXIBILITY IN HEAVY PLATES, LIGHT PLATES AND COILED PLATES

Designed with a 175in (4,450mm) width, the new Nucor Steel Brandenburg plate/Steckel mill will be among the widest plate mills in the world. The first challenge of the new rolling line is serving an extremely diversified market with over 500 different plate formats and grades required by leading consuming sectors, such as engineering construction and infrastructure (A36, Gr50, A514, 400F, 450F, 500F), power generation (A516 Gr70), and pipelines (X70-X100). The 2 reversible mill stand layout is equipped with coiling furnaces can deliver 3 hot rolled products, as shown in Table 1.

Heavy plates with thicknesses from 3in to 14in (76.2mm to 355.8mm) and hot rolled widths from 60in to 170in (1,524mm to 4,318mm) mainly obtained by rolling 12in ...
slabs and ingots with thickness from 17in to 36in (432mm to 914mm) and weight up to 50 short tons (45.4t).

**Light plates** with thickness from 3/16in to 3in (4.8mm to 76.2mm) and hot rolled widths from 60in to 170in (1,524mm to 4,318mm) obtained rolling continuous cast slabs with thicknesses from 8in to 12in (203mm to 305mm) and weights up to 80 short tons (72.5t).

**Coiled plates** with thicknesses from 3/16in to 1.25in (4.8mm to 31.8mm) and hot rolled widths from 60in to 125in (1,524mm to 3,175mm) and weights up to 60 short tons (54.4t) obtained from continuous cast slab. With 125in (3,175 mm) as the maximum hot rolled width and 60 short tons (54.4t) as the maximum weight, the new plate mill will produce the world’s largest hot coiled products.

**SUPERIOR QUALITY PLATES**
The second challenge for the new production line is ensuring premium plate quality for the entire diversified product mix, with special focus on:

**Mechanical properties** The plate mill is designed to meet the most demanding international standards in terms of mechanical properties. The main tool to hit the goal is represented by the customized rolling mill layout. The two horizontal mill stands plus the action of heavy vertical edger can apply an extremely powerful reduction on very thick semi-finished products, such as 8in to 12in (203mm to 305mm) for continuous cast slab and up to 36in (914mm) utilizing cast ingots, enabling a wider spectrum of reduction strategies and leading to an optimally refined microstructure.

**Weldability** Achievement of optimal mechanical properties, such as strength, elongation and toughness, will take place in conjunction with a controlled amount of C-equivalent content in the chemistry, to ensure good final product weldability. Automatic process control functions such as the Thermo-Mechanical Controlled
Process (TMCP), with an advanced plate cooling system (Exstream II) and intelligent modules, such as Q3-Intelligence, support microstructure engineering and are the key technological tools that will be used.

**Geometrical precision** Technological solutions, such as Hydraulic Actuating Gap Control (HAGC) with profile and flatness set up and adaptation models are implemented in the Level 2 automation system. EVO 6, multi-cassette, plate levelling technology will be provided for plates with superior flatness, within 3/4 of ASTM standards.

**Surface condition** A three-point, high pressure, water descaling system, designed with a maximum impact factor of over 2900lb/in² (20.0N/mm²) is incorporated as a tool to control as-rolled plate surface condition. This is particularly important for post-processes such as normalization, quench & tempering, corrosion protection coatings and painting.

### REAL THERMO-MECHANICAL CONTROL PROCESS (TMCP)

The application of a TMCP is mandatory for high quality, engineering construction grades, as well as for all grades undergoing heat treatment process. During the engineering stage specific attention was paid to tools for boosting the beneficial effect of TMCP.

### Layout (Figure 3)

Two, separate, reversing mills, stand in the configuration of a Reversible Rougher Stand (RRS) and a Heavy Vertical Edger (HVE), positioned 360ft (110m) away from a Reversible Finishing Steckel Stand (RFSS). This guarantees contemporaneous operations between the two machines and multi-piece management.

### Different Work Roll Dimension

The 2-stand layout permits selection of a different work roll diameter for the two horizontal stands. The RRS has a 44in (1,120mm) work roll diameter to support a heavy draft and reductions during the roughing stage, while the RFSS with a 38.6in (980mm) diameter, optimizes final profile and flatness control.

### Thermo-Mechanical Controlled Process Management and Multi-Piece Rolling Management (Figure 4)

The availability of automatic Level-2 functions for the TMCP as well as the four piece simultaneous management, combines process quality benefits with an optimized production rate.

### DANIELI EXSTREAM II ADVANCED COOLING CONCEPT (FIGURE 5)

The 8m long Direct Quenching (DQ) section works with pressurized water provided by booster pumps. It consists of four zones, divided by hydraulic activated pinch rolls. Each
zone is equipped with two top-cooling headers and two bottom-cooling headers, as well as proportional valves, individually controlled by the Level 2 cooling model. The maximum operating water flow of the whole DQ system is over 38,000gpm (8,705m³/h) at a pressure of 5bar. The headers are equipped with flat fan nozzles configured to optimize the water distribution on the material surface.

Downstream of the DQ system, a laminar Accelerated Controlled Cooling (ACC) system is installed over a length of 80ft (24.32m). Sixteen cooling units, each one consisting of one U-tube top header and two spraying bottom headers, provide a total flow rate of over 50,000gpm (1,148³/h). The flow of each unit is regulated by proportional valves (one top, one every two bottom) for optimal cooling control by the Level 2 automation system. The combination of DQ+ACC offers high flexibility in the definition of the cooling strategies for both strips and plates, enabling production of a wide range of steel grades [5].

**DANIELI EVO/6 HOT PLATE LEVELER FOR ASTM STANDARDS FLATNESS**

Levelling is a mechanical process consisting of a series of bending cycles applied to the material, mainly to stretch it over its plastic limit, eliminating undesired material waves, relaxing stresses and mechanical tensions introduced by upstream operations, such as rolling and cooling processes [6]. When the required product mix is sufficiently wide in terms of dimensions and grades to be processed with one levelling pass, a single cassette geometry becomes insufficient for the overall production [6]. Considering the mix of problematic thin formats such as 3/16in (4.7mm), as well as heavy gauges, Danieli has introduced the EVO/6 consolidated levelling technology, with specific reference to the utilization of a multi-cassette design. The machine starts up with an 11-roller cassette, specifically indicated for thin-gauge production, and can be upgraded easily in future with a second 9-roller cassette for medium-thick products of up to 4in (100mm) in thickness. The target flatness level is within 1/4 ASTM standards.

**14.0-READY, DANIELI AUTOMATION SYSTEM**

The contract scope includes Danieli advanced Process Control and Automation systems with Industry 4.0 technologies, as well as the main and auxiliary electrical equipment. The Level 2 process control systems of the melt shop and the plate/Steckel mill area are based on virtualized client and server configurations. They feature the latest Danieli models, proven in the field for automatic setup and developed to achieve the best quality liquid steel, plate and coil products. This includes both short-term and long-term self-tuning technology. Each phase of the process, from scrap melting, through slab and ingot rolling, to coil handling, or daughter plate piling, is controlled and continuously monitored to guarantee the overall production cycle.

A key feature of the Level 2 process control included in the mill package, is Thermo-Mechanical Rolling Management, for plate quality enhancement. This works in connection with Multi-Piece Rolling Management, a function that permits crucial optimization of the production rate, especially during thermomechanical rolling campaigns. The Q3 Intelligence module provides real-time plant and area Key Plant Indicators (KPIs) and dashboards, as well as advanced reporting and business analytic functionalities.

A very large amount of raw data is continuously acquired from a wide range of heterogeneous sources in the mill, such as intelligent sensors and instrumentation, process data loggers and automation systems of the different areas. These data are synchronized, stored in a centralized repository and transformed into useful information and knowledge, for user-friendly, in depth analysis and process optimization. In addition, Danieli Q3 Intelligence provides the platform for further Industry 4.0 technologies, such as machine learning based predictive tools.

The Danielli Condition Monitoring System monitors the health of the main equipment with smart sensors. Thanks to its specific technology it is even able to detect micro-defects and early signs of component deterioration. Data are updated in real time, meaning that it is possible to identify problems quickly, improve equipment reliability and reduce maintenance costs.

The Level 1 equipment control system features a user friendly operator interface, automatic control of regulation loops and operating sequences, to minimize the manual activities of operators. The equipment control platform, is based on the high performance Danieli HiPAC system for time critical technological control functions, and on standardized PLCs for the auxiliary control functions and sequences. Remote I/O units are connected to the PLCs.
via industrial Ethernet fieldbuses, allowing for reduced installation and maintenance costs.

An innovative operator interface has been designed according to 3Q concepts, with the ergonomic SCADA Human-Machine Interface running on thin client stations, ‘soft’ pulp control desks integrate smart Operator Assistants (OA), KPI displays (API/PPPI) and local control stations [7].

EAF ADAPTIVE PROCESS CONTROL: Q-MELT

Reducing process variability is a challenge for the EAF operation. It is linked extensively to the diversity of raw materials and different operating patterns of the EAF teams. Danieli has responded to this with Q-MELT, which has delivered with proven results in several successful installations around the world.

Q-MELT makes use of a statistical approach to identify process deviations in real time from process data. The extracted data makes it possible to identify the expected process behavior and, by means of the comparison between real time and expected trends, the system performs adaptive process control, acting on both electrical and chemical profiles. During this process control, the electrical and off-gas measurements permit quick access to real time process data, enabling Q-MELT to act where there are deviations from expected best practice.

The intervention of Q-MELT can be seen during the refining phase, on the control of decarburization, or steel bath oxidation. The application detects whether the decarburization process is proceeding at the expected rate, or the profile requires some adjustment, by automatically adjusting the oxygen injection, to hit the final carbon and temperature targets, without over-oxygenizing the heat. The end-point target is reached from the first valid cartridge sample measurement onward, where the Q-MELT tracks the bath carbon, temperature and dissolved oxygen, thanks to its integrated process models. This information is presented on the interface screen, where the operator can check for the correct evolution of the end-point temperature, carbon and oxygen ppm, until the tapping phase [8].

SECONDARY METALLURGY CONTROL

Being part of a strategic approach ‘from scrap to liquid steel’, the secondary metallurgy Level 2 system, permits timely synchronization between LMF, VTD and caster. In a modern steelmaking plant, coordination between plant units is done by mathematical models, which, by several suggestions, inform the operators of the critical path to be adopted. The twin LMF and twin VTD at Nucor Brandenburg share a common pulpit, equipped with Danieli’s secondary metallurgy management models, which are embedded in the Level 2 automation system.

The critical path is defined with consideration of the requests from the caster, regarding both time and superheat. This information serves as input data to the LMF, to establish the working point and the practices that will make it possible to arrive at the target. As each new ladle arrives at the LMF, the automation system defines the operation practice and interfaces with the materials library, to define the materials to be used in each step. On the VTD, aside from the control of the pump-down time and deep vacuum treatment, an Anti-Foaming Slag technological package makes it possible to have automatic control to avoid slag overflow from the ladle during vacuum.

The Anti-Foaming Slag (Q-AFS) system makes use of radar technology, to analyze the progression of eventual slag foaming and, where there is a risk of overflowing nitrogen, is automatically injected into the tank. This causes the slag to decline due to the increase of pressure inside the tank. In this way, overflowing due to late reaction from operators is avoided. On the other side, productivity is increased by avoiding an excessive pump-down time that may follow from over-reaction of the operator [8].

DANIELI PLATE/ STECKEL MILLS

Danieli is currently the market leader in plate/Steckel mill technology with 5 out of the 9 main new plants contracted worldwide since 1999. SSAB Alabama (formerly IPSCO) was Danieli’s first experience of a new mill started up in 2001. The years 2000 to 2015 saw rapid development in the Chinese market. Danieli started up a new plate/Steckel 3500 mill in 2005 with Anyang Iron and Steel. The plant was among the first to produce X70 plates from medium cast slab.

Jiangyin Xingcheng Special Steel trusted Danieli technology to commission a new 1.2Mtpa greenfield plate/Steckel 3500 mill in 2010. This mill belongs to the category of wide mills that produce discrete plates, with thicknesses ranging from 3/16in to 2in (4.5 to 50mm) and up to 128in (3,250mm) in width. The product range can be further extended thanks to the possibility to roll wide coils, with a thickness up to 1in (25.4mm) and being 118in (3,000mm) in width. A record jumbo coil weight of 58 short tons (53t) was achievable at that time. This makes it possible to produce non-standard formats, as compared with conventional plate mills and hot strip mills. ‘Thin and wide’ for pressure vessel construction and HSLA for machinery construction, either as rolled, or post-treated, are interesting products for the potential to reduce downstream welding operations, during fabrication. Moreover, the mill uses hot charging extensively, saving up to 40% of the total energy required by the hot rolling process [9].

Based on the cooperative spirit developed during the first mill installation, in the following year, 2011, Jiangyin Xingcheng Special Steel and Danieli started up a 1.6Mtpa, dual-reversing stand, conventional 4300 plate mill. This increased the company portfolio with heavy gauge, wide
plates, starting from heavy cast slabs and ingots, up to 39 in (1,000 mm). Another important example from Danieli of the application of modern plate/Steckel mill technology comes from the experience with Chinalco Group, a world giant in non-ferrous processing, which in 2015 installed a new complex, dedicated to the production of special alloys, at its subsidiary Chinalco Shenyang Non-Ferrous [9].

PLATE/STECKEL MILL ROLLED PRODUCTS
The previously mentioned SSAB Alabama plate/Steckel mill, is today the benchmark for abrasion-resistant grade production, thanks to investment in a new Q&T line in 2010 and the renowned product HARDOX®, as well as the high-strength structural steel with STRENX®. Moreover, the line is capable of producing a special dimensional range, from 2/16 in to 3/16 in (3.2 to 4.8 mm) thick and between 70 in and 98 in (1,800 and 2,500 mm) wide. This range is not possible with a conventional plate mill and HSM [9].

A noteworthy product from Jiangyin Xingcheng Special Steel is heavy gauge 1 in (25.4 mm), API-X80, also offered as coiled plates. The portfolio includes in-house developments for hydroelectric plant construction, such as XCS610D/E, XCS690D/E and XCS790D/E, in very high rolled thicknesses, of up to 14 in (350 mm).

Concerning wear-resistant grades, Jiangyin Xingcheng Special Steel also offers its own improved solution with XCHD360™-500, up to 6 in (150 mm) and high-strength steel for mobile engineering construction, such as XCHT1100. Special compound materials (bi-metallic) for sour-gas applications, such as acid-based pipelines, can also be produced under special technical agreements.

The production of Chinalco Shenyang Non-Ferrous is fully dedicated to the aerospace industry, including Titanium alloys (TA1, TA2, TC4), Nickel Alloys (N5, NiCu, Grade 718), Copper Zirconium alloys (CuCrZr) and stainless steel grades 304/316 [9].

CONCLUSIONS
Steel plates, despite being some of the oldest steel industry products, continue to reiterate their absolute importance to social development. The consolidated global tendency in green power generation investments, especially hydro-power and wind-power, offers new opportunities for such products and technologies.

The new plate mill in Nucor Steel Brandenburg, based on an environmentally friendly EAF melt shop will combine 3/16 in (4.76 mm) thin plates, 60 short tons (54.4 t) jumbo coiled plate and 14 in (355.8 mm) heavy plate production into a single mill, realizing an outstanding combination of product flexibility, quality and energy efficiency.

Danieli, a leader in EAF and plate/Steckel mill rolling technologies, offers solutions in terms of layout development, Extream II cooling system, and EVO/6 levelers, supported with advanced process control, and automation systems with Industry 4.0 technologies, while working as a team (Figure 6). [MIS]

Enrico Zambon is Sales Manager, Hot Rolling, with Danieli Germany, Paulo da Costa is Sales Manager, Steelmaking and Lorenzo Lusina is Project Director, both with Danieli & C. Officine Meccaniche S.p.A., Buttiro (UD), Italy, and Marco Mossutti is Sales Manager, Automation, with Danieli Automation S.p.A., Buttiro (UD), Italy

CONTACT: e.zambon@germany.danieli.com

REFERENCES
[1] Private Correspondence, Nucor, 12 February 2021
TEBULO
INDUSTRIAL ROBOTICS

MOVE FAST  MOVE FORWARD

Marking & Labelling Coils & Slabs
Destrapping Including High Strength Steel Straps
Product Handling & Specials
Dross Removing
Coil Eye Welding
Sample Plate Handling

www.tebulorobotics.com