Danieli Centro Combustion and Danieli Olivotto Ferrè provide the most efficient and low consumption heating and heat treatment systems for all steel and NF metals production processes.

Danieli Environment offers a full range of proprietary technologies for air pollution control, water treatment, solid waste recovery, noise reduction and energy savings.

Danieli Automation automates plants through integrated systems for equipment, process and power control, handling jobs from order placement through product delivery. Event prediction and problem-solving operator assistance are ensured by the innovative 3Q system.

Danieli Engineering and Danieli Construction International: your trusted partner with 37 years of experience in on-time project delivery and cost management.

Danieli Environment offers a full range of proprietary technologies for air pollution control, water treatment, solid waste recovery, noise reduction and energy savings.

Danieli Automation automates plants through integrated systems for equipment, process and power control, handling jobs from order placement through product delivery. Event prediction and problem-solving operator assistance are ensured by the innovative 3Q system.

Danieli Environment offers a full range of proprietary technologies for air pollution control, water treatment, solid waste recovery, noise reduction and energy savings.

Danieli Automation automates plants through integrated systems for equipment, process and power control, handling jobs from order placement through product delivery. Event prediction and problem-solving operator assistance are ensured by the innovative 3Q system.

Danieli Environment offers a full range of proprietary technologies for air pollution control, water treatment, solid waste recovery, noise reduction and energy savings.

Danieli Automation automates plants through integrated systems for equipment, process and power control, handling jobs from order placement through product delivery. Event prediction and problem-solving operator assistance are ensured by the innovative 3Q system.
ADVANCED COATING TECHNOLOGY

Take advantage of 50 Years of Experience in high performance wiping equipment

- 169 FOEN® Air Knives Wiping and Bath Equipment supplied worldwide
- 88 FOEN® Equipment supplied for Automotive Exposed applications
- 12 orders for FOEN DEMCOJET® integrated electro-magnetic stabilizing device received in 2018
- Line speed record with a FOEN® air knife and bath equipment: 250 mpm
- Bath hardware single campaign performance record with a FOEN® equipment: 97 days – 13,831,999 m. produced

FOEN® – TOMORROW’S TECHNOLOGY TODAY

Fontaine Engineering und Maschinen GmbH
Industriestraße 28
D-40764 Langenfeld
Tel. +49 2173 270021
E-mail: info@foen-gmbh.de
www.foen-gmbh.de

Fontaine Engineering, Inc.
2793 Benedum Drive
Bridgeport, WV 26330, USA
Tel. +1 304 842 8718
E-mail: foen@foen.com
www.foen.com

Fontaine Engineering China
1501 Tower A New World Center,
634 Jiefang Avenue, Qiaokou District,
Wuhan, Hubei Province P.R.China, 430030
Tel. +86 2787 184459
E-mail: info@foen.cn

Made in Germany
We work alongside our client-partners in metals and mining industries to design and develop innovative technologies and services that improve their business today and tomorrow as well. We are a team of more than three thousand forward-thinkers that share the long-standing principles of our industrial group and understand our partners’ needs. We are professionals who take a proactive approach to problem solving in every business area in which we operate, and are forever seeking new, cost- and energy-efficient ways to resolve the challenges our clients are facing.

Tenova, a Techint Group company, is a worldwide partner for innovative, reliable and sustainable solutions in the metals and mining industries.

Tenova S.p.A.
Via Gerenzano, 58
21053 Castellanza, VA - Italy
tenova@tenova.com
www.tenova.com
Contents

11 Foreword
David Price

IRONMAKING AND STEELMAKING

14 New off-gas de-sulphurisation process for sinter plants
Fabio Ferrari and Niccolò Griffini
Redecam Group S.p.A

18 Hydrogen-based steelmaking
Pablo Duarte
Tenova HYL

24 CO₂ emission reduction: A need for the future
Anand Kumar Agrawal, Dr.-Ing (Inpl) Klaus Peter Kinzel, Philipp Bermes, Cristiano Castagnola and Lorenzo Micheletti
Paul Wurth Italia s.p.A

28 BOF gas cleaning system upgrades for increased efficiency and off-gas quality
Matthias Meyn, Peter Klut and Ruud Herold
Danieli Corus, The Netherlands

36 BOF design improvements and upgrades
Günther Staudinger, Michael Skonianz and Uazir Bezerra de Oliveira
Danieli Corus

43 Consteel continuous scrap feeding and iRecovery
Holger Kehler, Tenova LOI Thermprocess GmbH
Dr. Peizhong Wang, Tenova LOI Thermprocess (Tianjin) Co., Ltd

43 Cold rolled non-oriented (CRNO) silicon steel production at Rourkela Steel Plant, SAIL
Nicola Monti and Uggero De Miranda
Tenova S.p.A. and Ori Martin S.p.A.

48 Sarralle new Bluesky-Plant® eco-technology for fume exhaust system (FES) in steel plants

49 Successful utilisation of mechanical vacuum pumps in steel degassing
Anke Teeuwen, Aditya Agrawal, Leonardo Bonifacio, Tom Burke and Frank Shi
Edwards Ltd

58 Edwards’ market-leading vacuum solutions for steel degassing applications
From John Cockerill to CMI. From CMI to John Cockerill.

The encounter between traditional values and modern trends has helped us to offer the best-adapted response to modern clients’ aspiration.

Inspired by the visionary and entrepreneurial personality of its founder, CMI once again becomes John Cockerill. Since 1817, the strong commitment to a culture of creative thinkers helped us to provide innovative and profitable answers to the needs of our clients. Resolutely oriented towards the future, innovation forms an inherent part of our engineering. While growth is substantial, the challenge is to focus on generating sustainable progress. This is what we have done for the past 200 years.

INDUSTRY METALS
Reheating Furnaces
Pickling
Acid Regeneration
Cold Rolling
Strip Processing
Automation
CASTING AND ROLLING

62 voestalpine Stahl GmbH – CC8 caster for high quality grades and exposed automotive steel
Gabriele Paulon, Loris Busolini, Thierry Gautreau, Herbert Moser and Peter Hodnik
Danieli Spa and voestalpine Stahl GmbH

67 Danieli QSP® – Quality Strip Production – at Nucor Steel Gallatin
Mateo Bulfone, Christian Bilgen, Mike Knights, Mathias Knigge, Alessandro Stenico, Paula Da Costa and Luca Faralli
Danieli

74 Mi.DA. 4.0: Endless casting and rolling process empowered by digital technologies
Andrea De Luca, Alessandro Ardesi and Luca Cestari
Danieli & C. Officine Meccaniche SpA and Danieli Automation SpA

82 Metal powder production for additive manufacturing at SMS
Markus Hüllen
SMS group GmbH

85 Energy recovery from steel reheating furnaces
Liliana Cioriciu and Luc Malpas
CMI Industry Metals

PRODUCTS AND APPLICATIONS

90 SMART CORE – new software makes intelligent use of quality data in a Smart Factory
Uwe Knaak and Marianna Schröter
LAP GmbH Laser Applikationen

96 Integrated strip stabilisation system FOEN DEMCOJET®

98 Electrical steel strip: Technical solutions for heat treatment
Dr. Peter Wendt and Wolfgang Eggert
Tenova LOI Thermprocess GmbH

101 Strip pre-oxidation for galvanised strip in a full radiant tube furnace
Michel Dubois and Louis Bordignon
CMI Industry Metals and CRM Group

106 REBAR measurement like never before with PROFILEMASTER® Systems from ZUMBA

108 Additive manufacturing at SMS group – philosophy and products
Nina Uppenkamp, Robert Banse, Sarah Hornickel and Axel Roßbach
SMS group GmbH

113 Safe and efficient robotic removal of high strength steel straps from coils
Henriëtte van Norel
Tebulo Industrial Robotics, The Netherlands

117 Optimal use of available floor space at a new storage location for steel coils
Daan Merkestein and Stevo Akkerman
Systems Navigator BV and Tata Steel Ijmuiden
In times of rapidly changing markets, you want to optimize your plants to stay ahead. We listen. We learn. We deliver: our automation and Digitalization specialists will help you implement learning mills that will boost efficiency, lower operating costs, and increase productivity. Whatever you envision, we will make it happen for you.

Leading partner in the world of metals
Foreword

Welcome to Millennium Steel 2019

In preparing to write this foreword, I was musing on whether peak steel had arrived, as crude steel production has been within the 1.6-1.7 billion tonne range for the last five years. There is, of course, a lot of conflicting economic and political information which will affect forecasts, however, the April 2019 Short Range Outlook from worldsteel.org envisages continued growth, albeit at a slower rate, reaching about 1.75bt of steel demand in 2020, so I concluded that, like peak oil, it has not arrived...just yet.

The topics in this issue do, however, reflect a continued change in how steel plant suppliers see the steel industry and what they want to showcase. For instance, there are no articles on new steel plants; what there is, is a series of excellent articles covering plant upgrades, primarily for improved quality and ability to produce a wider range of products, a concern about environmental issues reflected in subjects related to energy reduction, new or improved processes to minimise CO₂, particularly in ironmaking, and more efficient methods of gas/waste product removal/treatment.

There are also a number of articles covering more efficient production through better plant design and, particularly, the increase in automation and Industry 4.0 – the ‘smart factory’. Interestingly, for the first time, we have two articles on additive manufacturing, dealing with its use by a plant manufacturer to make better equipment, as well as providing powder for customers’ own processes and products.

I hope you enjoy this issue.

Production editor, Annie Cree and designer, Ray Belletty have produced an excellent, very readable publication, and I thank all the authors and advertisers for their support.

Work on the 2019 China edition of Millennium Steel will be starting soon and I welcome proposals for technical articles.

David Price
Editor
May 2019
The MIDREX® Process is the world’s most reliable and productive direct reduction technology.

Visit us at METEC! Hall 3

Your Partner For Success.

MIDREX® Plants have produced a cumulative 1 billion tons of direct reduced iron (DRI) since 1969, accounting for more than 60% of the world's DRI production. And we continue to improve the industry's most flexible, proven, and efficient process technology. We cooperate with the best plant operators in the world to design and implement practical, sustainable solutions for their operational success.
Ironmaking and Steelmaking

14 New off-gas de-sulphurisation process for sinter plants
   Fabio Ferrari and Niccolò Griffini
   Redecam Group S.p.A

18 Hydrogen-based steelmaking
   Pablo Duarte
   Tenova HYL

24 CO₂ emission reduction: A need for the future
   Anand Kumar Agrawal, Dr.-Ing (Inpl) Klaus Peter Kinzel,
   Philipp Bermes, Cristiano Castagnola and Lorenzo Micheletti
   Paul Wurth Italia s.p.A

28 BOF gas cleaning system upgrades for increased efficiency and off-gas quality
   Matthias Meyn, Peter Klut and Ruud Herold
   Danieli Corus, The Netherlands

36 BOF design improvements and upgrades
   Günther Staudinger, Michael Skorianz and
   Uazir Bezerra de Oliveira
   Danieli Corus

43 Consteel continuous scrap feeding and iRecovery
   Holger Kehler, Tenova LOI Thermprocess GmbH
   Dr. Peizhong Wang, Tenova LOI Thermprocess (Tianjin) Co., Ltd

43 Cold rolled non-oriented (CRNO) silicon steel production at Rourkela Steel Plant, SAIL
   Nicola Monti and Uggero De Miranda
   Tenova S.p.A. and On Martin S.p.A.

48 Sarralle new Bluesky-Plant® eco-technology for fume exhaust system (FES) in steel plants

49 Successful utilisation of mechanical vacuum pumps in steel degassing
   Anke Teeuwsen, Aditya Agrawal, Leonardo Bonifacio,
   Tom Burke and Frank Shi
   Edwards Ltd

58 Edwards’ market-leading vacuum solutions for steel degassing applications
New off-gas de-sulphurisation process for sinter plants

Sinter making produces large quantities of dust and gaseous pollutants, requiring extensive removal and recovery systems. As environmental standards continue to tighten, Redecam has developed an improved system for cleaning waste gases and dust removal, called RDS. The technology is based on that used in other industries, but specifically adapted to the steel industry. The benefits are lower levels of pollution in waste gases, better dust removal and lower CAPEX and OPEX.

Authors: Fabio Ferrari and Niccolò Griffini
Redecam Group S.p.A

The need to reduce emissions from industrial processes leads producers to adopt the best methods available at any moment in time, such as the Best Available Technology (BAT) system as used in Europe. It is important for industrial sector operators to have a broad spectrum of possibilities available when selecting the best emission reduction technology for their plants.

Several factors have to be considered during this selection, such as:

- The possibility to achieve the required emission target
- Technology reliability
- Interaction with other gas treatment technologies
- Technology flexibility
- By-products recovery
- The specific skills required to operate and maintain the emission reduction plant
- Operating and investment cost

For integrated steel plants, which are used for about 60% of steel production globally, one of the major sources of pollution is in the so-called ‘agglomeration area’, especially the sinter plants. Most of the emitted dust is in the PM10 fraction and contains various heavy metals, acid gases (SO2, HCl, HF, NOx), ammonia and organic compounds which contribute to the formation of secondary aerosols in the atmosphere.

BACKGROUND
Redecam Group is an Italian company with more than 30 years’ experience, providing high quality and highly technological products and services to many industrial sectors. It specialises in the design, manufacturing and installation of solutions ranging from simple filtration equipment to complex flue gas treatment systems.

Using this expertise, Redecam has developed a new de-SOx technology based on a Circulating Fluidised Bed (CFB)
semi-dry reactor with the trade name: Redecam semiDry System (RDS).

This technology is already widely used in the power and Waste to Energy (WTE) sectors. Although there are process differences Redecam have adapted it for use in sinter plants where the characteristics of the process, raw materials or fuels require a waste gas de-SOx treatment to achieve lower emissions. Sinter plant emissions are characterised by a generally high gas flow, a low moisture content (5-6% H2O), and lower temperatures (around 120°C), compared to other industrial sectors. These features allow the application of the RDS system, minimising water consumption and reducing the gap with respect to the dew point temperature without risk of condensation.

RDS PROCESS PRINCIPLES

CFB scrubbing technology is based on the fluidised bed principle. Hydrated lime powder (15-20m²/g BET specific surface) and water are injected into a reactor (see Figure 1) where the powder is suspended and mixed using a high velocity stream of flue gas entering from the bottom. The intense mixing between acid flue gas, solid reagents and water, and the presence, for a given time, of water over the reagent particles, allows SO2 reduction efficiency of over 95%. In the field of sinter technology, typical SO2 values are 500-700mg/Nm³ at the inlet, and less than 50 mg/Nm³ at the outlet, but of course higher baseline values are possible depending on the sector. Since the reaction between lime and SO2 is more efficient the more we approach the dew point, temperature is an important parameter which is controlled through the water injection flow rate.

A simplified chemical reaction can be described by:

\[ \text{Ca(OH)}_2 + \text{SO}_2 = \text{CaSO}_3 + \text{H}_2\text{O} \]

The system also removes HCl, HF and mercury at an efficiency in excess of 90%. Other trace metals can also be removed using no other reagents than lime.

Once mixed and reacted, the gas flow carries the solids out through the top of the reactor on to a fabric filter that separates the dust from the flue gas. The clean flue gas is then conveyed to the stack.

The dust is continuously recycled into the reactor; the recirculation rate can be some hundred times greater than the fresh lime injected. Since water is injected directly into the reactor, hydrated lime is fed in powder form, and no slurry handling is necessary. Moreover, as the water is totally evaporated in the reactor there is no wastewater to be treated and the final product removed from the filter is totally dry so there is no need for drying equipment. The dust is removed through airslides installed in the bottom of the hoppers, followed by a rotary airlock. Use of airslides was selected from experience, since they have proved to be the best way to assure a constant and stable recirculation.

Airslides are also commonly used to convey the dust from the filter hoppers in other sectors such as cement.

There are no internal moving parts inside the reactor as there is no need for a high-speed rotating atomiser, so there is less wear and consequently lower maintenance costs. Thanks to the efficient bed mixing, the lime conversion rate is high, even when elevated acid gas reductions are required, so allowing a Ca/S molar ratio around 1.8 or less. There is a fast response to SO2 fluctuations aided by SO2 analysis of incoming gas and closed loop response. Additionally, due to the very high recirculation rate, there is always a large amount of lime available to cope with SO2 peaks at the inlet – and the enhanced design supports stable operation at 50% of design flow without gas recirculation.

The fabric filter and internal design have been specifically designed for this application, taking into account the following factors:

- High dust load coming from recirculation
- Relatively low operating temperatures (usually 20°C above the dew point, typically about 80°C)
- Low air to cloth ratio
- On-line cleaning (no compartment inside the filter casing)
- The need for optimal distribution of the flow thanks to dual phase raw gas and dust
The final by-product is not usable in the place of gypsum as cement regulator, since it contains mainly CaSO₃·½H₂O (and only a minor fraction of CaSO₄·2H₂O), but has a wide range of other uses:

- Fertiliser in agriculture
- Building material additive for production of screed and mortar
- Additive for production of building bricks and lime sand brick, fibreboards, etc.
- Production of binders in road construction
- In surface and underground mining as an additive to the mining mortar or filling mortar
- Conditioning of sewage sludge

In this regard, RDS becomes a competitive option in cases where high %S reduction is necessary or when the operating cost of Dry Sorbent Injection (DSI) technology is not sustainable. The flexibility of this solution is really appreciated when there is a necessity to revamp an existing de-dusting system: in fact, it can be easily installed downstream of an Electrostatic Precipitator (ESP) or Multicyclone without long interruption to the production process. It also keeps a separation between the regulation of sinter machine or boiler by the existing fan and regulation of the new flue gas treatment with a dedicated ID fan located after the bag filter.

### PLANT OPERATING DATA

Tables 1 and 2 provide a comparison, at a level of process calculations, between an RDS as typified by the schematic shown in Figure 2 and a Flue Gas Desulphurisation (FGD) wet scrubber for a 680,000Nm³/h sinter plant (100m²) where it is required to reduce the SO₂ emissions by 95% (from 500mg/Nm³ to <30mg/Nm³).

The operating cost was evaluated starting from a hydrated lime cost of $110/t and a power cost of $50/MWh. The total operating cost of the two options is very similar: the higher reagent cost of RDS being balanced by the higher power and maintenance cost of the wet FGD. As the size of the plant decreases the comparison favours the RDS because the maintenance cost does not linearly decrease with plant capacity.

Additional benefits are that RDS is very competitive with a wet FGD regarding investment cost and, additionally, its footprint is smaller (no sections for slurry treatment and by-product drying), and does not require specific skills or additional personnel both for operation and maintenance. Finally, due to the necessity to have a specific filter design, RDS is a very interesting option to consider when it is required to reduce both SO₂, heavy metals, HCl, etc.) and dust emissions. A typical application could be when de-dusting is performed by an ESP or baghouse systems that have to be revamped. In this situation, an RDS installed downstream, or in the place of, the existing equipment can solve both gaseous and powder emission issues, without requiring heavy financial investments or large layout modifications.

**Note:**

Fabio Ferrari is Head of Products and Niccolò Griffini is with Sales & Business Development, both at Redecam, Sesto San Giovanni, Italy.

**CONTACT:** Barbara Gallo, BGallo@redecam.com

---

**Table 1 Process main technical features**

<table>
<thead>
<tr>
<th></th>
<th>RDS</th>
<th>Wet FGD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reagent used</td>
<td>Medium quality hydrated lime</td>
<td>Pulverised high grade limestone (&gt;95%)</td>
</tr>
<tr>
<td>Molar ratio Ca:S</td>
<td>1.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Reagent consumption</td>
<td>t/y 4,953</td>
<td>4,727</td>
</tr>
<tr>
<td>Reactor pressure</td>
<td>mbar 10</td>
<td>Negligible</td>
</tr>
<tr>
<td>Power consumption</td>
<td>GWh/y 8.6</td>
<td>14.3</td>
</tr>
<tr>
<td>Water consumption</td>
<td>m³/d 432</td>
<td>842</td>
</tr>
<tr>
<td>By-products (excl. kiln dust)</td>
<td>t/y 8,323</td>
<td>7,380</td>
</tr>
<tr>
<td>By-products recovery</td>
<td>Building materials, binders, etc.</td>
<td>Gypsum for cement making</td>
</tr>
<tr>
<td>Other issues</td>
<td>-</td>
<td>Visible plume at the stack</td>
</tr>
</tbody>
</table>

**Table 2 Operating costs in K$/y**

<table>
<thead>
<tr>
<th></th>
<th>RDS</th>
<th>Wet FGD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reagent cost</td>
<td>544</td>
<td>35</td>
</tr>
<tr>
<td>Energy cost</td>
<td>429</td>
<td>716</td>
</tr>
<tr>
<td>Process water</td>
<td>42</td>
<td>82</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>267</td>
<td>480</td>
</tr>
<tr>
<td>Gypsum recovery saving</td>
<td>-</td>
<td>-67</td>
</tr>
<tr>
<td>Total operating cost</td>
<td>1,131</td>
<td>1,360</td>
</tr>
</tbody>
</table>

---

**Note:**

Fabio Ferrari is Head of Products and Niccolò Griffini is with Sales & Business Development, both at Redecam, Sesto San Giovanni, Italy.

**CONTACT:** Barbara Gallo, BGallo@redecam.com
Redecam offers highly engineered turnkey air filtration and flue gas treatment (FGT) solutions, helping customers worldwide meet their air emission reduction targets rapidly and cost-effectively. We have a strong track record with over 2,700 references in more than 90 countries and on every continent. As legislation around the world becomes increasingly strict in regards to pollutant emissions, Redecam has been developing a variety of methods tailored to each industry to reduce flue gas contaminants, using low energy consumption and environmental friendly systems.

AIR FILTRATION
- Bag Filters (Baghouses)
- Electrostatic Precipitators
- Dual-Action Filters
- Extreme High Temperature Filters
- Multi-Input Integrated Systems
- Waste Heat Recovery Systems

FLUE GAS TREATMENT
- DeNOx (Selective Catalytic Reduction) (SCR), Selective Non-Catalytic Reduction (SNCR), Hybrid (SCR/SNCR), Catalytic Bags
- Mercury Adsorption System (MAS)
- Dry Injection Desulfurization (DID)
- Semi Dry Injection Desulfurization (RDS)
- Dioxin Removal

We also offer a wide variety of market-leading gas conditioning systems and handling & storage products as well as a full line of technical support & services.
Hydrogen-based steelmaking

Environmental and climate change pressures are demanding that the steel industry decarbonises. Tenova, with its ENERGIRON experience, is well based to help achieve the goal of carbon-free steelmaking. The use of hydrogen as an iron ore reductant is proven at laboratory and pilot plant level with ENERGIRON technology, utilising over 90% H₂ as the reductant. Demonstration plant trials are being progressed, however, to be competitive with fossil fuel-based ironmaking, H₂-based DRI production, the electricity from renewable sources needs to be reduced to $0.03/kWh or less, and CAPEX has to be significantly reduced.

As environmental and climate change concerns increase, the steel industry is seriously evaluating how its carbon footprint can be reduced. Overall, Europe is a leader in this field, researching the intensive use of hydrogen-based iron reduction as a long-term substitute for carbon-based processes. A major step, as described in the European Steel Technology Platform (ESTEP) Strategic Research Agenda, is the initiative on ultra-low carbon future European steelmaking. Specific future aspects of ESTEP will cover issues related to H₂ supply, use, transport and energy storage in general. Some projects oriented on this target are:

- ThyssenKrupp with the Carbon2Chem® project aimed at using CO₂ emissions from steelworks and surplus energy from renewable sources for chemical production. Currently shifting to the carbon direct avoidance (CDA) approach.
- Voestalpine, Siemens and Verbund with the H₂FUTURE project, building a pilot facility for green H₂ at Linz.
- SSAB, LKAB and Vattenfall with the HYBRIT initiative based on carbon-free steelmaking by using H₂. Thanks to the unique characteristics of its ENERGIRON process and its specific expertise in direct reduction of iron with H₂, Tenova HYL was a perfect fit and was contracted for the HYBRIT project. The pilot plant will be located in Luleå, Sweden, and is expected to begin operations in 2020.

- Salzgitter SALCOS (Salzgitter Low CO₂ Steelmaking) project with high-C DRI as feed to BF and EAF (replacing BOF) in combination with the GrinHy project to generate H₂ via reversible, high temperature electrolyser through renewable energy, to be used for DRI production. The SALCOS project, a study initiated by Salzgitter AG together with Tenova/ Danieli and Fraunhofer-Gesellschaft (FhG) in 2015, is designed to analyse the capabilities of already existing technologies to reduce greenhouse gas emissions, to investigate implications on integrated steel works and to demonstrate the possibility of generating a significant contribution to carbon footprint reduction.

ENERGIRON PROCESS

The ENERGIRON process (the HYL DRI technology jointly developed by Tenova and Danieli) began in the 1950s with the installation of the first industrial scale gas-based direct reduction plant at Hylsa in Monterrey, Mexico, using H₂-rich gas (in a ratio of H₂/CO~5) as the reducing agent. Subsequent developments have included selective CO₂ removal for increasing process efficiency while reducing energy consumption and providing a practical solution for CO₂ capture and commercialisation (CCU), developing the ZR (reformerless) variant for further process efficiency while producing high carbon DRI (>3%C), using the breakthrough reliable Hytemp system for hot DRI transport, and EAF feeding by environmentally friendly, pneumatic transport.

The ENERGIRON ZR process to produce DRI (see Figure 1, left) is a major step forward in reducing the size and improving the efficiency of direct reduction plants. Reducing gases are generated by in-situ reforming within the reduction reactor, feeding natural gas as make-up to the reducing gas circuit and injecting oxygen at the inlet of the reactor. The basic ZR process permits the direct use of natural gas but the plants can also use conventional steam-natural gas reformers as an external source of reducing gases. Other
reducing agents, such as hydrogen, syngas produced from coal gasification, pet coke and similar fossil fuels, and coke oven gas, are also potential sources of reducing gas, depending on the particular situation and availability. In any variant, the same basic process is used regardless of the reducing gas source. The current configuration of this technology employs a continuous shaft furnace-based process, with both the product quality and process efficiency having been significantly optimised over the years. ZR technology is currently the most flexible option for producing DRI based on its uniquely simple process configuration and its wide flexibility for using different energy sources and available raw materials, hence it was readily adaptable for use with hydrogen. A modern ZR unit is shown in Figure 2.

HISTORICAL USE OF H₂ IN DR-EAF STEELMAKING

Historically, the steelmaking route based on DR-EAF has always been characterised by the use of H₂, which is normally generated from natural gas (NG) through catalytic reformers. Since the hydrocarbon source is NG, the H₂ produced can be of variable concentration, and mixed with CO, depending on the oxidant ratio being used.

Since the 1950s, there are now hundreds of DR and hydrogen plants in operation using HYL/ENERGIRON technology with reformed gas as the source of reducing gas and a conventional NG/steam reformer. Specifically, there are more than 40 HYL/ENERGIRON plants having used this type of NG reformer in the steel industry. The typical operation characteristics for these plants and for the competing technology (Midrex) are shown in Table 1. Higher H₂ levels are indicated for ENERGIRON.

In any process variant, as long as NG is used as the primary source of H₂ generation, there will be CO₂ as by-product, which is emitted in both, the DR plant and the melt shop.

EXPERIENCE USING OF H₂ IN ENERGIRON REDUCTION OF IRON ORE

Thermodynamically H₂ reduces iron oxide more easily than CO (Gibbs free energy). Iron ore reduction with H₂ is a highly endothermic reaction, favoured at high temperatures, and requiring high H₂ concentrations at lower temperatures. Comparably, reduction with CO is an exothermic reaction, favoured at low temperatures and taking place at lower CO concentrations[2]. However, thermodynamic data do not provide information on the rate at which the reduction reactions would take place. This depends on the reaction kinetics, and the process parameters can be only determined by experimental testing.

Kinetically, the effect of temperature on the extent of iron ore reduction has been investigated using gases with...
different \( \text{H}_2 / \text{CO} \) ratios [3]. The degree of reduction at 1,000°C for \( \text{CO} / \text{H}_2 \) ratios of 1.0 and 0.1, are indicated in Figure 3. In general, the higher the temperature the faster the reduction process, whether the reducing agent is \( \text{H}_2 \) or \( \text{CO} \). However, the reduction of iron ore with \( \text{H}_2 \) is more than four times faster as compared to \( \text{CO} \).

**ENERGIRON ZR FOR INTENSIVE \( \text{H}_2 \) USE** The basic configuration of the ZR process is the same regardless of the source of reducing gas make-up. The only difference is that for \( \text{H}_2 \) utilisation higher than \(~73\%\) (energy) or \(~90\%\) volume at the reactor inlet, the process scheme is simplified by eliminating the need for a selective \( \text{CO}_2 \) removal system. For higher \( \text{H}_2 \) concentrations, any carbon input to the system via \( \text{NG} \), along with other components like \( \text{N}_2 \), are eliminated through the tail gas purge from the system, which is used as fuel in the gas heater. Figure 1 shows the process schematic at high \( \text{H}_2 \) concentration. [1]

In terms of energy consumption, the impact of \( \text{H}_2 \) (as % of total energy input), as compared to \( \text{NG} \) is indicated in Figure 4. There is a saving in energy consumption of ~2.0 GJ/t in the DR plant, since \( \text{H}_2 \) is already available, and there is no need of \( \text{NG} \) reforming; however, there is no credit of %C in the DRI [4].

**DEMONSTRATION/PILOT PLANT EXPERIENCE WITH \(~100\%) \text{H}_2**

In addition to the vast industrial experience using \( \text{H}_2 \) in reformed gas, in the 1990s Tenova HYL carried out extensive tests at a pilot plant (see Figure 5) with \(~90\%) (vol.) \( \text{H}_2 \), producing \( \text{H}_2 \) from reformed gas from an industrial DR plant by the water-gas shifting reaction and \( \text{CO}_2 \) removal [1]. The demonstration/pilot plant at Hylsa Monterrey had a production rate of 36tDRI/day with full flexibility to produce CDRI, HDRI for HBI production, and HDRI for direct pneumatic transport to an adjacent pilot plant EAF. This plant also included full capability for synthesis of all types of reducing gases; from 100% \( \text{H}_2 \) to 100% \( \text{CO} \), including reformed gas, typical coke oven gas and gases from coal gasification. In fact, the ZR process was developed and demonstrated in this facility in the 1980s.

The experimental campaign included 15 different process conditions, depending on the DRI type and quality to be achieved. This included production of CDRI and HBI with metallisation of 94-96% and carbon from 0.2 ~ 1%, depending on the \( \text{CO}-\text{CH}_4 \) concentration in the circuit.

These tests provided all necessary information to define:
- Process and design parameters mainly related to reducing gas optimised flow-temperature correlation
- DRI quality in terms of metallisation and carbon content
- Optimisation of operating pressure, reactor L/D ratio, solids residence time (\( \tau \)), consistently achieve the DRI
100% H₂ reduction in the DR plant and which will be fed to an EAF requiring a minimum carbon injection of 12-15kg C/tLS, specific melting operations and slag engineering practices.

Both options are workable but in terms of overall CO₂ emissions related to the integrated system DR-EAF, option 1) will result in emissions of about 150kg CO₂/tLS, and option 2) will produce about 50kg CO₂/tLS. Thus in terms of overall decarbonisation, option 2) would be the preferred choice for H₂-based steelmaking.

**ECONOMICS OF H₂-BASED IRONMAKING**

In terms of OPEX, producing hydrogen by water electrolysis implies a direct cost of the connection to the power grid. At a value of ~4.5kWh/Nm³ H₂, the energy consumption for DRI, based on the ENERGIRON ZR technology will be ~3.0MWh/t DRI. Since the H₂ will be produced from renewable energy, any cost analysis should be made on such a power cost. Currently this is high compared to fossil fuel power generation. However, costs are falling. In Germany, for instance, the power cost from renewable sources has dropped to about $0.05/kWh, which would mean an equivalent of about $16/GJ for DRI production, which is still high when compared to typical DRI energy-related production costs. Costs related to water make-up, CAPEX of electrolyser modules, H₂ storage and transport (when applicable) and CO₂ emissions targets, with corresponding credits, also need to be taken into account in the cost equation [1].

According to IRENA, the International Renewable Energy Agency [5], electricity from renewables will soon be consistently cheaper than from fossil fuels. They estimate that by 2020, all the power generation technologies that are now in commercial use will fall within the fossil fuel-fired cost range, with most at the lower end or even undercutting fossil fuels. Record low auction prices for solar photovoltaic energy (PV) in 2016 and 2017 in Dubai, Mexico, Peru, Chile, Abu Dhabi and Saudi Arabia have shown that an LCOE (levelised cost of electricity) of $0.03/kWh is possible from 2018 and beyond, with...
By 2019, the best onshore wind and solar PV projects will be delivering electricity for an LCOE equivalent of $0.03/kWh, or less, with CSP (concentrated solar power) and offshore wind capable of providing electricity very competitively. Increasingly in the future many renewable power generation projects will undercut fossil fuel-fired electricity generation, without financial support. To be competitive in terms of green H₂-based DRI production, as per current electrolyser efficiency and without CO₂ credits, the electricity from renewable sources should be ≤$0.03/kWh. CAPEX has to be also significantly reduced. This may be possible within the coming years.

CONCLUSIONS

- Environmental and climate change pressures will demand that the steel industry decarbonises
- The use of hydrogen as an iron ore reductant is proven at laboratory and pilot plant level
- Tenova’s ZR technology, utilising over 90% H₂ as the reductant, has been proven at pilot plant stage and is part of the HYBRIT fossil fuel-free steelmaking project
- To be competitive with fossil fuel-based ironmaking, H₂-based DRI production (using current electrolyser efficiency and without CO₂ credits), the electricity from renewable sources needs to be reduced to $0.03/kWh or less, and CAPEX has to be significantly reduced.
- Tenova, with its ENERGIRON experience, is well placed to help achieve the goal of carbon-free steelmaking.

Pablo Duarte is Senior Consultant at Tenova HYL, Monterrey, Mexico

CONTACT: joel.morales@tenova.com

REFERENCES

FROM THE MINE TO THE STEEL MILL


CO₂ emission reduction: A need for the future

Given the need to limit global warming to 1.5 °C compared to pre-industrial levels and the major contributing impact of the steel industry, Paul Wurth has been developing a range of CO₂-reducing BF technologies that aim to reduce emissions in a stepwise mode as political and cost uncertainties become clearer or even more urgent.

Authors: Anand Kumar Agrawal, Dr.-Ing (Inpl) Klaus Peter Kinzel, Philipp Bermes, Cristiano Castagnola and Lorenzo Micheletti
Paul Wurth Italia s.p.A

The Paris Agreement negotiated at the 2015 United Nations Climate Change Conference (COP 21) set the goal of limiting global warming to well below 2 °C, and, preferably, 1.5 °C compared to pre-industrial levels. According to scientists, this 1.5 °C goal will require zero emissions some time between 2045 and 2060, and they are therefore calling for immediate action.

The iron and steel industry is one of the major sources of industrial CO₂ emissions. Within an integrated steel plant, 70-80% of the carbon input is attributable to the ironmaking process, but only 20-25% of the CO₂ emissions are directly generated by the blast furnace (BF). Coke-based BF technology, known for more than 300 years, is still considered the most economic route for producing hot metal, at least in Europe. BFs are more flexible and dynamic with respect to ore quality and they excel in terms of production capacity compared to other ironmaking routes. Owing to these advantages, the BF-converter route represents the major share (60-70%) of the total crude steel production in the world today.

To comply with the targets set by the Paris Agreement, steel plant owners and operators have to implement drastic measures to cope with future CO₂ emission reduction requirements. Political uncertainty makes it very difficult for them to define measures for technological shift, as moving away from the traditional BF route implies very high costs and puts at danger the profitability of the complete steel plant, with a real risk of losing competitiveness in the global market.

Having always been committed to providing pragmatic solutions to its customers, Paul Wurth is presently developing in an intensive way a number of technologies applicable to the classical BF route for allowing a stepwise reduction of CO emissions, which are well balanced between ambitious environmental targets and given economic constraints. These solutions mainly concern the efficient utilisation of off-gases produced by a steel plant for reaching progressively lower emissions.

METALLURGICAL USE OF PROCESS OFF-GASES

While BF operation is responsible for 70-80% of the carbon input for the steel plant, the direct CO₂ emission related to the BF is only 20-25%. The remaining carbon exits in the form of BF gas, which is used as fuel in a variety of steel plant units, such as the coke oven plant, the sinter plant and rolling mills. Similarly, a large amount of carbon is exported from the coke oven plant in the form of coke oven gas to the different units of the steel plant. The volume of process off-gases such as coke oven gas, BF gas and basic oxygen furnace gas generated within a steel plant is much higher than their internal use as a fuel. The surplus is used mostly in power plants for the production of electricity.

By applying technologies that allow the use of all process off-gases for metallurgical purposes within the blast furnace, CO₂ emissions from steel plants could be significantly reduced. In this case, the required electric energy, preferably from renewable sources, can be bought from an external power grid.

UTILISATION OF COKE OVEN GAS IN BFS

With a high calorific value (16-18MJ/Nm³), coke oven gas (COG) is a potential energy source allowing substitution of coke in the BF, and thereby leading to CO₂ savings. COG can be injected into the BF either at tuyere level or at lower shaft level. Use of COG at the BF tuyeres increases the lower heating value (LHV) of the BF top gas. Presently in integrated steel plants, COG is used mainly in the hot blast stoves, reheating furnaces and coke oven plants, whereas process off-gases with lower calorific value are consumed in power plants. In order to use COG for metallurgical purposes in the BF, internal redistribution of gases within the steel plant is required and so internal electric power production will be reduced.

COG TUYERE INJECTION

COG injection at tuyere level is relatively easy to implement and has been known for decades. Paul Wurth is proposing different technologies, and has designed a new tuyere
COG can be injected in the BF as a substitute for natural gas, pulverised coal or coke. For economic reasons, however, customers often prefer to maintain a high rate of pulverised coal injection (>150kg/tHM), benefiting from the difference in market price of PCI coal and expensive coke. Considering that injection of cold COG along with a high rate of pulverised coal leads to a significant drop in the raceway adiabatic flame temperature (RAFT), only a relatively small amount of cold COG can be injected into the tuyeres. This limits the CO2 saving potential of this technology to approximately 3-4%. A schematic diagram is shown in Figure 1.

**COG SHAFT INJECTION**

COG injection in the lower shaft of the BF is an alternative technology to utilise a higher amount of COG in the BF (see Figure 2). Shaft injection is advantageous in many ways as it does not limit furnace operation in terms of RAFT. On the contrary, it improves the top gas temperature thanks to a larger shaft gas volume.

In the case of shaft injection, COG temperature should be equivalent to the temperature of the lower shaft (900-1,000°C) in order not to cool or overheat the shaft zone. However, heating up COG to such high temperatures brings about many technological challenges, such as carbon deposition and poisoning of the reactor surface due to impurities present in the COG. Furthermore, this option may lead to a redistribution of temperature isotherms near the shaft wall. To overcome these problems, reforming of COG can be carried out to convert the contained hydrocarbons into H2 and CO. Paul Wurth is presently working on the development of a COG reforming technology based on partial COG oxidation.

Combining tuyere and shaft injection allows significant savings in CO2 emissions (up to 10%), as the entire COG present in the steel plant is used. For higher CO2 savings from steel plants it is essential to develop technologies that use not only coke oven gas but also convert blast BFG into fuel suitable for use in the BF.

**UTILISATION OF BFG AND COG**

Proposals to use BF gas within the BF have already been made in the past – for example, in the ULCOS (Ultra Low CO2 Steelmaking) project. The idea is to capture the CO2 contained within the BF gas and re-inject the remaining portion of the gas into the BF tuyeres and/or shaft.

A major concern is the current lack of any profitable use of the huge amount of CO2 captured from a typical industrial BF. Therefore, Paul Wurth is following another concept based on dry reforming, in which hydrocarbons react with CO2 to produce H2 and CO-containing reducing gas. Paul Wurth is developing a technology to execute the dry reforming reaction at a higher temperature level not requiring a catalyst, which is usually prone to poisoning with COG.

Laboratory tests have been conducted to define the best process conditions for this approach. The process takes place in a specially designed reforming regenerative heat exchanger (a modified hot blast stove), which will convert the COG/BFG mixture into hot syngas.
The COG dry reforming hot stove operates in a similar way as a conventional hot blast stove. The compressed COG and BF gas will be reformed and heated to a temperature similar to the hot blast temperature (1,100-1,300°C). The generated hot syngas is then injected as reducing gas into the BF at tuyere level or at shaft level by mixing with suitable cold reducing gases. A schematic flow diagram is shown in Figure 3.

This technology provides the opportunity to exploit a significant amount of process off-gases in the BF, thereby achieving CO2 savings. Compared to the ULCOS BF, this process is interesting since it is based on hot blast stove technology, well known to steel plant operators and not requiring complex equipment.

**STEPWISE MODIFICATION OF BF PLANTS**

Considering political indecision regarding a CO2 emissions trade and cap system and the tremendous investment needed to switch to new technologies and any related competitiveness risk for European steelmakers against the global market, the actual CO2 reduction calendar is uncertain.

A solution could be a stepwise CO2 reduction approach based on the modification of existing installations, together with retrofit integration of renewable power in the processes. COG dry reforming technology fits into this scheme and would allow stretching the required investment in four steps over the time.

The first step of the COG dry reforming concept targets 17-18% of CO2 savings. It involves the shift of the steel plant’s off-gases from usage in the power plant to injection in the BF, facilitated through internal redistribution of off-gases to avail the entire COG for dry reforming.

The second step targets up to 30% reduction of CO2 emissions and is based on the use of the entire COG and BF gas for dry reforming and the injection of natural gas at different steel plant units.

The third step targets up to 40% of CO2 savings and includes the electrification of the steel mills, ie, replacement of all possible burners in reheating furnaces, coke ovens, sinter plants and other production units by electrical systems (for which the electricity would be produced from non-fossil renewable energy sources).

The fourth step involves the complete substitution of hot blast by oxygen injection in the BF and provides easy CO2 capture possibility from the BF.

**CONCLUDING REMARKS**

As the off-gas distribution and usage varies from one steel plant operator to another, Paul Wurth assists customers in the development of plant specific CO2 reduction strategies and has available now a number of CO2-saving technologies. Driven by its pioneering spirit that has marked traditional ironmaking throughout decades, Paul Wurth is committed to leading the transformation towards finally carbon-free iron ore reduction.

The authors are with Paul Wurth S.A., Luxembourg, and Paul Wurth Italia s.p.A., Genoa

**CONTACT:** steffen.koehler@paulwurth.com
anand.agrawal@paulwurth.com
PAUL WURTH is one of the world leaders in design and supply of the full range of technologies for coke-making, hot metal production and related environmental technologies. Our profound knowledge of raw materials and their transformation, combined with reliable equipment and advanced process automation, gives us the lead in finding innovative and connected solutions for your specific needs in technology, plant and modernization projects:

- Blast furnace design, technology and the entire equipment range
- Coke oven plants, machinery, gas treatment & by-product plants, quenching systems
- Agglomeration: sinter & pellet plant optimization
- MIDREX® direct reduction plants
- Environmental, energy-saving & recycling technologies
- Process and plant optimization services
- Advanced digital products

Leading partner in the world of metals

VISIT US AT METEC
Hall 5/E22
https://www.sms-group.com/metec
paulwurth@paulwurth.com
BOF gas cleaning system upgrades for increased efficiency and off-gas quality

Danieli Linz Technology, specialists in BOF steelmaking and Danieli Corus, one of the market leaders in blast furnace technology, have teamed up to accelerate developments in gas cleaning for BOF plants. A design comprising an improved scrubber based on that widely applied in the blast furnace, plus an improved mist eliminator, offers significant advantages over conventional designs is described.

Authors: Matthias Meyn, Peter Klut and Ruud Herold
Danieli Corus, The Netherlands

Danieli entered the steel converter business in 2011 with the inception of a new, dedicated business unit, Danieli Linz. Activities ramped up rapidly in this highly demanding and conservative area of steelmaking.

Danieli Corus is already very successful in blast furnace ironmaking as well as niche markets for oxygen steelmaking. For instance, it is market leader in the supply of sublance systems, together with one of the most advanced level 2 systems. With the integration of Danieli Linz into the Danieli Corus group, a great opportunity has emerged for further developing equipment for oxygen steelmaking.

Additionally, this is the first time that engineers of an equipment supplier of two disciplines (ironmaking and steelmaking) are working together in a single location. This opens up completely new opportunities for the joint development of tools and software for optimising both blast furnace and converter processes in terms of cost and resource savings.

An article on BOF design, also from this business unit, is on page 36.

In the area of converter off-gas capture, cooling and cleaning, current company activities are focused on maximising the hood design coverage at a minimum maintenance requirement. The completed redevelopment of off-gas scrubber and mist eliminator designs are discussed in this article.

WASTE GAS CLEANING – THE BACKGROUND

As BOF steelmaking is a batch process, the conditions and composition of the gas produced vary from the start to the end of a blow. When oxygen is blown, large amounts of high temperature (~1,750°C), dust-laden (70-200g/Nm³) gas are produced. This gas has to be cooled and cleaned (down to a dust level below 20mg/Nm³) before further processing. Process equipment is installed above and alongside the converter mouth to enable energy recovery as well as collection and recycling of dust.

For dust removal, either a wet or a dry type process is applied. Currently, more than 90% of the de-dusting systems deployed around the world are of the wet type. Dry systems employ electrostatic precipitators that can achieve a dust content below 10mg/Nm³. In wet systems, the gas is cleaned in venturi scrubbers followed by a mist eliminator, resulting in dust content below 20mg/Nm³. However, ESPs have a large footprint and operational disadvantages connected to preventing explosions.

The pressure drop required for gas cleaning is generated by an induced draft fan (IDF), which transports the gas through the cooling and cleaning processes. Typically, the cleaned gas with high calorific value (CO >30vol%) is stored in a gasholder before further processing, while the cleaned gas with low calorific value is flared.

In this article, the focus is on the wet-type cleaning systems. The first process step is quenching the mixture of gas and dust with water, primarily to reduce the temperature, although it also removes the coarser dust particles from the gas and entrains these in the water system. Finer dust particles remain in the gas stream. In the second stage, the gas stream is forced through a ‘narrow gap’ scrubber where the fine dust particles become entrained in the scrubbing water stream. The collected waste water streams from both stages are sent to thickener/flocculation tanks for settling and solids removal [1-3].

SCRUBBER DESIGN – VENTURI-BASED SCRUBBERS

Currently the venturi-based scrubber most commonly used in BOF gas cleaning is the ‘flap venturi’ scrubber, commonly known as the Baumco™ type. A typical example is shown in Figure 1 showing the key stages. The flaps are positioned in the adjustable throats.
TYPICAL ISSUES WITH FLAP VENTURI SCRUBBERS

Although flap venturi scrubbers are widely used, some disadvantages can be identified, including:

- Less efficient mixing of the gas and water flows in certain areas in the system, resulting in less efficient scrubbing
- Internal blockages can occur because dust deposits in internal channels and the resulting increase in pressure drop is detrimental to system performance
- The venturi throat is of a rather complicated design, with a substantial number of moveable parts
- Blockages of the nozzles used for water injection in the venturi throat occur, which results in a loss of scrubber efficiency; consequently, nozzles require regular maintenance (see Figure 2a)
- Cleaning rakes are used to address the blockages, but these are damaged frequently and need to be replaced/repaired (see Figure 2b)
- Clogging of the scrubber outlet has a detrimental effect on the efficiency of the quencher pumps and accelerates pump wear
- Several internal 180° turns of the gas cause friction losses that do not contribute to the cleaning efficiency.

IMPROVED SCRUBBER DESIGN

Danieli Corus has identified and implemented an improved design, called an RS Element scrubber, to address stricter dust removal requirements and improve operational efficiency and costs.

Scrubber structure

An RS Element scrubber is a two-stage single tower construction as illustrated in Figure 3. Stage 1 is the pre-scrubbing/cooling section located in the upper half of the scrubber vessel. It is an open design furnished with centrally arranged non-clogging type spray nozzles. Stage 2, containing the RS Elements and RS Element sprays, is located in the lower part of the scrubber vessel downstream of the pre-scrubbing/cooling section. Water consumption can be minimised by incorporating a water recycling system which recirculates stage 2 water to the top spray nozzles in stage 1. A hydraulic control system, which is used to position the RS Cone Elements and (sometimes) the water control valves, is also part of stage 2.

RS Element scrubbers

A recent development enabling greater dust removal, is the Annular Gap or RS Element scrubber (RS = Ring Slit = Annular Gap). Figure 4 (a and b) shows the basic differences between the two types.

RS Element scrubbers offer advantages that address many of the identified issues with Flap Venturi scrubbers:

- Optimised water and gas flow patterns resulting in a more efficient design
- A longer operating life since the design is more wear resistant
- Virtually maintenance-free, as proven in many blast furnace applications
- Lower operational costs when compared to a Flap Venturi Scrubber system with the same capital expenditure costs
- Straight flow pattern with minimal gas turns

The RS Element scrubber contains an RS Element that
The water that is sprayed into the collar zone at low gas velocity flows through the guide pipe into the annular gap, maintaining a uniform water distribution over the annular gap cross-section. Gas and water are forced through the annular gap creating high turbulence and intensive interaction, thus, all gas streams and dust particulates are thoroughly wetted to provide maximum gas cleaning. To obtain longevity, the main parts of the RS Element, such as the conical outer shell and the male conical body, are manufactured using highly wear and corrosion resistant materials.

The pressure drop between the inlet and outlet of the RS Element predominantly determines the dust removal capacity and is shown in Figure 5. The graph shows that in order to achieve a gas dust content below 20mg/Nm³ a pressure drop above 150mbar is required.

**Water injection nozzles** In the scrubber, the raw gas coming from the converter is conditioned by contacting it with water sprays coming from a series of nozzles positioned in a vertical arrangement alongside the shell of the scrubber, as shown in Figure 3. Each nozzle is installed on a spray arm that goes through the scrubber shell to be connected to the water supply. By contact with water the gas is cooled and the majority of the dust is wetted, thus enabling it to mix with the water.

Although robust, one of the areas enabling improvement is in the water distribution system, i.e., the number and placement of the nozzles and spray lances. More specifically, by improving the atomisation of the water droplets, the available surface area of the water droplets for contact with gas and dust particles will increase. This can be achieved by employing a spiral type of spray head compared to an open type, shown in Figure 6 (a and b), distributed via three spray arms installed in a 2-3-2 pattern at the same height (and only spraying downward).

The benefits of placing seven spray nozzles at one level can be summarised as follows:

- The droplet size becomes much smaller, (e.g., a reduction of the Sauter mean droplet diameter from 2,500µm for the hollow cone spray to 1,250µm for the spiral spray type) which accelerates evaporation
- An improvement in mixing and distribution of gas and droplets
- The increased number of smaller droplets and their improved distribution greatly improves the wetting of particles
- Spiral type nozzles can withstand high dust loads and saturated water flows

As can be seen in Figure 3, spray arms are still distributed over the column but the required number of entry points is reduced significantly. In the first layer, the aim is to pre-cool and saturate the gas with water. The aim of the following two layers is wetting of the dust (to capture coarser particles) and further cooling of the gas to approximately 55-65 °C.

Apart from the advantages mentioned above, the use of spiral type spray nozzles offers some additional benefits:

- These nozzles are less susceptible to clogging than the open type: spiral spray nozzles were originally designed for use in flue gas desulphurisation units for the injection of saturated slurries in a gas stream.
For more than thirty years, our Magnesia Carbon bricks have been consistently upgraded to meet the steel-making industry’s requirements. This means persistent innovation with unchanging high-grade raw material combinations. MACARBON® is still unbeatable in converters, electric arc furnaces, and steel casting ladles. Regularly upgraded. Also in future.

Find out more: www.macarbon.de
The spray patterns will overlap, so improving overall scrubber performance since the presence of areas with less water coverage will become highly unlikely.

Application of multiple spray nozzles in the scrubbers increases reliability compared to conventional scrubber designs.

**WATER REMOVAL**

Before the cleaned gas and captured dust can be efficiently used, as much of the water as possible used in the scrubbing process must be removed. This is done in a variety of ways:

- Initial droplet separation inside the scrubber – typically sharp turns of gas flow/axial rotation
- External mechanical droplet separation – typically a vertical axial mist eliminator
- Wet electrostatic precipitators – dropout and removal on plates.

Most BOF shops use a mist eliminator, the most popular of which is an axial cyclone type where the gas and droplets are brought into a spinning motion with a number of guide vanes, resulting in separation of the droplets from the BOF gas. The axial cyclone type mist eliminator is suitable for the removal of larger droplets but is less efficient in the removal of the finer droplets.

Unfortunately, due to the pressure drop over the annular gap element in this design, a large amount of fine droplets is produced and it is estimated that the free moisture content after the annular gap elements could be as high as 250g/Nm³. In that respect, the axial mist eliminator is doing quite well taking into account that the outlet free moisture content is in the range of 4-5g/Nm³ – an efficiency of 99.6%.

Despite all of these techniques, large amounts of liquid water are found at the ID fans, gas holder and the flare stack. Some of this water originates from sprays used at the ID fans and condensed water in the duct work but, given the pollution found in the water drains, it is also clear that the current mist eliminators do not work as efficiently as they should, resulting in dust emissions at the flare stack and the collection of dust laden water from condensate traps.

The intense contact of dust and water in the Annular Gap scrubber creates droplets that also contain dust. In current designs, the remaining 5g/Nm³ of water droplets after the mist eliminator will be carried towards the flare, the gas holder and eventually the burners of the BOF gas fired boilers. When BOF gas is burned this will create a dust emission.

The BAT BREF report [4] shows that limits of 5-10mg/Nm³ can be achieved with a venturi type scrubber, but it should be noted that these low values can only be
washing can be set on a regular interval or can be set on a differential pressure measurement. The wash water will be drained together with the collected droplets.

**BENEFITS**

As a result of the cooperation with Sulzer, there is now a patented mist eliminator design capable of achieving a droplet content below 0.1g/Nm³ in clean BOF gas, which equates to a removal efficiency of 99.96%. It also has a smaller footprint and similar CAPEX to conventional designs. This will lead to cleaner ducting, low dust emissions at the flare stack and BOF gas-fired boilers, trouble free ID fan operation and less maintenance and sludge arising at BOF gas holders.

**ALTERNATIVE MIST ELIMINATOR CONFIGURATION**

Where there is a considerable distance between the scrubber and the ID fan an alternative design is available whereby droplet removal can be split into two separate units. These comprise a carryover mist eliminator near the scrubber.

**NEW MIST ELIMINATOR DESIGN**

The newly developed mist eliminator is based on a three-step approach for droplet removal:
1. Shell Schoepentoeter™ at the inlet
2. Sulzer Mellachevron™ mist eliminator
3. Sulzer Knitmesh™ & Mellachevron™

The first step of the design is the diverter inlet, the Shell Schoepentoeter™, that feeds and distributes the BOF gas into the column while removing a large portion of the coarse droplets. The second step consists of a vane type Chevron Mist Eliminator, the Sulzer Mellachevron™, which consists of vertically positioned vanes that separate droplets using their inertia. The finest droplets, which pass the Chevron Mist Eliminator, need to be coagulated before they can be separated; the third step of the removal process. This coagulation is achieved by the Sulzer Knitmesh™ that is operated in a flooded mode, creating a horizontal droplet flow. The larger droplets that are created are collected in another Mellachevron™ positioned after the Knitmesh™. The droplets from all steps are collected at the bottom of the vessel and returned to the wet scrubber. The design is shown in Figure 8. The working principles of Knitmesh are shown in Figure 9.

**Mist eliminator cleaning**

A number of spray nozzles will clean the surface of the Mellachevron™ and Knitmesh™ parts of the mist eliminator to prevent clogging. This
and a condensate mist eliminator near to the ID fan. This alternative line-up is summarised in Table 1.

The condensate mist eliminator consists of a Mellachevron™ and a Knitmesh™ and lowers the droplet concentration to below 0.1g/Nm³. At these low droplet concentrations, the ID fan will operate more stably and should experience less vibration. It is expected that no water wash will be required for the ID fan.

**DESIGN SUMMARY**

A schematic of a typical gas cleaning plant of the new design is shown in Figure 10. Design improvements are as follows:

- Application of an RS Element scrubber design based on wet scrubbing technology widely applied and proven in blast furnace ironmaking. The straight gas flow through wide passages avoids redirection and unwanted pressure drop. Water injection through quick exchangeable spiral type nozzles allows for less stringent water quality requirements at improved scrubbing performance including changes to the water dispersion patterns and their distribution throughout the scrubber tower. Application of special internal coatings reduces clogging and abrasion.

- A new mist eliminator design with a higher efficiency than the traditional axial type. Also, the application of an advanced, multi-stage mist eliminator design with proven track record in other industries is presented. The effective droplet separation further reduces particulate emissions and helps with operational problems and damages of Induced Draft fans. The elaborated design offers great advantages over conventional axial droplet-separators. The application of the improved mist eliminator that can lower the droplet content in the BOF gas to below 0.1g/Nm³ will lead to cleaner ducting, low dust emissions at the flare stack and BOF gas fired boilers, trouble free ID fan operation and less maintenance and sludge arising at BOF gas holders.

**CONTACT:** Edo.Engel@danieli-corus.com

Matthias Meyn, Peter Klut and Ruud Herold are with Danieli Corus, IJmuiden, The Netherlands

**REFERENCES**

Silica Bricks
High Alumina, AMC, ASC Bricks
MgO, MgO-C & MgO-Chrome Bricks
Spinel Bricks
Precast Shapes
Monolithic Lances
RH Degasser Refractories
Isostatic Products
Complete Ladle Solutions
BOF design improvements and upgrades

Since its launch in 2011, the converter division of Danieli has revamped/redesigned five converters and is currently working on a further two. Design changes include vessel size and shape, vessel suspension system, vessel shell construction materials, cone water cooling, barrel air cooling, converter temperature monitoring and equipment condition monitoring systems.

Authors: Günther Staudinger, Michael Skorianz and Uazir Bezerra de Oliveira
Danieli Corus

Danieli entered the steel converter business in 2011 with the inception of a new, dedicated business unit, Danieli Linz Technology (DLT). Activities ramped up rapidly in this highly demanding and conservative area of steelmaking. Currently, five BOF converters supplied by DLT are operating worldwide with sizes between 80t and 350t. Another two are currently under fabrication (see Table 1).

Since July 2018, Danieli converter technology has been fully integrated into Danieli Corus at IJmuiden (The Netherlands). See also the Danieli article on page 28. All these BOFs are bespoke but based on best practice, input from end user and other requirements. The designs include fixed bottom, detachable bottom, welded and bolted top cones, with and without knuckle sections, forced draft air cooling and water cooling (see Figure 1).

<table>
<thead>
<tr>
<th>Plant</th>
<th>Tap weight t</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArcelorMittal Dobrava Gornicz</td>
<td>350</td>
<td>May 2014</td>
</tr>
<tr>
<td>Aperam Timoteo</td>
<td>80</td>
<td>Dec 2015</td>
</tr>
<tr>
<td>ArcelorMittal Krakow</td>
<td>155</td>
<td>Nov 2016</td>
</tr>
<tr>
<td>ArcelorMittal Kryvyi Righ</td>
<td>160</td>
<td>Aug 2017</td>
</tr>
<tr>
<td>ArcelorMittal Galati</td>
<td>180</td>
<td>Dec 2017</td>
</tr>
<tr>
<td>ArcelorMittal Temirtau</td>
<td>300</td>
<td>2019</td>
</tr>
<tr>
<td>USIMINAS Ipatinga</td>
<td>180</td>
<td>2020</td>
</tr>
</tbody>
</table>

Table 1 Reference plants

Fig 1 Reference plants
CONVERTER PROCESS EFFICIENCY

The BOF converter remains one of the most important process units worldwide for producing high quality steel. To facilitate the physical and chemical reactions during blowing the converter has to provide a certain reaction volume, bath depth and reaction surface. The characteristic benchmark is the specific volume (defined as ratio of inner reaction volume to mass of liquid steel \([m^3/t]\)) which should be maximised.

Several boundary conditions have to be considered, however, when upgrading or revamping a vessel in an existing steel plant. These include:

- Clearances during charging, tapping and to the off-gas system
- Tilting torques
- Foundation loads

Various design iterations are made during the engineering phase in order to find the right solution for each plant configuration and revamp.

A typical example is the 350t BOF revamped for ArcelorMittal Dobrava Gornicza (Katowice) in 2014. Figure 2 shows the original and new vessel designs. It can be seen that the new vessel is slightly taller and wider, giving an inner volume increase from 225m³ to 275m³ and an increase in specific volume from 0.64m³/t to 0.79m³/t, but it still fits into the original space.

VESSEL SUSPENSION SYSTEMS

A key design feature of a converter is its suspension system which has to:

- Keep the vessel shell in the correct position at all times
- Withstand all possible conditions which can occur during operations, such as high temperature, water shocks, mechanical impacts, burn-throughs and solidified steel bath
- Be maintenance free. This is the most challenging issue

In principle, suspension systems can be subdivided into...
vertical and horizontal suspension elements, which are characteristic for all modern suspension systems for vessel sizes of more than 50t. The loading of these elements is dependent on the actual tilting angle of the BOF.

For the vertical loads Danieli Corus applies the well-known lamella-type suspension elements (usually eight in number) but with an improved design to provide a better load distribution within the elements which should also increase their operating life. The thermal expansion and long term deformation are compensated by elastic deformation of the lamella elements.

The horizontal loads are typically carried by only two elements, which are, therefore, the most critical. Danieli Corus has developed a new patented element, the so-called DANIELLA element (see Figure 3). There is a centre bracket welded to the vessel shell and two brackets welded to the trunnion ring, with the lamella plates arranged between these. These lamella plates do not have a fixed connection to any bracket but are simply located in the positions shown.

During vessel heating at the start of a campaign as well as during production, the vessel brackets are exposed to a higher heat load than the rest of the assembly. This results in more thermal expansion and is compensated by elastic deformation (bending) of these plates within a provided the clearance to the centre plate (see Figure 4). The long term deformation of the vessel shell (creep) is not hindered at all in this DANIELLA element and does not cause any additional stress or deformation.

This is a simple and very robust structure which does not require special elements like bearings, forgings or castings, leading to simpler repairs (eg, in an emergency case) which can be carried out by the regular maintenance team, and so minimising downtime and costs.

Figure 5 shows the installation of the Danieli suspension system and detail of the Daniella plates.

The advantages can be summarised as:
- Simple and robust design
- No special parts involved (repairs can be done by maintenance staff only)
- Lamella plates are simply inserted between welded-on brackets and held in position by holder plates. Thus, these plates can easily be changed or adjusted eg, in an emergency

**CONVERTER LIFE**

In the BOF supply market, there is an increasing demand to provide complete system responsibility. This means optimising converter and refractory technologies with the aim of increasing their lifetimes in parallel as a system.

There are two aspects to converter life: campaign life, as measured in number of heats between refractory relines, and overall vessel productive life, as measured in years, and which is influenced primarily by shell distortion. Both directly influence the cost of liquid steel via Opex and Capex, respectively.

To help maximise vessel refractory life, the refractory should be maintained for as long as possible, and hence is at high temperature over a long period. However, for maximum productive life of the vessel shell, its temperature should be as low as possible. These are obviously in contradiction – a condition that worsens as the lining thins during a campaign. Today, campaign lives are measured in thousands, lasting even one to two years, but this requires using slag splashing and rocking at every heat to maintain a certain minimum lining thickness in order to avoid further shell overheating or even burn through.

Modern efficient plants also operate with ever shorter tap-to-tap times so there is less time for shell cooling. Under these conditions vessel life can be reduced to less than 10 years, from a more normal 20 years or more (some converters have been in operation up to even 40 years). Consequently, compromises need to be made.

The possibilities for converter suppliers to increase the lifetime of the vessel shell as such are rather limited. The most reliable technologies can be summarised as:
- Application of high creep resistance material for the vessel shell
- Installation of a water cooling system for the converter top cone
- Installation of an air cooling system for the converter barrel section
- Installation of a temperature monitoring system for the complete vessel shell

**Creep resistance** Creep resistant steels which can be used for a converter vessel, are more or less limited to the following pressure vessel materials (based on European Standards): 16Mo3, 13CrMo4-4, 10CrMo9-10 and P420MHT. A comparison in terms of stress to reach 1% creep strain for a temperature level of 500°C is shown in

![Fig 6 Stress for 1% creep strain at 500°C](image-url)
16Mo3 is a very common material, having excellent mechanical properties up to 500°C, reasonable creep resistance, and is moderately easy to weld. The best grades in terms of creep are the Cr-Mo-alloyed steel varieties, 13CrMo4-4 (ASTM A387 Gr.11) and 10CrMo9-10 (ASTM A387 Gr.22). These demonstrate excellent creep resistance but require very careful welding as well as post weld heat treatment (PWHT). This is not an issue for the supplier but has to be taken into consideration for on-site repairs. These materials have been in use for many years in converters in North America and are now being accepted in other parts of the world.

An additional potential steel is P420MHT, a thermo-mechanical rolled grade which does not require PWHT. However, if it is overheated during vessel operations (above 600°C) its mechanical properties can degrade so it is not the preferred material for BOF application by Danieli Corus.

**Top cone water cooling** The top cone is the most exposed part of the BOF in terms of temperature, particularly during tapping and from slopping slag. In some plants the temperature of the top cone is so high that it almost becomes a ‘wear’ part. A possible solution is to use water cooling, as a result of which lifetime can be significantly increased (even doubled). However, because of the extreme conditions and the risk associated with water by eg, contacting liquid steel, leakages must be quickly identified and the cooling system shut off and repaired (eg, during the next shut down or relining period).

**Air cooling of the barrel** The barrel section is of utmost importance because the deformation in this area defines the end of the lifetime of the converter body. For instance, with severe heat distortion the vessel shell can even extend across the trunnion ring gap. Air is a very ineffective cooling media but for the barrel section there is really no alternative available.

Danieli Corus uses forced air cooling of the vessel shell which flows through hundreds (even thousands) of holes in air panels or on the inside of the trunnion ring web plates into the air gap between trunnion ring and converter. These air flows disrupt the natural air flow within the trunnion ring, providing turbulence and a mixing of the hot air with the cooler, and increases the convection factor outside the vessel. Air cooling is more effective at higher shell temperatures.

**Converter temperature monitoring system (Q-TEMP)** Another feature to prolong converter life is monitoring of the vessel shell temperature. Danieli Corus has already installed a converter temperature monitoring...
system, the so-called Q-TEMP, on an 180t BOF in Ukraine. However, this installation is to be further improved in terms of lifespan of the sensors, which are based on thermo-resistance elements, as well as providing better access. Based on the combined experience of the Danieli Corus ironmaking team, where similar applications are successfully installed on blast furnaces, and the experience from BOF applications, the next generation – Q-TEMP 2.0 – has been developed and will be applied in a new BOF in Brazil.

This system is based on two different measurement methods. In the top half of the vessel (with no direct visual access) thermocouples are arranged directly onto the vessel shell. In the bottom half, which has visual access the temperature is measured by infra-red cameras (see Figure 7).

There are 32 thermocouples arranged in four horizontal rows on the vessel shell. The data is transferred via hardwired cables through the trunnion ring to the outside of the trunnion pin. From there a WiFi connection is provided for data transfer and further processing. The recorded data are saved on a hard drive and displayed in the main pulpit. (An example of the displayed temperature distribution of a converter vessel is shown in Figure 8.)

Q-TEMP 2.0 has following new features (see Figure 9):

- Use of thermocouples instead of thermo-resistance elements
- All thermocouples can be maintained and exchanged from inside the trunnion ring
- All elements are arranged in such a way that they permanently contact the vessel shell and so can follow all vessel shell deformation
- Not necessary to remove slag shields for maintenance of the protection piping of the elements

STATE OF THE ART

Recently Danieli Corus has been awarded a contract to replace an 180t BOF in Brazil where all the above factors were essential for this order (see Figure 10). The design includes:

- High creep resistance steel for the vessel shell
- Water cooling system for the top cone
- Air cooling system for the barrel section
- Temperature monitoring system for the complete vessel shell

DANIELI CONDITION MONITORING SYSTEMS (DCMS)

In modern challenging steelmaking scenarios, there is a common focus on cost reduction while maintaining high plant availability and reliability. This is somewhat of a contradiction because, on the one hand, maintenance reduces the operation time, but it aims to avoid total failures of components which can create major shut downs...
and disable production. Hence, there is an optimum of how much maintenance should be applied. In principle three types of maintenance are possible:

a) **Breakdown or emergency maintenance** Repair or change of components after breakdown. Most risky and can cause major shutdown if spare parts are missing, if repairs are complicated and can be a time-consuming repair, so should be avoided.

b) **Preventive maintenance** Is applied on a regular basis when a machine or components are overhauled at specified time intervals, regardless of the condition of the parts.

c) **Predictive maintenance** The maintenance requirement is determined by continuously analysing the condition of the machine or components in order to predict and schedule the most efficient repair action prior to failure. This is the preferred option.

In principle, the DCMS measures machine vibrations in dedicated locations. The vibration signals are collected through accelerometer sensors installed directly on the machine body. Data sampling and acquisition is managed automatically and is configurable on the server with different modalities.

The vibration data is synchronised to the machine movements in order to relate the vibration signals with the working condition of each piece of equipment. A server collects the data and performs on-line processing, data archiving and post-processing. The vibration values acquired during the machine working condition are compared with the pre-fixed threshold limits for automatic alarm generation and management.

In the BOF this system can be typically applied in the converter tilting drive (bull gear and primary gears) as well as in the main bearings. An overview of the application is shown in Figure 11.

**CONCLUDING REMARKS**

Since its launch in 2011, the converter division of Danieli Corus, with the aim of improving process efficiency and lowering capital and operating costs, has revamped/redesigned five converters and is working on a further two. Design changes include vessel size and shape, vessel suspension system, vessel shell construction materials, cone water cooling, barrel air cooling, converter temperature monitoring and equipment condition monitoring systems. **MS**

**Günther Staudinger, Michael Skorianz and Ulazir Bezerra de Oliveira are with Danieli Corus, Ijmuiden, The Netherlands**

**CONTACT:** [Edo.Engel@danieli-corus.com](mailto:Edo.Engel@danieli-corus.com)
Our extensive knowledge of the Graphite Electrode manufacturing process, coupled with our long-standing commitment to quality has enabled SHOWA DENKO to be a preferred partner to the global steel industry.

When it comes to electric steel production, SDK’s UHP Graphite Electrodes remain the product of choice.

QUALITY – RELIABILITY – CONSISTENCY
The proof is in our performance
Consteel continuous scrap feeding and iRecovery

Ori Martin has completed the revamping and modernisation of its Bressica Consteel EAF – the first such unit in Europe. The project scope included design advancements to improve operational efficiency and the installation of a heat recovery system on the primary off-gas line. This latter system is used to recover thermal energy in the gas for the production of steam used for district heating and to feed an ORC (Organic Rankine Cycle) turbo-generator to produce electrical energy.

With the aim of increasing meltshop flexibility and reducing steel production cost, Ori Martin has successfully revamped and recommissioned its steel plant at Bressica, Italy, the site of the first European Consteel EAF unit, together with the installation of a heat recovery system on the primary off-gas line. The installation of the latest Tenova technologies has significantly improved the Consteel EAF performance and, thanks to the new iRecovery system, a significant amount of thermal energy is now recovered and delivered to the city of Brescia’s district heating grid during the winter months or fed to an ORC (Organic Rankine Cycle) turbo-generator to produce electric energy for Ori Martin’s internal use in the summer. The new installation has provided Ori Martin with one of the most environmentally friendly and energy efficient steelmaking plants in the world (see Figure 1).

THE NEW CONSTEEL PLANT

Following evaluation of operating results of the original plant configuration and the numerous tests carried out jointly by Ori Martin, backed by Tenova Engineering and Process departments, a number of goals were identified, including improving energy efficiency utilisation, environmental performance, product quality and plant flexibility, while keeping production focused on special steel grades.

The project was based on the following fundamental concepts:

- Rebalance the two main components of the melting unit (Consteel and EAF) to efficiently achieve the productivity goals
- Improve the thermal exchange between the EAF off-gas and the scrap in the different charging conditions (greater exposed surface and lower height of the scrap layer)
- Improve the distribution of scrap entering the liquid steel bath (larger surface area where scrap falls in the steel bath) to speed up the melting with a lower interference with the steel bath stirring
- Keep the connecting car pan inserted inside the EAF for any furnace tilting angle, so as to have the metallic scrap charging and the electrical power-on to the EAF electrodes starting together with minimal delays
- Reduce ambient air suction inside the Consteel and the primary off-gas line by increasing the efficiency of the Consteel seals and by better control of ambient air intake through the dynamic seal
- Maintain high temperatures of the EAF off-gas
- Reduce off-gas flow rate in the primary off-gas line and consequently reduce the electric consumption to the fume treatment plant
- Improve the conditions of the off-gas at the inlet of the heat recovery system installed on the primary off-gas line.

Process control is via a completely new and innovative system for supervision and control that is able to interact consistently with management systems of the other production units. This type of system is part of the global solution iSteel, developed by Tenova for the continuous...
The technological improvement of the steel production cycle. The automatic control of spillage TAT (Tenova Auto Tapping) has been implemented to control slag flow through the EAF eccentric bottom tapping (EBT) into the ladle and to minimise human intervention during this operation.

The melting process at Ori Martin is rather atypical when compared with the other Consteel EAFs as it employs only limited oxygen and carbon injection, leading to a modest quantity of energy in the off-gases. The main goal of the revamping project, therefore, was to maximise the recovery of the off-gas energy by improving the heat transfer to the scrap in the heating tunnel and by optimising the conditions of the gases at the tunnel’s exit to properly feed the downstream recovery system.

The transfer of heat to the scrap is improved by increasing the scrap exposed surface through the installation of the widest possible conveyor (2,400mm) compatible with the existing EAF geometry. At the same time, the new Consteel drive allows the conveying speed to increase by 2m/min. These changes result in a reduction of the average scrap height from 800mm to 500mm, which boosts the average scrap charging temperature at the EAF.

The heating tunnel hoods have been completely redesigned, applying the results of a computer fluid dynamics (CFD) analysis on actual off-gas flow data. The aspect ratio of the hoods has been changed – they are wider and lower, while the overall section has been reduced by about 20%.

The efficiency of the energy recovery, both in the Consteel tunnel and in the downstream iRecovery, improves dramatically with increasing temperature of the gases. Additionally, a completely redesigned set of seals has been employed to reduce air ingress to a minimum. The sealing chamber at the open end of the conveyor (a dynamic seal) has been reconfigured to achieve this result.

To seal the gap between the heating tunnel and the EAF shell, a new circular flange, divided into two independent sectors, has been installed. The position of the upper flange can be regulated to adjust the quantity of post-combustion air to assure the complete combustion of CO and H₂ generated in the EAF. Both flange sections are retractable to give the necessary clearance for the shell changeover between campaigns. The improvement of the seals and the changes in the design of the dynamic seal allows significantly higher fume temperatures than the ones observed before, both inside the tunnel and at the tunnel’s exit.

To reduce the dust load in the fumes sent to the waste heat boiler and improve the deposition of the metallic dust particles on the scrap layer, the offtake hood has also been redesigned, increasing both the horizontal section and the height to reduce the vertical speed of the fumes and increase their residence time (see Figure 2).
platform cradles were replaced to match the EAF tilting axis and the flange axis, and the connecting car was also improved so that it can be left inserted throughout the whole process, eliminating process delays.

iRECOVERY

The heat recovery system, iRecovery (Figure 3), has been running successfully since early 2016. This system, installed downstream of the new furnace, has the task of recovering part of the energy contained in the fumes generated during the EAF production cycle. The energy extracted from the fumes converts the recirculation cooling circuit water into steam. This is made possible thanks to the use of cooling water at boiling conditions that, by circulating and absorbing energy, will be subject to partial phase change generating saturated steam.

During winter months the steam produced is sent to a heat exchange unit dedicated to district heating for the town of Brescia managed by A2A Group. During the summer the steam is used to feed an ORC turbo-generator supplied by Turboden for the production of electricity for internal use.

The heat exchanger, generally called a waste heat boiler, consists of a single convective exchange unit, operating between fume temperatures of approximately 500-550°C down to a temperature of approximately 200°C. However, since the EAF process generates heat loads which are not constant over time (scrap melting, liquid steel refining and superheating, tapping, EAF preparation), the fume temperature varies significantly during processing. The recovery of heat and its transfer to the users is carried out according to a continuous cycle where water, coming from the degasser (see later), evaporates into the waste heat boiler, cools down in the heat exchangers and then...
temperature rises from about 105°C to a temperature close to the boiling point, at a defined pressure, in the steam drum, and resulting in a lower off-gas coming temperature.

- Automatic recuperator cleaning system that allows the cyclical separation of dust deposited on the surfaces of the exchange units inside the waste heat boiler.
- Dust extraction system to collect and convey the dust separated in the recuperator up to a storage bin.

Heat exchange section with A2A district heating system
Here, the steam coming from the steam accumulation section transfers its energy to the water of the district heating grid. The unit comprises a condensing heat exchange unit consisting of two condensing heat exchangers operating in parallel, a flash tank inside of which all the condensate is conveyed, and an additional condenser which condenses the flash steam bringing it in exchange with the same district heating water (see Figure 5). All the condensate is subsequently sent to the degasser through a booster pump group.

ORC section
This converts the recovered thermal energy into electrical energy and consists essentially of a turbo-generator (see Figure 6) with an ORC that uses the steam from the recovery section and converts the recovered thermal energy into electrical energy.

Water supply section
This comprises a thermo-physical degasser with turret which has two duties: first, to ensure continuity of supply to the recuperator in case of non-supply of make-up water, second, to allow the elimination of gases dissolved in the make-up water. The water in the degasser is drawn from a group of feed pumps and transferred to the recuperator steam drum. The pump group is provided with a level control valve that regulates the flow of water depending on the level of water in the steam drum.

Steam pressure accumulation and reduction section
The steam produced by the recuperator is conveyed to a steam accumulator whose function is to accumulate the thermal energy. In its outlet on the delivery lines to the users, there are some thermal expansion valves to reduce and ensure the steam pressure at a value below the preset value. Additionally, between the steam drum and the accumulator there is a valve that prevents pressure in the steam drum falling below a predetermined value.

OPERATING RESULTS
Operating data analysis from start-up of the new Consteel EAF, through commissioning and start-up of the iRecovery system indicates excellent performance was achieved by...
these two integrated systems. The performances were measured by calculating a cost index that considers energy and material consumptions. The expected reduction of more than 8% of this cost index compared with the previous average values was confirmed.

The productivity of the furnace shown during tapping in Figure 7 has increased by more than 13%, exceeding all expectations, so becoming an outstanding reference value for the production of steel via an EAF. Further developments and continuous improvement are ongoing, exploiting the high potential demonstrated by the system to exceed expected values.

The operation achieved with the new Consteel EAF is the base upon which the expected performance of the iRecovery system to recover more than 90kWh/tonne of good billets of thermal energy from the primary off-gas that will be available for district heating and the ORC turbo-generator. Thanks to a commitment to optimise plant tuning, the steam flow rate is now controlled based on the average thermal load of the fumes expected and can now be kept uniform over tap-to-tap time due to the thermal buffer of the steam accumulator. After more than one year of operation the results show that the amount of energy recovered from the off-gas is in line with the expected results.

CONCLUSIONS

The new Consteel EAF and the new iRecovery system have been fully integrated and the operation of the whole system is steady and consistent, enabling Ori Martin to be one of the most flexible, efficient and environmentally friendly steel making plants in the world. It also provides the company with the opportunity to exploit an additional lever for a more flexible and efficient operation of the plant. Furthermore, the potential already demonstrated by the system offers additional opportunities for the optimisation of performance and costs in many different scenarios.

Nicola Monti is with Tenova S.p.A., Castellanza, Italy and Uggero De Miranda is with Ori Martin S.p.A., Brescia, Italy

CONTACTS: nicola.monti@tenova.com, uggero.demiranda@orimartin.it
Sarralle new Bluesky-Plant® eco-technology for fume exhaust system (FES) in steel plants

Sarralle offers solutions based on Eco efficiency, with a warranty of a minimum environmental impact in the steel manufacturing process.

The new eco-technology Bluesky-Plant® offered by Sarralle is a technological advance since, with the filtering of the fumes and the injection of particles of various materials, it fully guarantees the more restrictive limitations of the European Environmental Regulations. The aim of the system of aspiration is to improve the extraction of fumes from steel melting plants throughout the manufacturing process which, in practice will prevent the accumulation of exhaust in the facilities, improving the air quality and the health of the employees and minimizing emissions to the exterior contributing to the conservation of a cleaner atmosphere.

Bluesky-Plant® developed with an eco-efficient management of the production processes, not only reduces the volume and pollution of the waste generated, but also increases the competitiveness of our customers. Sarralle contributes to the sustainable economy by offering eco-friendly engineering solutions with the recovery of steel dust among others.

TURNKEY PROJECTS
In recent years Sarralle has accomplished several projects in the area of fume extraction systems, applying its new eco-technology Bluesky-Plant®.

Bluesky-Plant® is decisively contributing to the adaptation that many mills are undertaking to comply with the new environmental regulations, through new investments. These include different international turnkey projects and recently the new two projects for the company Megasa (dedicated to the production and distribution of long steel products), to renew the fume extraction system in the two plants that the company owns in Portugal, specifically in Lisbon (Seixal) and in Porto (Maia).

ABOUT SARRALLE
Sarralle is a business group created in 1965 in Azpeitia, a leader in industrial engineering in the Environment (with waste recovery and water treatment projects among others), Energy and Steel sectors, and is dedicated to the development of turnkey solutions.

The business group covers the design, engineering, manufacturing, assembly and commissioning of machines and installations for these sectors worldwide.

Sarralle has 5 business lines: Steelmaking, Rolling Mills, Coil Processing Lines, Environment & Energy and Workshop & Storage Systems for different sectors.
Successful utilisation of mechanical vacuum pumps in steel degassing

Mechanical dry vacuum pumps are increasingly replacing traditional steam ejectors in vacuum secondary steelmaking plant applications because of their ‘greener’ credentials and proven record of reduced cost of ownership by as much as 97% compared to steam ejectors. This calculation takes into consideration the cost for production of steam, water circuit pumps, maintenance and disposal of condensate versus lower power consumption of mechanical pumps with its maintenance cost.

To achieve and maintain these economic advantages at high production rate over many years, good systems design and maintenance of equipment are required.

Edwards Ltd, a major manufacturer of vacuum pumps, has the largest installed base of dry pumps in the global steel industry with many years of field experience.

Authors: Anke Teeuwsen, Aditya Agrawal, Leonardo Bonifacio, Tom Burke and Frank Shi
Edwards Ltd

The steel market is increasingly demanding higher grade steels, be it for mobility such as automobiles, ships and railways, or structural steel for bridges and high buildings. The use of vacuum treatment of molten steel to ensure removal of nitrogen, hydrogen or carbon, appropriate to steel application requirements, is a key part of the modern steelmaking process route. The various vacuum degassing processes used are proven methods and have been traditionally equipped with steam ejectors to help produce the vacuum.

However, over the last 15 years, use of dry vacuum pumps has increased markedly. Starting from installations in foundry billet operations that were relatively light duty, their utilisation has progressed to the high volume requirements for continuous caster operations seen today. These operations require that the pumping equipment runs continuously during campaigns with high uptimes, and these demands on pumping system design and reliability currently dominate conversations in the industry.

The change from steam ejector to a mechanical pump is not just an exchange of equipment, rather, it is a change in paradigm, requiring a different approach in both operation and system design.

STEEL DEGASSING VACUUM REQUIREMENTS

The main secondary metallurgy treatments under vacuum are Vacuum Degassing (VD), Vacuum Oxygen Decarburisation (VOD) and Ruhrstahl-Heraeus (RH). The process regimes have, in common, a pump down requirement to 0.67mbar (0.5 torr) within 5-9 minutes and a treatment of about 20 minutes at this pressure. VOD and RH-OB variants include a preceding oxygen blow at higher pressures to decarburise the steel.

The suction speed requirements at low pressures are large, with approximately 1,200m³/h/t of steel for VD, 1,500m³/h/t for VOD and 3,200m³/h/t for RH. These are values based on field experience, but may vary depending on stoichiometric metallurgy design calculations. These numbers refer to optimised installations, not considering unnecessary additional gas loads.

The installed capacity of steam ejectors in older installation is typically oversized to counter its creeping deterioration of performance due to dust deposits in the nozzles and extend its maintenance intervals. Thus it is not a suitable benchmark for comparative sizing of mechanical vacuum systems.

The process gases are a mixture of Ar, N₂, H₂, C, CO and others, and with large amounts of fine pyrophoric dust also present.

Authors: Anke Teeuwsen, Aditya Agrawal, Leonardo Bonifacio, Tom Burke and Frank Shi
Edwards Ltd

This article outlines the difference between a steam ejector as a mass conveyor and the mechanical vacuum pump as volumetric conveyer, and the implications for systems design (sizing, installation in pump room, filters), on-site performance testing, operation and maintenance for use in VD and VOD facilities, with the target to achieve an optimal solution.

STEEL DEGASSING VACUUM REQUIREMENTS

The main secondary metallurgy treatments under vacuum are Vacuum Degassing (VD), Vacuum Oxygen Decarburisation (VOD) and Ruhrstahl-Heraeus (RH). The process regimes have, in common, a pump down requirement to 0.67mbar (0.5 torr) within 5-9 minutes and a treatment of about 20 minutes at this pressure. VOD and RH-OB variants include a preceding oxygen blow at higher pressures to decarburise the steel.

The suction speed requirements at low pressures are large, with approximately 1,200m³/h/t of steel for VD, 1,500m³/h/t for VOD and 3,200m³/h/t for RH. These are values based on field experience, but may vary depending on stoichiometric metallurgy design calculations. These numbers refer to optimised installations, not considering unnecessary additional gas loads.

The installed capacity of steam ejectors in older installation is typically oversized to counter its creeping deterioration of performance due to dust deposits in the nozzles and extend its maintenance intervals. Thus it is not a suitable benchmark for comparative sizing of mechanical vacuum systems.

The process gases are a mixture of Ar, N₂, H₂, C, CO and others, and with large amounts of fine pyrophoric dust also present.
which adds to the operating cost.

Steam ejectors are mass conveyers, as the operating principle is about moving a defined amount of gas, independent of gas temperature. Performance is measured, for instance as: kg/h DAE (Dry Air Equivalent). The performance within one stage remains quite constant. Figure 2 shows 20-30lb/hr range per stage.

FEATURES AND BENEFITS

- No moving parts – low maintenance regime and spares inventory
- Large internal clearances – requires just regular cleaning after clogging and decreasing performance
- Filter beneficial but not mandatory
- Lower initial installed suction capacity limitation due to low additional investment
- No inlet temperature limitations, in case no filter is used

DISADVANTAGES

- Capital cost high when steam not available from BOF as boiler for steam production required
- Even if steam available, in some cases boiler required to improve quality of steam
- High power consumption for steam production with boiler
- Uprating of performance after installation not possible
- Maximum cooling water temperature 25°C to ensure condenser performance
- High disposal cost for condensates, liquid-ring-pump feed water and cleaning slush
- Time consuming maintenance in particular if no filter is used
- Low readiness for cyclic production in campaigns as pre-heating of boiler required

MECHANICAL VACUUM PUMPS

Unlike steam ejectors, mechanical vacuum pumps are volumetric conveyers. As the internal pump volume, which is exposed to the vacuum system, increases, the gas from the vacuum system expands to fill this added volume and the system pressure drops. It is this phenomenon which makes mechanical vacuum pumps work.

For compression to atmospheric pressure the screw pump principle is, today, state-of-the-art in steel degassing. Two shaft screw-shaped rotors push the process gas by multiple windings out to the exhaust (see Figure 3).

Traditional single ended screw mechanisms which are compressing towards one end may suffer additional axial load and heat generation at the exhaust. To overcome this, Edwards technology either has a high technology single screw with tapered pitch design or double ended screw
mechanism as shown in Figure 4, which compresses the flow to both ends. This ensures longer lifetime of bearings and avoids overheating and consequential seizures in the harsh duty of steel degassing.

Screw-type vacuum pumps have excellent ultimate pressures compared to steam ejectors of <\(0.1\) mbar at inlet (depending from individual design) compressing to atmospheric pressure in the outlet.

Multiple layers of Roots vacuum pumps or so-called mechanical boosters (MB) are added to achieve high performance towards lower pressures, with very low power consumption!

A schematic of a Roots pump is shown in Figure 5. These pumps are designed either as two-shaft rotor machines which convey the gas in one step without inner compression or as pre-inlet gas cooled pumps which are used in some designs with higher pressure stages.

All pumps are equipped with frequency inverters for soft start of the screw pumps and the boosters during pump down.

**VACUUM PHYSICS – BOYLE’S LAW**

In the mid 17th Century, Robert Boyle observed that the product of the pressure and volume of a confined gas held at a constant temperature are observed to be nearly constant. The product of pressure and volume is constant for an ideal gas as per the well-known equation, 

\[ p \cdot V = \text{constant} \]

The volume captured at low vacuum contains low number of molecules, with compression from stage to stage the mass density in the gas increases. This is illustrated in Figure 6.

During pump-down, the boosters are filled with process gas of higher mass density as the pressure is high, consequentially the compression work is far larger and power consumption would, theoretically, go up to impracticable values with regards to power requirements. This is why all mechanical boosters start with lower frequencies, by means of capturing smaller volumes at higher pressures and is why the suction speed curve of a mechanical system increases towards lower pressures to a maximum, while mass flow performance decreases (see Figure 7).

The control philosophy varies depending on vacuum systems concepts and booster compression capability of different manufacturers.

The Edwards modular concept considers starting of boosters at atmospheric pressure then as the pressure decreases, the boosters begin to steadily accelerate towards full speed against their current limits set on the frequency inverter. This allows us to push the pumps within safe limits and achieves an optimised performance right from start of the system, as shown in Figure 7.
System performance increases from installed 1,000m/hr backing pump towards lower pressures.

By design principle the power consumption of boosters is lower compared to atmospheric pumps, as process gas is conveyed only into the next stage and thus the compression work is lower. The installed motor power on a booster depends on two factors, the delta pressure capability, with intention to use it, and the mechanical loss due to high inertia of big masses:

- Boosters with high delta pressure capability are helpful to enable short pump down times, in particular when installed next to the screw pump
- Large boosters with low rotational speed consume additional power to overcome the inertia of the heavy rotors, and at the same time the acceleration is slower, impacting the pump-down time performance

The Edwards system design concept utilises strong compression in the second stage and in the top stage a new design high performance booster with innovative lightweight rotor technology as shown in Figure 8, which is suitable to cope with dust.

**PERFORMANCE TESTING**

Performance measurement on mechanical vacuum pumps and systems is described in DIN28426. The use of a pressure dome (see Figure 9) ensures stable gas flow conditions into the pump inlet. A volumetric flow meter is connected to the gas inlet port, and a pressure gauge at a clearly defined port on the pressure dome to ensure that the results are not influenced by turbulence. All instruments must be calibrated on a regular basis, and selected in the appropriate range for the individual pump or system to ensure reproducible results.

In-house testing of Edwards’ mechanical systems is executed before shipment following this method to ensure the full performance.

For on-site measurements during commissioning the simple method of measuring mass flow with HEI-calibrated nozzles (see Figures 10 and 11) is standard practice. HEI nozzles have been developed by the Heat Exchange Institute based on wider calibration works, and are commonly accepted as flow metering standards. The nozzles are applied to ports on a test rig, which is connected to a branch of the suction pipe downstream of the filter. The pressure gauge is typically installed on a port provided at the inlet manifold for this purpose.

As gas and conditions are not ideal (even in a laboratory), the volumetric flow rate, evaluated at different vacuum pressures, can be calculated from the following equation:
The system should be leak tested to avoid the effects of additional gas load. A tolerance of 10% according to DIN 28426 and ISO 1607 on suction speed measurement is permissible to compensate the normal inaccuracies.

**ADDITIONAL GAS LOAD**

System leak tightness is essential for the efficiency of vacuum systems. A hole with diameter of 1 cm, for example, causes a leak of 65 kg/hr. This corresponds to a suction speed requirement of 81,800 m/hr at 0.67 mbar, an equivalent to a process gas performance requirement of a 55 t VD system! As an increasing leakage rate will lead to a rise in achievable process pressure, this could affect attainment of the appropriate steel degassing required and, in the worst case, affect steel quality.

It is recommended to introduce regular leak test routines for filter and tank by implementing an automatic pressure rise test. Localisation of leaks can be done with leak detectors as shown in Figure 12.

Leaks on gas system connections (welded or flanges), as well as protection gas for cameras, water vapour from the water-cooled tank seal, or humidity from the refractory can all add unnecessary gas load to a system.

These gas loads add to the process gas flow and so require additional performance to achieve the required process pressure. In particular, existing refining stations require careful investigation and overhaul to minimise this gas load. Water seals should be rebuilt to dry solutions, cameras consuming high amounts of protection gas should be replaced, as well as any others sources of additional gas load, and all leaks found then sealed.

This will lead to an optimised system as investment for equipment and consequential cost, such as integration into control, footprint for pump room and foundations,

\[
W = \frac{\dot{m} h}{\rho} = \frac{\dot{m}}{\rho} \cdot \frac{R \cdot T}{P} = \frac{\dot{m}}{\rho} \cdot \frac{P_0}{P} \cdot \frac{T}{T_0}
\]

Where:

- \(W\) (m³/hr) Volumetric flow rate
- \(\dot{m}\) (kg/hr) Mass flow rate
- \(\rho\) (kg/m³) Density of air at the vacuum pressure
- \(R\) (J/kgK) Gas constant (for air \(R=287\ J/kgK\))
- \(P\) (hPa) Vacuum pressure
- \(T\) (K) Ambient temperature (= system temperature)
- \(P_0\) (hPa) Reference air pressure (1013.25 hPa)
- \(\rho_0\) (kg/m³) Reference air density (1.293 kg/m³)
- \(T_0\) (°C) Reference air temperature (0°C)

---

Fig 9 Schematic of a pressure dome

Fig 10 Calibrated HEI nozzles

Fig 11 Test rig on a steel plant
will be lower, and return on investment will be faster, as fewer equipment requires less maintenance and has lower media consumption, thus lower cost of ownership. Last, but not least, new refractories must be completely dry before starting production as water evaporation will limit achievable pressure and add load on the pumps, which can lead to overheating.

COOLING WATER QUALITY

Good quality cooling water is important for a mechanical vacuum system, as passages for cooling water on the pumps are relatively small, compared to other equipment in a steel plant.

Cooling is required for:
- Direct cooling of boosters for oil, mechanical seals and process gas flow
- Direct or indirect cooling of screw pump

The cooling water is assumed to come from a water treatment plant. However the passages of cooling water circuit on the Edwards mechanical pumps can be easily flushed for cleaning, as circuits are not branched and passages are sufficiently wide.

It is good practice to install two water filter cartridges in parallel in the main cooling water line to the vacuum system to ensure particles are retained from the cooling circuit of the individual pumps. Three-way valves allow switching from one filter to the other in case of clogging. Pressure gauges at inlet and outlet indicate the pressure drop across the filter and hence the status of clogging and requirement for cleaning.

The cooling water temperature should be 38°C max., the differential pressure across the system 2 bar with a maximum of 5 bar(g) at the inlet.

INSTALLATION OF THE MECHANICAL VACUUM SYSTEM

For several reasons it is good practice to install mechanical vacuum pump systems in a protected environment. One aspect is ambient temperatures, which are for mechanical vacuum pumps typically in the permissible range of 5-35°C.

Depending on region, air conditioning may be required to ensure appropriate cooling in hot summers, while in cold winters, heaters will prevent cooling water from freezing when the system is not in use or ensure oil is not too cold when pumps are started. Also, the vacuum system would be protected from steel plant dust.

Another aspect for modern steel plants is to protect operation personnel from noise, as vacuum pumps are rotating machines and create noise. Noise into the stack can be lowered with silencers on the
individual screw pump and/or on the common exhaust manifold. In some cases the exhaust gas line runs into the steel plant dust filtration system. In this case silencers are not required.

Installation drawing of the systems give advice on good foundation design. The inlet manifold should be welded to the support as opening or closing of the inlet valves can move the bellows quite forcefully.

Good accessibility of each pump will ensure easy inspection and maintenance routines. This can be ensured by design of ducts for cables and all supply media such as cooling water, nitrogen, compressed air.

A crane should have free access for exchange of pumps or motors and to keep intervention time to a minimum.

The lowest points in the pump system as well as exhaust manifold should offer ports to drain condensate on a regular basis, as the process gas contains water vapour, in particular in humid regions.

A local control box installed close to the vacuum pump system will ease up any testing of pump system without a second person in the pulpit, eg, for maintenance purposes such as leak testing, functionality testing, or cleaning procedures.

A typical pump room is shown in Figure 13.

M A I N T E N A N C E

On Edwards vacuum systems, most of the maintenance work can be owned and executed by site personnel. All mechanical pumps should be regularly inspected for undue noise and vibrations to prevent from unexpected failures.

Oil levels of the gear boxes can easily be checked on the sight glasses and oil topped up if needed. Drainage points at the lowest points allow release of possible condensate in the system; this is good practice before starting a system from cold.

The interior of the pumps can easily be checked for dust deposits, but with normal occurrence of dust, only the screw pump will require cleaning from time to time, as it is the lowest point of any mechanical system. The intervals depend on usage rate, quality of filter bags but also on presence of humidity, which can make the dust very sticky.

The Edwards IDX screw pump design allows an easy in-situ solvent flush cleaning, no less than once per year.

As dust ingress would lead to contamination of oil in the gear box and hence require more frequent oil changes, a purge gas flow of nitrogen is used to protect the gear box from process gas.

Other maintenance works are checking and cleaning of strainers, oil filters and media supply (nitrogen, cooling water) pipes and ports, intervals are depending from usage rate and quality of filter bags (see next section). Couplings between motor and pump can easily be checked and exchanged if worn.

Regular oil change is required depending on usage rate, from once per year up to every three years. After 3-5 years’ operation, depending on usage rate, a major intervention including bearing exchange is necessary. Also the filter needs regular checks for damage of bags and consequential exchange is mandatory.

F I L T E R

Mechanical pump robustness to dust is dependent on clearance between rotor and stator. The high amount of fine dust coming from the process would lead to seizure of the mechanisms, so a filter in the suction line is mandatory. Bag filters with integrated cyclone are state-of-the-art and are installed in the suction line, either indoors or outdoors (see Figure 14).

Dust handling is crucial for the success of the installation as the dust is pyrophoric and self-ignites when oxygen is present. Regular cleaning of the filter with staggered nitrogen impulses is required and should be executed immediately after each process cycle to avoid air ingress during the next pump-down and consequential perforation of the bags by ignition of dust. Burns will do greater damage, as shown in Figure 15.

Installation of a dust detector connected to the automation system is recommended to get early information of holes on the filter bags. By field experience it is a slow process of deterioration so this trend can be monitored over several treatments.
Interlocks, warnings and alarms must be properly integrated into the control system. Functionality of safety relevant instruments should be highlighted on the HMI to ensure early exchange. HMI design should be well thought out to allow the operator a good overview. Only relevant information should be shown on the desktop for operation. Detailed information can be displayed on other layers and looked at on demand. This will enable quick decisions for the operator. Data storage of historical trends is helpful for any tracking of issues.

Typical process cycling will work in pre-programmed sequences, which the operator can easily utilise with push-buttons or on a touch screen for ‘start’ and ‘stop’ of the vacuum system and process. A lamp should be associated with each button to indicate which sequence is in progress. This will make the operation simple and avoid failures.

The tank system may also provide a nitrogen gas admittance facility to allow the operator to manually increase tank pressure if required due to slag-foaming. All sequences should have safety relevant interlocks included, as well as best-practice operation methods for long life time of pumps.

The Edwards scope includes a detailed document, describing options for sequences, interlocks, alarms and warnings. The control of the vacuum system is then part of the automation for the refining station and can be easily adjusted to the individual process requirements without support of the vacuum pump system supplier.

**SUMMARY**

Good cooperation between steel plant, engineering and vacuum system supplier can create an installation with utmost environmental and economic success.

A well-designed refining station with optimised volumes and leak rates, a good filter system, an appropriate installation of vacuum pumps and a simple and safe automation, are key to success.

Last, but not least, trained site personnel will make the success durable, with proper usage and maintenance of the equipment. **MS**

Anke Teeuwsen is Global Market Sector Manager Steel with the Division of Edwards Ltd, part of Atlas Copco Vacuum Technique, Global Technology Centre, Burgess Hill, UK.

Aditya Agrawal is with Edwards India Pvt. Ltd, Leonardo Bonifacio is with Edwards Spa, Tom Burke is with Edwards US and Frank Shi is with Edwards Technologies Trading (Shanghai) Co Ltd

**CONTACT:** anke.teeuwsen@edwardsvacuum.com

---

For processes with an oxygen blow and additional cooler in the suction line upstream, the filter is mandatory to reduce heat load at higher pressure and prevent bag damage. Sparks from the degassing treatment must be absolutely prevented from entering the filter, as this will also burn the filter bags. A cyclone can help if a filter is installed close to the tank. Discharge of dust from the filter requires careful control as the dust is still reactive (see Figure 16) when exposed to atmosphere.

**CONTROL**

All mechanical pumps are equipped with frequency inverters for soft start and frequency control. On the Edwards 3-stage modular systems, all boosters are running from atmospheric pressure against their inverter current limits and a maximum frequency setting depending on tank pressure.

This ensures maximum performance for pump down within the operation limits of the pumps.

Unlike for steam ejectors, pressure control, eg, for oxygen blow is smooth, ie, without staggering as it is controlled by simple frequency control of the pumps.
DEDICATED TO STEEL DEGASSING

Edwards is the smart choice if you’re looking for a complete module with proven performance, or if you want to replace any mechanical booster. The new Edwards GMB40K leads the pack in the large booster class thanks to:

- An extremely compact design
- Unrivalled performance that results in faster pump down
- A small carbon footprint because of its low energy consumption
- Worry-free maintenance with spare parts that are readily available
Edwards’ market-leading vacuum solutions for steel degassing applications

100 YEARS OF VACUUM. 100 YEARS OF EDWARDS.
100 years of vacuum innovation can mean a lot. 2019 marks 100 years since F.D. Edwards first set up shop, importing vacuum equipment from his office in South London. Over the past century, Edwards’ people and technologies have enabled countless innovations that have improved life for millions of people around the world. Their innovations for industry have greatly benefitted the thousands of companies around the world who have leveraged Edwards’ vacuum technology to improve their own processes and end-products. The Edwards pioneering spirit sits at the heart of the promise they make to their customers – to engineer environments where innovation thrives. This commitment has led them to continually invest in R&D and their people.

A NEW VACUUM INNOVATION FOR THE STEEL INDUSTRY
A successful example of this continued innovation is the GMB40K high capacity Roots vacuum booster pump. Specifically developed for the tough requirements of steel degassing, the new GMB40K mechanical booster provides a nominal capacity of 40,000 m³/h and features an innovative modular rotor and compact design, which enables unrivalled performance and a faster pump down time on the smallest carbon footprint available in its class. It is simpler to integrate into a system and with spare parts that are readily available, maintenance is virtually worry-free.

The core piece of the booster’s innovation is the lightweight rotor design which is suitable to cope with dust. The machine around the rotor has been designed in close cooperation with Edwards’s service teams and is based on the experience of Edwards’ large installed base of mechanical vacuum pumps in the global steel industry. The result is an industrial pump with standard motor and an extremely compact design, which is easy to handle and maintain and features low energy consumption.

HELPING DEVELOP SUPERIOR QUALITY STEEL
A leading Mini Steel plant specialized in the manufacture of Alloy Steels, Stainless Steel and Special Steels in the shape of castings, forging and rolled products had been using a four stage mechanical vacuum system. This consisted of a pump combination with locally supplied pre-inlet cooled booster pump with a total installed motor power of 435KW. Even with this high level of power requirement, the system was not able to achieve the process pressure and the required pump down time.

Edwards Vacuum was able to supply a customized version of the modular steel degassing system that offered additional backing capacity to meet the pump down requirements.
The latest version of the ESDM (Edwards Steel Degassing Module) incorporates the new mechanical booster pump – the GMB40K. With overall connected motor load of just 200KW, the system produced less noise and required far less quantity of water to be supplied for cooling.

The Edwards system solution offers:
- Improved process quality and productivity
- Significantly reduced energy consumption
- Decreased environmental impact

The simple pre-assembled installation and fast commissioning contributed to maximize efficiency. Edwards ESDM achieve a vacuum level of less than 0.5 mbar (a) within the required time-frame that has helped the steel plant to improve its productivity and efficiency. The operating costs also reduced as it demands less power and water.

Achieving a consistent and reliable quality of vacuum improves the overall quality of the end product.

**THE SUPERIOR BENEFITS OF DRY VACUUM TECHNOLOGY**

Edwards’ dry vacuum pump technology systems provide huge economic and environmental benefits compared to traditional steam ejectors. Dry pumps are proven to reduce energy cost by as much as 97% compared to steam ejectors, achieve higher pumping speeds and lower ultimate with minimal maintenance, and lower environmental impact. The ESDM is simple to install; the pre-assembled installation and fast commissioning ensures the operations of the plant are not delayed.

To summarize the key benefits, the Edwards Steel Degassing Module equipped with the GMB40K high capacity Roots vacuum booster pump offers improved process quality and productivity, decreased environmental impact and lower energy consumption.

Edwards has a proven global track record in steel degassing systems, with over 200 installations since 1998.
For the newest vacuum systems that are ideal for VD, VOD, RH and other steel degassing processes, depend on Leybold. Our state-of-the-art mechanical vacuum solutions are extremely robust, compact and highly efficient, giving you superior process control and highest uptime. Leybold provides ATEX certified systems for steel degassing applications handling explosive gas mixtures. If you want to increase productivity and process safety while decreasing energy use and space requirements, please contact us.

Leybold system solutions - utmost efficiency through vacuum

Leybold GmbH
Bonner Str. 498 · D-50968 Köln
T +49 (0) 221-347-0
F +49 (0) 221-347-1250
info@leybold.com
www.leybold.com
Casting and Rolling

62 voestalpine Stahl GmbH – CCB caster for high quality grades and exposed automotive steel
Gabriele Paulon, Loris Busolini, Thierry Gautreau, Herbert Moser and Peter Hodnik
Danieli SpA and voestalpine Stahl GmbH

67 Danieli QSP® - Quality Strip Production – at Nucor Steel Gallatin
Mateo Bufone, Christian Bilgen, Mike Knights, Mathias Knigge, Alessandro Stenico, Paula Da Costa and Luca Faralli
Danieli

74 MLDA. 4.0: Endless casting and rolling process empowered by digital technologies
Andrea De Luca, Alessandro Ardesi and Luca Cestari
Danieli & C. Officine Meccaniche SpA and Danieli Automation SpA

82 Metal powder production for additive manufacturing at SMS
Markus Hüllen
SMS group GmbH

85 Energy recovery from steel reheating furnaces
Liliana Cioriciu and Luc Malpas
CMI Industry Metals
voestalpine Stahl GmbH – CC8 caster for high quality grades and exposed automotive steel

Danieli was awarded the contract to supply the CC8 slab caster at voestalpine Stahl, Linz, in January 2015 with the objective of installing a state-of-the-art machine able to produce crack-sensitive steel grades used predominantly for automotive and electrical applications. Full shift operations were achieved after just five weeks and monthly design capacity was reached in only nine months.

Authors: Gabriele Paulon, Loris Busolini, Thierry Gautreau, Herbert Moser and Peter Hodnik
Danieli SpA and voestalpine Stahl GmbH

The single-strand caster is a 9m radius vertical curved machine with a vertical bender, six bow segments, two unbending segments and six horizontal segments. It is designed to produce slabs with a nominal thickness of 225mm and widths from 740mm up to 1,820mm and, considering the specific product mix, has a design capacity of 1,200,000t/yr of slabs.

TECHNOLOGY PACKAGES
CC8 is equipped with a full suite of the latest Danieli technology packages, including mould displacement and level fluctuation control, electromagnetic stirring, dynamic secondary cooling, dynamic soft reduction and segment dimension measurement and control; all of which were successfully hot commissioned. Some of these are described below.

ELECTROMAGNETIC STIRRING
There are two stirring systems: mould and strand.

Mould Multi Mode Electro Magnetic Stirrer (MM-EMS) Many years of experiments and steel production on continuous slab casters have established that an optimal steel flow pattern in the mould is mandatory to achieve the best surface and sub-surface product quality, and to minimise the defects resulting from non-metallic inclusions and mould powder entrapment. MM-EMS provides intelligent control of three functions for slowing down, accelerating and rotating the liquid steel in the mould to reduce the steelmaking defects.

CFD simulations and true-scale water modelling were used to determine the fluid flow associated with different casting conditions, ie, casting speed, slab width, SEN immersion depth and argon flow, as well as an extensive campaign of nail board tests to capture the steel flow direction and intensity at the meniscus. Some examples are shown in Figure 2.

Water models are used to study the natural flow pattern of liquid steel into the mould. Argon injection is modelled by air injection into the stopper rod and the flow is traced with methylene blue (1). Meniscus shape is detected through digital camera level topography (2), and results are analysed to reconstruct the wave (3). Sub-meniscus velocities are measured with an ultrasonic velocity profiler (4), allowing a complete characterisation of the flow pattern.

According to these measurements, the control functions of the MM-EMS have been fine-tuned and, based on product quality results from the downstream process lines, all contractual surface quality performance guarantees for the caster were fulfilled.
Casting and Rolling

Strand Electro Magnetic Stirrer (Strand-EMS)
Moving from the mould down along the strand, the focus shifts from surface and sub-surface to internal slab quality. In order to improve the equiaxed zone, a box-type strand stirrer has been installed. Strand-EMS is used to improve the internal solidification structure in terms of increased equiaxed zone.

The main reason for adopting the strand stirrer on CC8 is the silicon steel grades, which have a Si content of about 2.3%. Figure 3 shows examples of grain structure taken from three slab positions, as shown in Figure 4. The equiaxed zone size ranges from 50.5% to 56% of slab thickness – an excellent result.

Q-COOL: Dynamic Secondary Cooling System
To reach the required quality levels in terms of internal and surface quality for all the different slab sections, the cooling system for CC8 has been designed to control the water distribution across the entire slab width in the smoothest way possible. To achieve this, the common arrangement in sprayed cooling sections across the width has been enhanced by adding the ability to control them independently by means of dedicated control loops with separate valves for air and water flow control. This is shown schematically in Figure 6, with a specific example in Figure 7 from the bender zone exit. The spray nozzles have been carefully designed to compensate for both the overlap effect across a single row and the total water density at the end of the spray cooling zone given by the overlapping of all the nozzles along the length of the caster.

Based on actual measurements performed by the nozzle supplier, each individual nozzle feature has been implemented within the detailed model so a full picture of the secondary cooling system is completely considered by the solidification model, providing a complete 3D map of the solidification conditions of the slab along the entire caster strand. An example is shown in Figure 8.

Dry Casting
Crack-sensitive and some high quality steel grades slabs are prone to develop cracks when they pass through two critical areas of a vertical curved design machine: the bending zone and the unbending zone.

To avoid the formation of cracks in these areas it is important to control the deformation stress and the slab temperature. Temperature is a critical factor in the ductility trough area, where even relatively low values of stress can induce crack formation. This may not be a significant problem in the bending part of a vertical curved caster where the slab temperature is still high, but can be very significant in the unbending area.

The concept of ‘dry casting’ can be applied to this phenomenon. The idea is very ‘simple’ and involves switching off slab secondary cooling water to reduce the heat extraction from the slab and achieve a slab temperature above 900°C. There are, however, considerable drawbacks:

- Exposing the machine equipment to higher temperatures which could significantly compromise the life of rolls and bearings
- Losing control of the solidification process and...
so introducing internal defects such as centerline segregation and cracks.

The key factors to enable dry casting are:
- The design of the equipment in terms of roll and bearing cooling to protect parts
- Introduce minimum required contact cooling effect on the slab
- Use a tight roll pitch to ensure proper containment to control bulging and segregation
- Use tuned application of soft reduction to achieve an even centerline quality
- Limit conditions resulting from the significant removal of spray cooling.

Fig 6 Spray cooling sections with independent control across the slab width

Fig 7 Total water density across the width at bender zone exit

Fig 8 Model computed surface temperature

An internally cooled peripherally drilled rolls (PDR) design, together with a controlled and tuned internal cooling water, flow have proven to be successful in reaching higher temperature values at the unbending area, with an acceptable distribution across the slab width. The slab internal quality achieved is in line with expectations and comparable to other less critical steel grades.

CCB is equipped with PDR from segment 3 to segment 8. Some trials were necessary to evaluate the influence on the slab temperature and the effect on the roll cooling during dry casting condition. The driven rolls from segment 3 to 8 on the inner bow were equipped with additional thermocouples to measure the influence on the cooling water temperatures of the PDR rolls over the width. The output of these trials was an optimised cooling flow for the PDR rolls to be sure that dry casting will not lead to any roll damage. Additionally, some software changes relating to machine safety were incorporated in the control models.

An example of slab temperature across the width with dry and conventional casting is shown in Figure 9.

Q-CORE: DYNAMIC SOFT REDUCTION

An important role is played by the solidification model and dynamic soft reduction control model, which have been merged into a unique advanced model that controls spray cooling flows and segment position dynamically, according to the different casting conditions, steady or unsteady.

The development of a meshless algorithm to compute the heat exchange equations makes it possible to reduce the computational time enough to allow handling of a full two-dimensional slice model in real time.

It is thus possible to simulate the behaviour of each individual nozzle across each sprayed row to attain a full map of the cooling behaviour over the entire slab surface, and a full picture of the solidification progress within a slab section at any distance from the meniscus.

Coupled with a flow control split across the sprayed width the model allows fine-tuned control of the temperature distribution to reduce differences across the width.

Coupled with slab cooling control, the model integrates the functions for applying Q-CORE so that, according to the different steel compositions, different thickness reduction profiles can be dynamically applied on the three main areas of liquid core, mushy core and solid core. Examples at two
casting speeds are given in Figure 10 showing segment gap (blue) and solid fraction (grey) during soft-reduction.

**OPERATIONAL RESULTS**

Following an extensive period of cold commissioning, hot start-up began in January 2018, working up to full shift operations within five weeks. Production has been steadily increased as shown in Figure 11, with 103,000t produced in October 2018, exceeding the design capacity of the plant. A total of 95% of the product cast was of high quality vacuum-treated steel, of which more than 80% was interstitial-free (IF) grades for the automotive industry. Since October, machine design and process reliability has been demonstrated by casting 101 heats in a sequence with 16 fly tundish changes.

**CONCLUDING REMARKS**

Thanks to the quality and reliability of the Danieli mechanical equipment and technology packages, in synergy with the experience and knowledge of voestalpine stahl, the new CC8 continuous slab caster has exceeded all expectations both in terms of productivity and product quality during a highly successfully work-up period, and has been accepted for full production.

These impressive results are only possible due to the extremely strong teamwork between the voestalpine and Danieli project teams and are a testament to the hard work and detailed planning undertaken by all involved. MS

Gabriele Paulon, is with Danieli SpA, Loris Busolini is with Danieli Automation, Thierry Gautreau is with Danieli Rotelec, and Herbert Moser and Peter Hodnik are with voestalpine Stahl GmbH.

**CONTACT:** g.paulon@danieli.it

---

Fig 9 Comparison of slab surface temperature (between segments 7 and 8) of dry and conventional casting

Fig 10 Segment gap (blue) and solid fraction (grey) during soft-reduction: top at 1.3m/min; bottom at 0.8m/min

Fig 11 CC8 daily and cumulative production
Descaling Equipment, complete Systems

Complete Descaling Systems for Billet Mills
- Descaling Box with adjustable spray ramps
  - selective adjustable spray nozzles
  - constant high impact
  - turn key
- (redundant) Descaling Valve Unit
- surrounding equipment

Complete Descaling Systems for Plate Mills
- High Pressure Accumulator Unit incl. Level Measurement, Accumulator Shut-off Valve & Compressor Unit
- Delivered as complete unit on a base frame - ready for installation
  - High Pressure Valve Stand (475 bar) for Descaling

Selective Descaling for Strip Mills
- High Pressure Spray Bar
  - selective adjustable spray nozzles
  - constant high impact
  - avoid wear
  - save large amount of energy
  - save cost
  - improve of quality

(Selective) Roll Cooling Systems
- for Steel Rolling Mills, Aluminium Hot- & Cold Rolling Mills, Copper Rolling Mills
- Spray Bars & Spray Valves for directly / remotely controlled spray systems
  - customized Spray Bar design
  - system specific Control Cabinets
- electrical / pneumatical connection between Spray Bar and Control Cabinet

- Specific Systems, Special Valves
- Customized & energy-saving Solutions
- Consulting, Development, Engineering
- Revamp / Upgrade of existing Systems
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
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

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 original expansion plan called for the new equipment to be a copy of the existing installation.

In October 2014, Nucor Steel became the owner of the Gallatin Steel Company and, following a review of options, Danieli was selected to work closely with Nucor to find the best solution for the Ghent mill to produce higher added value products. After about 12 months’ work this resulted in the selection of Danieli QSP® technology as the best solution. The technology is described below. Danieli will supply the complete equipment and automation system.

**QSP® BACKGROUND**

Over the past 25 years the thin slab casting and rolling (TSCR) process has gained a major market share in the production of hot rolled strip, progressively decreasing the exclusive advantages of conventional hot strip mills. Danieli has developed a complete portfolio of plant layouts adopting TSCR technologies, each of these conceived to optimise CapEx and OpEx parameters in line with market requirements. Benefits include:

- Exceeding production of 3.0Mt/yr
- Expanding the product mix to include virtually all

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

**Fig 2 Current (a) and proposed (b) plant layouts**

<table>
<thead>
<tr>
<th>Vertical curved TSC</th>
<th>Tunnel furnace</th>
<th>2 + 6 HSM design</th>
<th>In line thermo-mechanical</th>
</tr>
</thead>
<tbody>
<tr>
<td>For highest quality and productivity</td>
<td>With swivel ferry system</td>
<td>For an unlimited product mix</td>
<td>For tailor made properties</td>
</tr>
</tbody>
</table>

2.2 MS19-01 2nd proof.indd   68  
2/5/19   22:09:32
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 pulpits. 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 coolers 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, ▶
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®.

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

CONTACT: m.knigge@germany.danieli.com
Eradicate inclusion problems in steel

The comprehensive OES inclusion analysis solution: ARL iSpark with Spark-DAT Software Suite

For many steel grades, controlling non-metallic inclusions is crucial for the smooth running of production process, and to guarantee targeted steel properties. The Thermo Scientific™ ARL iSpark™ OES Metals Analyzer performs inclusion analysis simultaneously with elemental analysis, enabling real-time control of inclusions for hundreds of samples analyzed every day in a steel production. ARL iSpark can be automated with ARL SMS-2500 system for unattended operation.

The Spark-DAT Software Suite includes all the on- and off-line software modules and features needed for inclusion analysis, analytical method development and set-up, as well as in-depth investigation, control and reporting of inclusions. The ARL iSpark with Spark-DAT Software Suite is the perfect solution to prevent cost and quality problems caused by inclusions.

Discover more at www.thermofisher.com/sparkdat
Mi.DA. 4.0: Endless casting and rolling process empowered by digital technologies

Mi.DA., or ‘Micro-mill Danieli’, has been in industrial operation since 2009. Its benefits in terms of cost reduction and operating efficiency are well documented. Over the last decade there has been an incredible development of information and communications technologies as the availability and speed of mobile internet connections has constantly increased. These changes are not only influencing our way of life, but will also affect the way we work, and are often referred to as Industry 4.0, where new technologies will increasingly blur the lines between the physical and digital worlds.

In this scenario, Danieli has created a new cross-functional business unit named DIGI&MET to deliver digital innovation to customers under new business models.

Its result, the “Smart Plant”, is a safe, flexible, efficient and environmentally friendly concept of manufacturing, founded on the extensive digitalisation of processes, the deep integration of cyber and physical worlds and the strong interconnection between humans and intelligent systems. In a Smart Plant, systems and equipment autonomously execute complex tasks and support humans in decision making or even provide intelligent decision automation.

From the early 2000s, Danieli has understood and faced the challenge generated by the trends in the energy saving economy. This evolved into a new vision which led to the innovative concept of Mi.DA.® endless casting-and-rolling technology, an extremely compact mini-mill able to produce rebar in bundles and coils via a high speed single strand caster directly connected to the rolling mill.

With Mi.DA., liquid steel is transformed into finished product in less than 15 minutes. The process is continuous and stable, and the ‘never-ending’ billet is rolled for many hours, achieving high efficiency in terms of yield and energy savings, and leading to the most cost-efficient rebar production available in the market today.

Following the acknowledged success of the first Mi.DA. commissioned at CMC Arizona, the endless casting-and-rolling (ECR®) process has been developed and fully supported by a growth strategy able to generate unbeatable performances in terms of Capex and Opex reduction. In recent years, a key pillar of this strategy has been the integration of innovative digital technologies into the whole process chain.

This paper deals with a summary of the implemented solutions and highlights of the future steps.

DANIELI Mi.DA.: A DISRUPTIVE INNOVATION
Mi.DA., which stands for ‘Micro-mill Danieli’, is based on the regional-mill/product-focused concept which, with a relatively low production capacity (300-800 kt/yr), is designed to serve a specific market (local or regional), focusing on a specific product range and making extensive use of local scrap supply [1].

The key concepts behind this concept are:

- Super-compact productive unit for rebar steel
- Energy saving, with only two hours from scrap to finished product
- Uses local scrap market
- ‘Endless’ smooth production system
- Fast construction and commissioning path
- Lowest cash and depreciation cost
- Highest quality bundles

The concept began in the late 1990s at the ABS Luna plant, Italy, where Danieli started extensive research on high speed casting and endless rolling. Using the large amount of experimental data collected, extensive numerical computational models were developed, leading to the design of a new mould geometry with the aim of providing optimal control of temperature distribution and gap formation, even in the most extreme high speed casting conditions. The Power Mould – the name given to the new development – is a copper mould solution specifically designed for such casting speeds which provides high
thermomechanical strength and uniform heat transfer with optimised cooling conditions. A new generation of mould oscillator systems was also developed – Fast Cast Cube (FCC) technology – which is a compact design with a bearing-free suspension system, avoiding any shaking of the meniscus, even at the highest oscillation frequencies [2].

Finally, the Direct Rolling and Bundling (DRB) process was developed, enabling cutting to final commercial length of high tensile rebar directly off the last finishing stand. The first industrial application of Power Mould and FCC was completed at Sidenor Sovel, Greece, which then became the first European plant able to industrially operate one endless strand.

Starting in 2007, extensive testing and tuning of the new copper mould technology and FCC resulted in a stable casting process with a speed range of 3-6m/min on a 140 x 140mm square billet. Later, a rolling mill was installed in-line with the ‘fast cast’ strand and which started to produce bars and coils with a productivity up to 50t/hr, while the other five strands in the caster continued to feed the old rolling mill via an innovative direct charging process.

By 2009 everything was ready for the implementation of the first full micro-mill, and this happened when Danieli approached CMC with the design concept that eventually led to the construction of the mill in Arizona. Here everything was designed around the idea of first class equipment with advanced automation packages specifically developed to match the endless process [3].

Following the success of the first Mi.DA. plants, Danieli has, more recently, commissioned four micro-mills in North America, South Africa and in the MENA region, and two in China, boosting the plant productivity up to 1.6Mt/yr [4], as shown in Figure 1.

Today’s scorecard for this technology is impressive with:
- A sequence casting speed of 7.0m/min (7.5m/min max.)
- Longest ‘never-ending’ billet: 28 hours/40 heats, more than 10 miles long
- 99% yield
- Plant uptime exceeding 92%

Typical plant layouts are shown in Figure 2 and consist of:
- Continuous scrap feeding into the AC EAF (Danieli ECS)
- Ladle furnace with a double ladle car
- Single-strand caster featuring ultra-high-speed FCC® ‘Power Mould’
- Induction furnace for billet temperature equalisation
- 16-stand continuous horizontal/vertical rolling mill
- In-line QTB quenching
- Patented Direct Rolling and Bundling (DRB)
DIGI&MET VISION AND MISSION

Over the last decade we have experienced an incredible development and diffusion of information and communications technologies (ICT) as the availability and speed of mobile internet connections has increased. The possibilities of billions of people connected through smart devices, with unprecedented calculation power, is boosted by emerging technologies such as artificial intelligence, robotics, autonomous vehicles and quantum computing. These changes are not only influencing our way of life, but will also affect the way we work, and are the milestones of the upcoming fourth industrial revolution, where new technologies will increasingly blur the lines between the physical and digital worlds. In this scenario, Danieli has created a new cross-functional business unit named DIGI&MET to deliver digital innovation to customers under new business models.

The DIGI&MET vision can be summarised as: ‘From a Plant to a Smart Plant’. The Smart Plant is a safe, flexible, efficient and environmentally friendly concept of manufacturing, founded on the extensive digitalisation of processes, the deep integration of cyber and physical worlds and the strong interconnection between humans and intelligent systems. In a Smart Plant, systems and equipment autonomously execute complex tasks and support humans in decision-making or even provide intelligent decision automation.

The mission consists of the implementation of a customer-centric model that takes advantage of disruptive digital technologies to achieve the following targets:

- Increase the overall plant efficiency in terms of higher productivity, higher yield, reduced lead times, improved plant availability and optimised use of resources.
- Deliver quality products to customers in order to establish stable and effective relationships, creating so-called customer intimacy.
- Improve workers’ health and safety by adopting solutions aiming at avoiding accidents or reducing their effects.
- Monitor and control plant energy and utility consumptions and implement efficient recovery strategies, which is currently one of the most important objectives of the metals industry and represents a first step ahead towards the so-called ‘Green Metals’ challenging target.

THE SMART PLANT APPROACH

Several innovative solutions and digitalisation-enabling technologies have been implemented and specifically customised for the Mi.DA. process chain, in order to facilitate the transition from a conventional to a digitally enabled plant.

Data-driven approach

The core of the digitalisation process is represented by the data-driven approach (see Figure 3), which represents the most innovative and disruptive element among the ones introduced by the fourth industrial revolution, aiming at the application of innovative digital technologies such as machine learning and artificial intelligence to extract knowledge from data for supply chain and process optimisation. A modern data-driven approach requires the right organisation and business model to work properly, and the availability of an integrated platform for data acquisition, analysis and problem solving is the first precondition that must be fulfilled.

Q3 Intelligence is Danieli’s proven state-of-the-art Business Intelligence solution dedicated to the metals industry that allows collection and merging of multiple and heterogeneous data sources into a unique centralised repository, and to provide KPI libraries and advanced statistical analytics tools to support decision-making and process optimisation.

To achieve the maximum benefits in terms of business value, predictive analytical techniques are then applied to extracted data to find correlations on past production and discover insights about future trends. Machine learning analysis is ideally suited to integrate or replace traditional analytical or physical models in highly complex and multi-physics processes, where not all available input variables are exactly known or when environmental conditions are varying over time.

Data-driven predictive models based on machine learning technologies have been applied successfully by Danieli to several fields along the production route, from through-process optimisation, such as steel temperature control or calculation of the optimal recipe for ferroalloy additions, to the prediction of critical events such as SEN clogging or non-spontaneous ladle nozzle openings, up to the estimation of mechanical properties in the final product, from the analysis of chemistry and process recorded data.

Along the Mi.DA. process chain, machine learning concepts are already applied from scrap arrival, with Q-ASC,
a dedicated application for automatic scrap classification. This feature is based on the automated processing of images on tablets and smartphones captured by cameras on cranes and on fixed portals installed at various points in the yard. The roadmap of development for automatic classification is performed in three phases: learning, suggesting and classifying.

Scrap classification allows for a characterisation of the material independently from the operator’s choices and enables achievement of a better management of non-conformities. In fact, the system is also able to generate warning messages in cases where detection of unwanted or dangerous items, such as tyres or gas bottles occurs.

The most successful example of a data-driven application in the meltshop process is represented by the Melt Model, which is the core application of Q-MELT furnace control package. Melt Model is based on a statistical approach to identify process deviations in real time: the calculated ‘fingerprint’ represents the expected process behaviour of the heat, and compares the real-time values to the expected trend, which is the basis to perform an adaptive process control. Melt Model is implemented not only for conventional melting based on bucket charging, which in Mi.DA. is typically employed on the first heat of the sequence to generate the proper hot heel in the furnace shell, but also for continuous scrap charging by means of conveyors, being thus perfectly integrated in Danieli ECS – Endless Charging System.

At the start of a heat, the fingerprint of the key process variables (off-gas CO, CO₂, H₂O, total O₂ and C flow rates, etc) is retrieved from the historical database, selecting the information by means of the most relevant filtering criteria. This fingerprint represents the reference behaviour of the heat. By comparing the expected trends with their real-time counterparts, the application detects whether the decarburisation process is proceeding at the expected rate or requires adjustment. The soft landing controller thus modulates the oxygen injection to hit the carbon and temperature targets [7].

Q-MELT is usually supplied as a technological package integrated with other modules, to guarantee stable improvements in furnace performance, reduction in process variability and transformation costs, and to increase overall quality and safety of operation. QREG+ is the advanced digital electrode regulation system provided for control of arc operating set-points, coal and lime injection in order to promote arc thermal efficiency and reduce electrode consumption, optimising arc coverage and stability, and managing foaming slag conditions. An innovative electrode radiation model is also integrated in the system to track thermal power losses and balance radiation stability in real time. Q-SmarTEC is a solution for electrode cooling based on dynamic control of water and air flow for an electrode spraying system which uses sprays with special tips design ensure the best water impact on the electrode surfaces.

### ADVANCED HUMAN-MACHINE INTERACTION

Increased automation complexity and technological advances also require a different approach to assist workers in realising the full potential of the Smart Plant while taking on the role of strategic decision-makers and flexible problem-solvers. Smart, agile and innovative ways to advance production must be provided with technologies that complement and augment the quality of human labour and reduce industrial accidents caused by process failure.

In these regards, the DIGI&MET 3Q Digital Pulpit (see Figure 4) represents a revolutionary solution. One of the key points of the digital pulpit concept is the provision of a full ‘soft desk’, totally based on computer screens, through which the operator can both monitor the plant and operate it. Simply by replacing the software of the automation system, this revolutionary pulpit is then able to drive all the processes from EAF to caster and rolling mill.

For the specific requirements of Mi.DA., a compact, unified 3Q pulpit for casting and rolling operations has been designed where full monitoring and control of the entire endless production is enabled from a single location. This desk has several innovative features, such as:

- **Operator Assistant (OA)**, a multi-touch operator interface that offers an innovative approach to process control, thanks to the Auto-Pilot Mode, that reduces the number of commands the operator has to handle, minimising his/her interaction only to essential tasks and situations.
- **Area Performance Indicator (API)**, which provides a detailed view of a specific process, highlighting the main set points, the relevant KPIs, the most significant...
trends and, where possible, the estimated time to end.

- **Plant Performance Indicator (PPI)**, a monitoring system that allows the production manager to obtain an overall vision of the given process area and of the upstream/downstream ones.

### Smart logistics and traceability

Significant effort is placed on the implementation of automated logistic solutions, especially automatic yards with dedicated automation and control systems that improve the plant overall efficiency through the following functionalities:

- Material tracking and inventory
- Raw material and product yard management
- Crane movement optimisation
- Automatic material identification
- Vehicle identification and tracking.

The adoption of these technologies can provide a significant contribution by supporting automatic identification and localisation of materials, assets and workers, therefore improving plant efficiency, product quality, but also enhancing workers safety. Even if working environment and extreme operating conditions often represent a constraint to their application in the metals industry, Danieli has developed several reliable solutions based on optical, radio frequency and barcode/QR code technologies.

Scrap and raw materials are tracked from when they enter the yard until being charged into the furnace. All the movements (pick up and deposits) of the materials are logged in a database, together with the data that characterises the material: class, density, supplier, transport information and pictures. The system generates alarm messages if there are inconsistencies in charging or discharging positions. The system also allows the operator to query and report movements or verify the suppliers of materials used in a specified heat, a useful feature for management of claims to suppliers. A volumetric system, based on laser scanners, is installed on cranes and allows generation of a real-time 3D map of the yard status. The operator can also check the volumes and quantities of all types of materials present in the yard, in order to properly schedule scrap procurement.

For handling of endless continuous scrap charging, Danieli has developed Q-STS, a material tracking solution based on a specially designed laser scanner technology. Scrap volume data are visualised in 3D for a quick assessment by the operator of scrap unevenness. If a conveyor-filling device is present, the system can activate it to even out the scrap flow to the EAF. If a gap is detected to have passed beneath the laser, it is tracked by the system until, on approaching the EAF, the conveyor can be run at maximum speed in order to pass over this gap as quickly as possible, so minimising bath overheating. Then, the previous speed setting can be restored once the gap detection alarm is reset. The application of this system allows maintaining an optimal scrap distribution and thus optimised scrap feeding rate and more stable melting conditions. The system is shown in Figure 5.

Automatic identification and tracking of large equipment, like ladles or tundishes, is performed with the help of the Q-ETS package, an automated patented machine-vision solution with several successful reference applications, which is based on a 2D unique pattern printed on panels, to guarantee increased reliability of reading even with a limited field of view from the camera. Real-time information about ladle location also allows estimation of thermal and refractory wear status and to manage more efficiently sequence and maintenance cycle scheduling.

Key technological equipment, such as the Power Mould, is tracked throughout its lifetime with the help of a custom radio frequency identification (RFID) solution that turns the copper tube into a real Industry 4.0-enabled asset. The smart mould carries a chip on board that stores the unique identification alphanumeric code of the device and is also able to supply recorded production data. The tag is connected to a receiver/transmitter located on the mould body assembly, which in turn is activated when it receives the consent to start casting. This device is connected to casting machine process control, which transmits detected data in real time. The large amount of information received from both the mould tag and other smart devices on the casting machine is managed by Q-MOULD, an integrated software package that is able to provide a detailed picture of actual casting system performances, with modules for the estimation of heat transfer and mould friction factor, storage and generation of reports for the key features for every single copper mould through its entire service life.

**Smart sensors and instrumentation** The plant digitalisation process requires a wide deployment of intelligent sensors that gives access to data not accessible or monitored before. Such sensors, where raw measurement
is often coupled with on-board processing tasks, should not be considered only as carriers of information, but as intelligent units capable of direct evaluation and elaboration of measured values. This approach allows to significantly improve efficiency, availability and utilisation of the plants, as well as to leverage high rationalisation opportunities through the integration of new systems.

According to the DIGIMET concept, all sensors and automation units share a common architecture with all the other packages, with a unified communication core where different hardware and software modules take advantage of the same messaging gateway and connectivity technology, allowing all systems to link each other by subscribing to the common interface with seamless data sharing between them.

Solutions based on optical technology and machine vision are applied during steelmaking. For instance Q-SLAG is based on a thermal camera which measures the slag quantity passing into the ladle during tapping, ensuring up to a 10% reduction in the amount of slag carryover, and thus improving quality and reproducibility of treatment and refractory lining life. Q-EBT SAND is an on-board automatic EAF EBT closing system based on Q-EBT EYE monitor, a visual inspection system employing high-resolution camera which is able to verify automatically the cleanliness of the taphole channel and the wear status of refractory rings. After inspection, the automatic EBT closing system enables refractory sand to fill the tap hole with a remote command and without any manual operation.

For real-time off-gas analysis, LINDARC is a laser-based technology that allows collection, in real time, information about CO, CO₂, temperature and H₂O for water leakage detection. The instrument can be installed in the fume movable duct and is able to continuously measure the composition and temperature of the fumes crossing the laser light source. In addition, for continuous scrap charging, information about off-gas flow rate and O₂ content is also available, thanks to the newly developed EOS-Pro system. All the information collected by the sensors is sent to the Q-MELT package for dynamic adaptive control of combustion and efficient bath temperature and carbon control.

In continuous casting, monitoring of the correct thickness of casting powder in the mould is performed by means of the Hi-MOULD-P system, an innovative sensor developed in cooperation with C.S.M. RINA Consulting, and based on the resonant microwave cavity operating principle. Knowledge of the exact depth of the slag layer gives well known advantages for the quality of the product, especially when coupled via a closed loop with an automated powder feeding system.

Casting process monitoring, as well as a correlation speed gauge for precise cut-to-length, is obtained using the speed meter SM3200, a system based on high-speed processing of infrared images of the cast strand. Based on a CCD detector and solid state lighting, it accurately measures speed including stand-still, by comparing successive images and computing the distance travelled over a known time interval. This system has also a unique capability of estimating mould friction, on-line, based on frequency analysis. In rolling mills, the corresponding SM3100 system is used, in which the principle of operation is based on the correlation of the signals acquired by two infrared sensors. As the two sensors scan the bar in two consecutive areas the emission detected by the second sensor is delayed by a time interval depending on the bar speed. The speed of the rolled stock can be accurately calculated applying mathematical algorithms. This system is widely used to improve cut control and for cut optimisation.

Automatic in-line product quality analysis is performed by means of Hi-PROFILE, a reliable surface inspection system able to obtain a high density and accurate 3D surface map of the product in real-time, with 10k per second complete profile acquisitions of the bar. In addition to the established product profile measurement, the new release of the system also features a defect detection package with a novel 3D laser sectioning inspection technique, based on high speed cameras and an adaptive algorithm which can detect surface defects even on fast rolling mill products with a complex profile [8]. Examples of these technologies are shown in Figure 6.

Robotics Robotic solutions can be employed to replace humans in many shop-floor tasks which are executed in a hot, noisy or polluted environment, or are physically demanding or subjected to process-related hazards. Robot->
In bar rolling mills identification tags are placed on bar bundles to allow proper assignment to casting lot and for product quality certification. Q-Robot ROLL BUNDLE TAG is a system comprising a label printing station, where the robot head picks up the label and by means of a single pin or wire, welds the label on a selected bar of the bundle, according to pre-configurable criteria. The most suitable position for the attachment is identified by a 3D artificial vision system, which communicates the target location to the robot actuator.

Predictive maintenance The maintenance strategy pursued by DIGI&MET is a systematic approach called Danieli Reliability-Centered Maintenance (DCMS), for evaluation of facility equipment and resources, resulting in a high degree of reliability and cost-effectiveness. This maintenance strategy also includes the implementation of combined condition and process monitoring using a common analysis platform. An additional feature is that it enables the operators to infer possible equipment malfunctioning from the relevant process data, eg, early roll wear deterioration that can be inferred from a material surface quality defect, when it is not possible to monitor equipment health directly.

The DCMS condition monitoring solution for moving items is based on innovative MEMS accelerometers to detect vibrations using a higher frequency response compared to conventional sensors: signal acquisition is performed by remote I/O unit, using Ethercat protocol for fast deterministic synchronous data acquisition and PAC real-time controller unit for vibration magnitude calculation. The information collected from the field is used by Danieli Maintenance Management System (DMMS) for historical failure analysis, scheduling of maintenance jobs and spare parts provision, and is fed to predictive models with a forecast engine able to predict the probability of future failures occurrences.

Energy monitoring and control In countries where the cost of electrical energy is significant and the trend is to focus on renewable sources, the most power-demanding operations are planned preferably during lower power demand time windows, such as during night shifts or weekends. These requirements require reliable power demand forecast and intelligent and flexible scheduling systems. The Danieli Energy Management System (DEMS), is a multilevel platform dedicated to energy management and consumption control in the plant. DEMS is fully tailored to the requirements of the steel industry and in compliance with standard ISO-50001. The result is an extremely flexible suite of a modular set of packages, adaptable in according with customer requirements.
controllers and real-time data analytics, support and reduce the commissioning phase, leading to full plant utilisation very quickly after startup.

REFERENCES

Andrea De Luca is with Danielli & C. Officine Meccaniche SpA. Alessandro Ardesi and Luca Cestari are with Danieli Automation SpA, all based in Buttrio, Italy.

CONTACT: info@dca.it

CONCLUSIONS
Mi.DA. endless casting and rolling is, today, a proven technology, the best available in the market to fulfill the demands of high efficiency and energy savings in steel rebar production.

Advanced automation and innovative digital solutions are now integrated and optimised for application in the Mi.DA. ecosystem, supporting the operators in decision making with an impressive flow of information and thanks to the implementation of intelligent systems based on smart sensors and machine learning technologies, thus enhancing the safe, flexible, efficient and environmentally friendly concept of endless technology.

In addition to the well-known benefits already achieved on Opex by endless casting and rolling, digitalisation and smart automation via process sensors, networked controllers and real-time data analytics, support and reduce the commissioning phase, leading to full plant utilisation very quickly after startup.

IntelliGrid is a high-level module, designed to manage the main transmission line energy flows, and available for monitoring of all different types of energy, not just electrical, but also gas, oil, air and water. Power Monitoring is the low-level module designed to analyse energy consumption and efficiency of all the auxiliary machines in the plant, a solution which can be easily adopted and expanded to any machine in the plant, with particular attention to the main loads.

Power Demand Control is the module dedicated to control and supervision of power consumptions for the included power loads. The target is to achieve the highest possible utilisation of permissible power, without exceeding the contractual limitations and avoiding price peaks and penalty charges.

All the modules are integrated with the general Q3Intelligence architecture for data storage, reporting and analytics, allowing the generation of customised web dashboards for constant monitoring and analysis of energy consumptions and giving real-time support to planning and scheduling activities. Examples of the dashboards are shown in Figure 9.

Fig 9 Q3Intelligence dashboards: Condition and energy consumption monitoring
Metal powder production for additive manufacturing at SMS

SMS has designed, built and commissioned a powder atomisation plant at the SMS group facilities in Mönchengladbach. The facility is an industrial scale demonstration plant and will form part of a new Demonstration Centre for use by SMS and its customers. The objective is to offer SMS customers complete Additive Manufacturing plants on a turnkey basis, by integrating the entire process chain from powder production through to the finished products while ensuring production at a high, reproducible quality level with minimum costs. Customers will receive modular, scalable solutions tailored to their individual requirements.

Author: Markus Hüllen
SMS group GmbH

The powders look unspectacular but have properties from which a completely new manufacturing sector is going to evolve. Powder particles are extremely fine and typically are spherical measuring 15-45μm in diameter.

SMS PILOT PLANT

In designing and building a pilot plant, our objective is to master – and allow our customers to master – the complete process chain of this innovative technology. This is why we deliberately chose to build an industrial-scale pilot plant rather than a small-scale unit. Only in this way can we test the process under real conditions, ie, at high temperatures and pressures and in long production cycles. We will work with our cooperation partner, Additive Industries, who are developers and providers of selective laser melting systems for 3D metal powder printing.

PLANT DESIGN

The plant, 13m tall and shown schematically in Figure 1, was commissioned in May 2018 and contains all the process steps of AM.

Its main components are:
- Vacuum induction furnace with a crucible and tundish
- Atomisation equipment arranged in the powder tower
- Vacuum pumps
- Cyclones, gas coolers, bag filters and air separators
- Screens for powder grading

PLANT OPERATION

All the steps and all the processes from metallurgy, melting, inert gas based vacuum technology through to quality control, have built on SMS group experience and competencies.

The plant melts the metals and the alloys inductively and under vacuum. Vacuum technology is key to achieving an ultra-clean product and reliably preventing the material from reacting with oxygen. If this is not guaranteed, oxides, oxide inclusions and other contaminations may result; ultra-clean powder can only be produced under
inert conditions. Melt size is 100-500kg, with an annual capacity of 4,000kg.

In the next process step, the liquid metal is atomised in a jet nozzle of just a few millimeters diameter by using pure high pressure argon (see Figure 2). The particles then cool as they fall down the atomisation tower, producing spherical particles in the µm range. The powder is then graded by grain size, resulting in fractions of high purity spheres, with defined grain sizes between 15µm and 45µm with an exact chemical analysis and free from inclusions and agglomerations (see Figure 3).

The plant can process a wide range of alloys including superalloys, Ni-based alloys, CoCr alloys, special steels, maraging steels and copper alloys. New alloys with new properties will be developed jointly together with our customers and, uniquely, under real production conditions.

As part of the development programme we are establishing the basis for Industry 4.0 in powder production, as we are going to implement an automated, seamless quality control system covering the complete AM process chain. This type of consistent documentation and 100% traceability are an absolute necessity, for example, for components produced for the aerospace industry.

The new powder atomisation plant has accomplished a first major milestone. SMS group has always set great store by complying with highest quality standards and, in order to be able to produce high-end, high-performance components from powder, it is essential that the powder does not come in contact with oxygen in the downstream production processes. Therefore, we have been developing solutions that ensure it is protected by an inert gas atmosphere until it is processed in the 3D laser printer of our cooperation partner, Additive Industries. All production steps, including transportation, screening, classifying and packaging, take place under an argon atmosphere. This involves significant effort, but guarantees the high quality level as required, for example, for safety-critical components.

DEMONSTRATION CENTRE

As powder production and AM are very young technologies, there are very few established quality standards. To address this, a Demonstration Centre, as illustrated in Figure 4, is to be set up comprising the complete process chain, ie, powder production, powder handling, 3D printing, heat treatment and machining, inspection, quality checks, logistics and a dedicated automation system. The facility will be available for use by SMS customers.

CONCLUDING REMARKS

Our objective is to offer SMS customers complete AM plants on a turnkey basis, by integrating the entire process chain, from powder production through to the finished products, while ensuring large-scale production at a high, reproducible quality. The pilot plant will allow us to optimise the processes to maximise productivity and minimise total costs. Our customers will receive modular, scalable solutions tailored to their individual requirements. MS

Markus Hüllen is Vice President, Additive Manufacturing and Powder Metallurgy, SMS group GmbH, Mönchengladbach, Germany

CONTACT: thilo.sagermann@sms-group.com
AS RELIABLE
AS STEEL

TECHNOLOGY AND
RELIABILITY
IN ROLLING MILLS
FOR LONG PRODUCTS

NCO offers state-of-the-art technology, highest equipment reliability and quality of service. We supply a complete scope of any green-field rolling mill plant for long products (re-bar, wire-rod, SBQ, small to medium section), as well as upgrades of existing mills. From the initial concept to commissioning and start-up, we design, manufacture and install your hot rolling mill from A to Z.

• Turn-key plants
• Auxiliary systems
• Roll process engineering
• Process control and automation

NCO Headquarter:
25076 Odolo (BS) - Italy - sales@nco.it - www.nco.it

MORE THAN 100 COMPLETED PROJECTS WORLDWIDE
Energy recovery from steel reheating furnaces

Saving energy in a steelworks is both cost-effective and environmentally friendly. CMI designs and builds reheating furnace energy recovery systems which convert ‘waste’ heat into steam for re-use, providing up to 35% of a typical steelworks steam requirement.

Authors: Liliana Cioriciu and Luc Malpas
CMI Industry Metals

Well known as high energy ‘consumers’, reheating furnaces can become energy sources by recovering the heat generated during the process. Such energy recovery systems are increasingly included in newbuilds, but they can also be retrofitted to existing furnaces. The energy is usually recovered as steam which can be used elsewhere in the steelworks, however, if desired, the steam can be converted to power.

WATER/ STEAM PHYSICS
Water and steam can coexist at any pressure at the appropriate saturation temperature. Steam at a temperature above the saturation condition is known as superheated steam, and water at a temperature below the saturation temperature is called sub-saturated water.

At atmospheric pressure the saturation temperature of the water is 100°C. However, if the pressure is increased, this allows the addition of more heat per unit volume and an increase of temperature without a change of phase. Therefore, increasing the pressure effectively increases both the enthalpy of water and the saturation temperature, thus saturated steam is a high energy medium that can be used in other parts of a steelworks. There are two main ways to recover waste energy as steam: via a waste heat recovery boiler and via an evaporative recovery system. These will now be described.

WASTE HEAT RECOVERY BOILER (WHRB)
Modern reheat furnaces use a heat exchanger to use heat from the hot waste gases to preheat the combustion air. Since the waste gases exit the main heat exchanger at around 400°C, one way to recover this remaining heat of the waste gases is to install a WHRB in-line towards the stack as illustrated in Figure 1.

The hot wastes and cold water have a crossed circuit as follows: Hot wastes heat the overheated water in the super heater and generate steam. The remaining heat arrives in the evaporator where warm water arrives from the economiser where the cold water feed absorbs the remaining heat.

Figure 2 shows the water circuit and the way its steam is generated.

Authors: Liliana Cioriciu and Luc Malpas
CMI Industry Metals

Well known as high energy ‘consumers’, reheating furnaces can become energy sources by recovering the heat generated during the process. Such energy recovery systems are increasingly included in newbuilds, but they can also be retrofitted to existing furnaces. The energy is usually recovered as steam which can be used elsewhere in the steelworks, however, if desired, the steam can be converted to power.

WATER/ STEAM PHYSICS
Water and steam can coexist at any pressure at the appropriate saturation temperature. Steam at a temperature above the saturation condition is known as superheated steam, and water at a temperature below the saturation temperature is called sub-saturated water.

At atmospheric pressure the saturation temperature of the water is 100°C. However, if the pressure is increased, this allows the addition of more heat per unit volume and an increase of temperature without a change of phase. Therefore, increasing the pressure effectively increases both the enthalpy of water and the saturation temperature, thus saturated steam is a high energy medium that can be used in other parts of a steelworks. There are two main ways to recover waste energy as steam: via a waste heat recovery boiler and via an evaporative recovery system. These will now be described.

WASTE HEAT RECOVERY BOILER (WHRB)
Modern reheat furnaces use a heat exchanger to use heat from the hot waste gases to preheat the combustion air. Since the waste gases exit the main heat exchanger at around 400°C, one way to recover this remaining heat of the waste gases is to install a WHRB in-line towards the stack as illustrated in Figure 1.

The hot wastes and cold water have a crossed circuit as follows: Hot wastes heat the overheated water in the super heater and generate steam. The remaining heat arrives in the evaporator where warm water arrives from the economiser where the cold water feed absorbs the remaining heat.

Figure 2 shows the water circuit and the way its steam is generated.
Cold water is fed in on the right side and it descends through gravity towards the mud drum where it leaves any solids as sediment. Once heated, the density of the water diminishes and it rises towards the steam drum where it is overheated.

The main issues are that the pressure regulation of the furnace can be affected if the draft of the chimney is not well maintained, and that accessibility of the WHRB for maintenance can only occur during furnace stoppages. A draft drop at the chimney is very unlikely with the CMI approach and, in addition, an exhauster is installed to recover any draft drop and maintain the appropriate pressure in the furnace. Some customers prefer to have full access at any time to the WHRB without stopping the furnace. In this case, if the length of an existing waste gas tunnel to the stack or specific layout allows, a bypass can be considered. Figure 3 shows an engineering drawing of such a system with the WHRB in blue at the top and the bypass line below.

**EVAPORATIVE COOLING SYSTEM**

The second approach to extract even more waste heat is to install an evaporative cooling system (ECS) for the skids and posts of the walking beam section of the furnace. Cooling of the skids and posts can be achieved either by the classical solution of circulating cold water in a closed loop in the tubes of the skids and posts or by an ECS that circulates a water/steam mixture at 105°C which is then heated to about 200°C through heat exchange between the furnace atmosphere and the skid and posts. The pressure under which the water/steam mixture circulates is around 15 bar(g) in order to allow the oversaturation.

The overheated water/steam mixture travels to a steam drum where the steam is separated from the water, which is re-sent to the system. Most of the steam is sent to the plant grid at a pressure required by the customer, and the remainder is used to preheat the completion water back to 105°C and hence back to the skids and posts. The water volume is permanently completed from a chemically treated water supply system.

As there is continuous contact between high temperature water and steel pipes, the quality of the water has to be thoroughly controlled and maintained so, before reaching the skids and posts, the preheated water is chemically treated and de-aerated through special equipment. The overall water flow system is illustrated in Figure 4.

As the system has to be especially watertight, a special design of swivel joints was conceived to follow the movement of the mobile skids and link the fixed and mobile skids in order to assure the continuity of the circuit. These swivel joints were developed by CMI through inhouse studies and are shown in Figure 5.

Since it works with high temperature saturated water, ECS has the additional benefit in producing lighter skid marks on the steel being heated. It is essential to well
maintain the refractory lining on the skids and posts in order to avoid the exposure of the metallic structure to the high furnace temperatures which may result in water leaks.

Since both WHRB and ECS systems need water at high temperature, they can be linked in order to provide only one source of steam to the plant network. As an example, for a 350t/hr capacity reheating furnace, a mixed heat recovery system (WHRB + ECS) can supply 31t/hr of steam at 20 bar(g) for 100% refractory lining of the skids and posts.

A complete energy recovery system from reheating furnaces can provide as much as 30-35% of the steam needed at a steelworks.

**INDUSTRIAL APPLICATIONS**

Despite general historical reservations against steam generation in reheating furnaces due to apparent non-reliability, the concept has already been installed at a number of our customers’ works, and in all cases the feedback was positive. Such projects have been installed at AM Eisenhüttenstadt (WHRB) and AM Gent (ECS). A combined WHRB and ECS is planned for JSW Bellary India for three reheating furnaces. **MS**

Liliana Cioriciu and Luc Malpas are with CMI Industry Metals, Seraing, Belgium

**CONTACT:** liliana.cioriciu@cmigroupe.com
Excellence in Strip Processing Technologies

Since 1955, our name has been synonymous with premium equipment and technical solutions which set benchmarks for the metallurgical industry. In addition to the steel and stainless steel metal industries, we have been a reliable partner to the leading aluminium and non-ferrous metal producers for many years, with a focus on:

- Strip processing lines
- Specialty processing equipment
- Coil handling equipment
- Modernisation of existing processing plants

We have an excellent track record of realising new ideas based on thorough research and development, which have led to significant increases in productivity, product quality, energy efficiency and environmental performance.

We look forward to working with you on the implementation of technological solutions that meet the highest standards of quality and innovation.
Products and Applications

90 SMART CORE – new software makes intelligent use of quality data in a Smart Factory
Uwe Knaak and Marianna Schröter
LAP GmbH Laser Applikationen

96 Integrated strip stabilisation system
FOEN DEMCOJET®

98 Electrical steel strip: Technical solutions for heat treatment
Dr. Peter Wendt and Wolfgang Eggert
Tenova LOI Thermprocess GmbH

101 Strip pre-oxidation for galvanised strip in a full radiant tube furnace
Michel Dubois and Louis Bordignon
CMI Industry Metals and CRM Group

106 REBAR measurement like never before with PROFILEMASTER® Systems from ZUMBACH

108 Additive manufacturing at SMS group – philosophy and products
Nina Uppenkamp, Robert Banse, Sarah Hornickel and Axel Roßbach
SMS group GmbH

113 Safe and efficient robotic removal of high strength steel straps from coils
Henriëtte van Norel
Tebulo Industrial Robotics, The Netherlands

117 Optimal use of available floor space at a new storage location for steel coils
Daan Merkestein and Stevo Akkerman
Systems Navigator BV and Tata Steel Ijmuiden
SMART CORE – new software makes intelligent use of quality data in a Smart Factory

With the new ‘SMART CORE’ software for the measurement of long products, quality data can be integrated deeply into the customer’s process network environment, allowing the data to be used across various processes within a Smart Factory.

Authors: Uwe Knaak and Marianna Schröter
LAP GmbH Laser Applikationen

Since their market launch, the laser measuring systems of LAP’s CONTOUR CHECK family have proved highly successful in a great number of long rolling mills and have become an indispensable asset in the rolling process. The systems have been providing reliable real-time geometry data of the rolling stock as a basis for optimal rolling stand adjustment.

However, the growing digitalisation of industrial processes calls for the measuring systems and their software to be thoroughly and consistently networked within the mill structure. In the digital factory, machines organise production processes automatically, exchange information autonomously, trigger actions and mutually control each other.

According to LAP, Industry 4.0 in a rolling mill starts when the data generated by measuring systems smartly interlinks with the customer’s works data systems. The aim is that all this data becomes available for use within works-wide networked production processes and for specific evaluations.

This data should also include measurements of the rolling stock during production. The plant operator can use this data to optimise higher level processes and evaluate performance indicators such as quality and yield.

Driven by these considerations and with a view to Industry 4.0, LAP has thoroughly redesigned the software of its CONTOUR CHECK gauges for in-line measurements of long products. The high connectivity software provides expanded smart functionalities for the evaluation of measurement values and for their integration within customer networks.

With this future-orientated move, which makes consistent and intensive use of large quantities of geometric data, LAP is making a significant contribution to optimising the production of bars, sections, tubes and wire.

The measured contour data can be used to interlink different processes as well as uninterrupted quality control from liquid metal down to the packed product.

Additionally, the data can be evaluated as a basis for pass/fail decisions and integrated into MES or ERP systems. Last but not least, they provide a wealth of input for Big Data analyses and for future supply chain optimisation.

DATA AVAILABILITY AT ANY PLACE AND TIME

The sensors in LAP’s systems capture shape and contour deviations with the laser shadowing or the light-section methods. Features recognised include:

- Overfill and underfill on one or both sides
- Out-of-spec dimensions of the rolling stock
- Surface defects
- Roll misalignment
- Roll wear

When used in a stand-alone configuration, LAP gauges already help operators speed up and enhance the precision of line adjustments after size changes. Thus the operator can produce the new size much more quickly to the required tolerances, increasing the yield of the rolling mill.

Classifying the rolling defects automatically and unequivocally helps to systematically eliminate the sources of the defects because rolling parameter setting is no longer a matter of subjective estimates.

The new SMART CORE software collects the contour data from the various types of sensors LAP uses in its shadowing and light-section gauges and processes all the data within a common software platform. With this future-orientated approach to geometry measurement of long products, LAP is gearing up for the requirements of networked processes within the increasingly digitalised automation landscape in the steel industry.

The SMART CORE software package generates intelligently processed data, which the operator may use as direct input at the process lines or which may be used to interact with other systems within the data structures of an Industry 4.0 production environment.
SMART CORE merges the values measured by the CONTOUR CHECK sensors in one central point and processes them in real time. This central software core provides the advantage that the operators will be using a uniform HMI throughout the mill, even if there are different measuring systems in place. SMART CORE also simplifies software maintenance and facilitates the control of the systems.

LAP supplies SMART CORE in three versions for its CONTOUR CHECK systems:

- **SMART CORE BASIC** collects data from CONTOUR CHECK WIRE systems for round product of smaller diameters. Based on measurements with the shadowing method, the software provides information about the product’s exact diameter and ovality.

- **SMART CORE ADVANCED** collects and processes data from CONTOUR CHECK BAR & TUBE and ROUND & EDGE systems, which also work on the laser shadowing principle. They provide multi-axis measurements of steel bar, rectangular sections and tubes. The software, which can be customised to the user’s specific requirements, is able to generate additional information about the measured product, such as the height, width or, for rebar, the weight per meter.

- **SMART CORE PRO** has been designed for the CONTOUR CHECK SHAPE series, which uses the laser light-section method. These gauges inspect hot and cold steel sections of any shape (round, rectangular, flat or hexagonal) by way of a three-dimensional reconstruction.
of the surface. They capture shape deviations originating from the rolling process, including surface defects such as scale, scabs or roll spalling.

The integrated database stores the measured data for several months. Extensive statistical analysis tools are provided for evaluating the stored data by a range of criteria, e.g., by coil, rolling charge or batch.

LAP specialists work closely with customers to understand their needs and be able to recommend the optimal system configuration for them to get the best out of their data. LAP also supports them in matters of data handling and the transfer of the data to the process control system, the customer’s evaluation software or to a graphical HMI.

The users can access all the geometry data from any computer within the company’s Intranet or cloud, in real time and independent of a platform. With just a few mouse clicks, any authorized user can configure the screen masks in such a way that they see exactly the data relevant to their task. For example, for employees working at the rolling line, the software could display the contour measurements in the form of a pie or line chart, while the quality assurance staff could receive more comprehensive information and statistical data for evaluation purposes.

**PROCESS ANALYSIS ACROSS VARIOUS PRODUCTION STAGES**

As SMART CORE comes with its own communication gateway, it is ready for integration within networked systems. The software uses standard process interfaces such as TPC/IP for the data transfer. If required, the interfaces to the mill operators’ requirements LAP can be customised.
The interlinking of data from several systems makes it possible to instantly recognise and track along various process stages any effects on the contour of the finished product triggered by the upstream rolling stands. The SMART CORE software can present the data in such a way that it will be possible for the operator to compare, in real time, the geometrical data from the roughing and intermediate mills with data from the finishing block. This will make trends more obvious across various processes and plants and enable corrective action to be immediately taken. The operators can also instantaneously check whether the action taken has the desired effect. A screen shot example is shown in Figure 1, together with a typical example in a steel mill shown in Figure 2.

This close interlinking of SMART CORE with the processes allows the plant operator to establish an automated process to optimise the roll stand settings. To this end, one gauge is placed ahead and one after the mill stand. The sensors of both gauges communicate with one another via SMART CORE, enabling the screwdown values for the rolls to be exactly determined, for example, to directly correct the set-point in case of roll misalignment.

A key requirement here is that the system is able to reliably track the orientation of the section during rolling. It would be difficult otherwise to reliably determine which one of the rolls in a stand is responsible for the measured deviations. It will not always be possible to install the gauge right after the rolling stand exit. In such cases, any eventual turning of the section between the rolling stand and the measuring position has to be compensated.

Therefore, LAP has developed an algorithm capable of recognising the orientation of the rolling stock. That means the contour is always measured in the true orientation of the rolled section and the deviations from the target section shape can be clearly assigned to the responsible rolls – a key feature without which it would not be possible to automate the process of roll pass adjustment in two-, three- or four-roll stands.

Based on a similar target/actual value comparison, SMART CORE also determines roll wear in the stands.

OUTLOOK

With SMART CORE, LAP provides operators with a powerful tool to use real-time contour data most effectively in a Smart Factory environment. The measured data can be used not only straightforwardly for the control of the rolling process, but also as input for comprehensive analyses by the production control system or for quality assurance purposes. Additionally, SMART CORE helps to optimise complete process chains and supports Big Data analytics, adaptive manufacturing concepts and self-learning systems.
In a nutshell: the reliability and availability of the rolling mill will improve, costs will be cut, and the risk will be minimised of material that does not meet the customer's specifications leaving the mill.

SUMMARY

With LAP’s new SMART CORE software, data from contour measurements of long products can be used for many purposes within works-wide system networks. The software supplies not only measured values for immediate use in the production process, but also intelligently processed data for use in higher-level systems.

With its high connectivity, SMART CORE paves the way for exchange of data between humans, machines and processes as well as for the use of extensive contour data in a Smart Factory. Thus the software allows the mill operator to take a holistic approach to optimising the rolling process from the liquid metal to the packed product ready for shipment.

LAP’S CONTOUR CHECK FAMILY

Systems of the CONTOUR CHECK family can be used at all stages of the rolling process, from the billet to the finished section. LAP supplies a variety of standardised systems with measuring of between 50 and 760mm.

- **CONTOUR CHECK WIRE** measures the diameter of long products with small cross-sections. This system comes with one axis for measuring wire, and with two or three axes for measuring hot rolled bar steel. The three-axis version is suitable for measuring rebar.

- **CONTOUR CHECK BAR & TUBE** is the system of choice for measuring wire rod, steel bars and tubes in the medium diameter range at temperatures of up to 200 °C (see Figure 3).

- **CONTOUR CHECK ROUND** is the standard option for measuring round sections. The three- and six-axes versions also permit high-accuracy scanning of sections produced using the three-roll process (see Figure 4).

- **CONTOUR CHECK EDGE** employs sensors mounted on a circular rotating base plate. This makes it possible to also scan square, flat and hexagonal sections.

- **CONTOUR CHECK SHAPE** is based on the light-sectioning principle and is equally suitable for long products with convex contours, such as billets, bar and sections with a round, rectangular or hexagonal cross-section, as for tubes and wire (see Figure 5). Figure 6 illustrates typical rolling defects detected.

Uwe Knaak is Product Manager and Marianna Schröter is Marketing Manager, both LAP GmbH Laser Applikationen, Lüneburg, Germany.

**CONTACTS:** stein@vip-kommunikation.de
m.schroeter@lap-laser.com

---

![Typical rolling defects detected](image)
CONTACTLESS QUALITY CONTROL OF ROLLED LONG PRODUCTS

360° profile measurement with surface inspection

REAL-TIME LASER PROFILE MEASUREMENT
- Full profile measurement
- Detects defects of surface
- Ready for Industry 4.0: Connection via Level2 interface
- High accuracy and simple calibration

PROFILES
- Bar
- Square
- Rebar
- Flat
- Tube
- Hexagonal

www.lap-laser.com
Integrated strip stabilisation system

FOEN DEMCOJET®

The FOEN® air knife system is well-known as the most advanced galvanising system for the production of all steel grades used in the automotive industry with highest demands on surface qualities. The first integrated solution of an air knife in combination with a strip stabilisation system was also executed with the FOEN DEMCO® system. As a subsequent improvement of this solution the FOEN DEMCOJET® was recently developed minimising the distance between air knife and acting stabilisation point to approx. 500 millimeters in order to achieve the best coating result. Up to now, already 12 FOEN DEMCOJET® systems have been sold in galvanising lines all around the world. The system is or will be integrated soon at first class producers of galvanised strip like Ternium, US Steel, Tata Steel, Nucor, Stelco, HBIS, CSN, voestalpine or Salzgitter.

In principle electromagnetic strip stabilisation systems feature electromagnets which are arranged on both sides of the strip in the same height above the air knives. A position measuring system is installed below on each top side magnet which continuously measures the distance to the strip in a non-contact manner. The strip position determined by this sensor is compared to the target position. By means of variations in the current flowing through the stabilisation coils, the magnetic attraction for the steel strip can be controlled systematically in a way that the strip movements are equalised.

NEW REQUIREMENTS
Strip stabilisation systems are a necessary feature in modern hot-dip galvanising lines, since the requirements on the process and the surface quality are continuously increasing due to various reasons. New industrial standards require closer tolerances, especially for the automotive industry. For example, demands the new European standard for the automotive industry (VDA 239-100) a single area test instead of the formerly used three area test. Thus, the standard is stricter since small deviations have a stronger impact on the evaluation. In addition, the surface quality in general has to be higher and more homogenous, which is only possible with a stable strip run in the air knife. For an economical production, the yield of high-quality material has to be as high as possible and cut-outs because of thickness changes have to be avoided. At the same time, resources have to be saved to keep operational costs low. This can happen with a reduction of over-coating and lower possible wiping pressure due to closer distance between strip and nozzles.

MINIMISATION OF STRIP-TO-NOZZLE-DISTANCE

The main goal of strip stabilisation is a minimisation of the distance between air knife and strip to reach the jet core zone. A low distance will lead to many benefits concerning the galvanising process and fulfill all mentioned requirements. The main condition to lower the distance is a stable strip run within the air knife. If the strip run is stable and smooth, the distance can be lowered systematically without the risk of scratching the strip. Three pre-conditions have to be fulfilled to reach a stable strip run. An efficient vibration reduction is necessary to reduce movements of the strip, cross-bow compensation is necessary to have a proper strip shape, and the distance between strip stabilisation and knife gap has to be minimised in order to ensure a stable strip run not only in the strip stabiliser but also in the wiping system.

CONVINCING OPERATIONAL RESULTS

The operational results have shown that all pre-conditions for a stable strip run within the air knife could be reached with the FOEN DEMCOJET®. Since the highly dynamic control system works with a response time of 1 msec the strip vibrations could be effectively reduced by more than 50%. The moveable magnets of the FOEN DEMCOJET® in combination with the control system compensates and almost eliminates the cross bow. Thus, the main goal could be reached and the distance between nozzle and strip was reduced significantly. The distance could be reduced from 9 to 6 millimeter and lower which was sufficient to reach the jet core zone.

Installations of the FOEN DEMCOJET® at voestalpine or at TATA resulted in many benefits concerning quality,
The FOEN DEMCOJET® is an integrated solution which combines the most advances galvanising system with an efficient electromagnetic strip stabilisation system and thus optimises the galvanising process and product quality.

Production and operation. The coating uniformity was better, which lowered the zinc consumption. There was an increased yield of high-quality material since the strip losses due to cut-outs at weld could be reduced significantly (approx. 200 meters). In general, the processing speed could be increased up to 20%. Pressure could also be reduced, which lead to energy savings and reduction of dross formation. Another benefit was the reduction of the correcting roll intermesh which went along with less wear of bath rolls, sleeves and end caps.

PATENTED SYSTEM

Based on the comprehensive operational experience FOEN® is now continuously optimising the FOEN DEMCOJET® to increase the performance even more. The technological advantage of the system is secured comprehensively by several international patents. MS
Electrical steel strip: Technical solutions for heat treatment

The world’s leading electrical strip producers have placed their trust in tried and tested Tenova LOI Thermprocess heat treatment plants for most of their new plant and modernisation projects.

Authors: Dr. Peter Wendt and Wolfgang Eggert
Tenova LOI Thermprocess GmbH

In principle, electrical strip can be differentiated into non-grain oriented (NGO) electrical strip – also called dynamo strip, and grain-oriented (GO) electrical strip, also known as transformer strip.

Over the past 15 to 20 years, the construction of new electrical strip production lines and the modernisation of existing lines has boomed due to two main factors: lack of earlier investment between 1970 and 2000, and growth in demand as a result of efforts to improve energy efficiency and from new applications. A key aspect is the trend towards e-mobility, which has led to investments in the NGO strip sector, including a trend towards thin strip. A modern annealing and coating line for heat treatment of NGO is shown in Figure 1.

In the GO electrical strip segment, there has been growth in demand as a result of efforts to improve energy efficiency by minimising hysteresis losses. Some regions or countries are boosting their production capacities at an above-average rate as a result of the rapid pace of infrastructure development. In China, for example, several new plants have been constructed, such as those at Baosteel Group and the Shougang Group. Wuhan Iron and Steel and Angang New Steel have also expanded their capacities. In India, the JSW Group has developed new capacities and thyssenkrupp Electrical Steel has expanded and modernised its production facilities. In Europe, many existing plants have been modernised and a few new plants have been constructed, for example for voestalpine in Linz (KGL-2) or Stalprodukt (Poland), thyssenkrupp Electrical Steel (see Figure 2) or the NLMK Group at its locations in Lipetsk and Yekaterinburg.

ELECTRICAL STRIP TECHNOLOGY

Electrical strip ranks among the so-called magnetically soft materials. Since its magnetisation and demagnetisation is easy – particularly in an external magnetic field – its use in electrical systems enhances optimal energy saving. Due to its typical magnetic features, electrical strip is characterised by a wide application field in all kinds of electrical systems.

Almost isotropic conditions regarding the mechanical and magnetic properties are typical of dynamo strips, i.e., the
structure grains are uniformly aligned in all directions. For this reason they are used preferably in moving machines such as motors or wind power plants. Depending on the manufacturing process, dynamo strips are sub-divided into so-called ‘fully finished NGO’ and ‘semi-finished NGO’. Fully finished NGO is delivered to customers with all the required final properties and has already been varnished. Semi-finished is delivered without insulation and so it is usually finally annealed by the customer in the form of tailor-made stacks of sheets.

Due to this fact, semi-finished transformer strips (GO) are anisotropic, ie, the grains are oriented in one direction – the rolling direction – with a variance as low as possible. For this reason, these materials are used mainly in static applications such as transformers. With regard to their magnetic properties, transformer strips are sub-divided into CGO (conventional grain-oriented) and HGO (high permeability grain-oriented) strips, also known as HiB-qualities, and which have considerably lower hysteresis losses. The hysteresis loss is defined as the share of energy that the material absorbs as heat in the alternating magnetic field, and is thus an index of energy efficiency. Most developments in the field of transformer strip strive mainly to lower the specific hysteresis loss. The hysteresis losses for HGO qualities are a function of the strip thickness and steel grade and amount to 0.8-1.25W/kg at 50Hz and 1.7t, whereas they generally exceed 1.10 (up to 1.65)W/kg for CGO-qualities.

Transformer strips (GO) and dynamo strips (NGO) are divided into further sub-classes, which are described in the respective EN-standards: EN 10107 for grain-oriented electrical strips (GO, transformer strip) and EN 10106 for non-grain-oriented electrical strips (NGO, dynamo strip).

A high degree of purity, the content of silicon and aluminium, low quantities of other alloy components as well as hot rolling, cold rolling, annealing and coating processes, essentially influence the magnetic properties of electrical strip. The annealing processes in particular are of great importance.

**STRIP TREATMENT**

During manufacturing, dynamo strip (NGO) undergoes at least two different heat treatment processes. Prior to cold rolling, the hot rolled strip is annealed in batch annealing furnaces (BAF) or in combined annealing and pickling lines (APL-lines). After cold rolling, the material passes through an annealing and coating line (ACL) followed by finishing with various coatings and a drying and backing process. Due to the trend towards higher heat treatment temperatures and thinner strip – down to 0.2mm are under discussion – such furnace plants have to meet new and more sophisticated requirements.

Transformer strip requires at least four different heat treatment processes. Prior to cold rolling, the strip usually passes through an APL. If the cold rolling process takes place in several steps, various manufacturers make use of so-called ‘intermediate annealing lines’ between the individual rolling steps. Following cold rolling, the strip is heated and decarburised in a decarburisation and coating line (DCL), nitried, if necessary, cooled in a controlled manner, then coated and dried.

The next heat treatment process comprises high temperature annealing at approximately 1,200°C in an electrically or gas-heated multi-stack batch annealing furnace (MBAF), followed by stress-relieving annealing and coating in a flattening and coating line (FCL). These strip treatment plants are usually horizontal and several hundred metres long.

As a function of the maximum coil weight, the multi-stack batch annealing furnaces are designed in one or two layers. Traditionally such plants were mainly electrically...
heated, but Tenova LOI Thermprocess has developed a gas-heated MBAF that incorporates all advantages of both the alternative, gas-heated rotary hearth furnace (RBAF) and a MBAF. This furnace type has been in successful operation for several years. An example is shown in Figure 3.

The key component of any electrical strip treatment line is the heat treatment section, i.e., the furnace. The mechanical equipment of these lines is technologically less critical and less complicated because the lines are operated at relatively low strip speeds (up to 200 m/min). In the furnace section, special, precise temperature control, changing gas compositions and dew points, precise slow and fast cooling as well as automated operation, based on a model if possible, are important aspects. Various thermochemical treatment steps such as decarburising and nitriding, take place in the furnace sections of a strip treatment line which are separated by a number of separators.

PLAN INSTALLATIONS
Since 2000, Tenova LOI Thermprocess has received a total of 59 orders for electrical strip treatment lines; 33 of these were new plants, while 16 orders included comprehensive modernisation work. Ten of the projects are ongoing. Figure 4 provides detail of the individual plant components.

Whereas Tenova LOI Thermprocess supplied the heat treatment section of the electrical steel strip for these orders, the mechanical parts have been supplied in cooperation or in consortium with major mechanical suppliers such as Tenova Strip Processing, Andritz Sundwig or the SMS Group. In some cases, Tenova LOI Thermprocess was the leader of the consortium, as for the ACL-2 line for China Steel Corporation or the electrical strip treatment plants for Wuhan Iron & Steel Co. Ltd. In other cases, leading electrical steel producers such as voestalpine, Austria explicitly chose to cooperate with Tenova LOI Thermprocess for their new KGL-2 line constructed in 2011 to be able to anneal NGO strip up to a width of 1,650 mm.

The new ACL for JSW Steel Ltd in India shown in Figure 5 was realised entirely by Tenova. The new heat treatment line for dynamo strips (NGO) was installed in the Vijayanagar Works in Toranagallu in the federal state of Karnataka. After a design and installation phase of approximately two years, production started in 2015. The plant was designed for a throughput of 33 t/h at a maximum strip speed of 180 m/min (furnace section 120 m/min), and a strip treatment temperature of 1,100°C maximum.

Tenova LOI Thermprocess designed and supplied the heat treatment section (furnace) including the drying furnace downstream of the coater, the appropriate measuring and control system as well as the entire furnace automation system. Tenova Italimpianti was the supplier of the entire strip mechanics. Subsidiaries of the Tenova group located in India gave support in the form of local supplies and supervision services. Thanks to this new plant installation, JSW managed to establish itself within a very short space of time as one of the high-quality suppliers for dynamo strip (NGO) in the Indian market.

One of the largest new electrical strip plants was constructed by the Chinese customer Shougang in Qian’an. All seven heat treatment lines (furnaces and control systems) were supplied by Tenova LOI Thermprocess, with Shougang covering the engineering, supply and commissioning of the following furnaces:

- Two APLs for NGO & GO strip, each with a capacity of more than 60 t/h
- Three DCLs (see Figure 6) for GO strip, each with a capacity of more than 9 t/h
- Two FCLs for GO strip, each with a capacity of more than 15 t/h

A MBAF for the high temperature annealing of GO strip with a total of three multi-stack bases completed the facilities for grain-oriented electrical strip production. The furnaces started production between 2011 and 2013 and in the first half of 2012 the first HGO/HiB strip was annealed. The projected capacity of 150,000 t/yr was reached in 2015.

According to information provided by the customer, the plant is fully used for the production of HiB grades with ‘low-temperature plus nitriding’ technology.

Dr. Peter Wendt is Vice President Sales and Wolfgang Eggert, Director of Sales, both at Tenova LOI Thermprocess GmbH, Essen, Germany

CONTACTS: Peter.Wendt@tenova.com
Wolfgang.Eggert@tenova.com
Products and Applications

Strip pre-oxidation for galvanised strip in a full radiant tube furnace

Advanced high strength steel grades are known to have poor zinc wettability when using a full radiant tube processing cycle. A laboratory study was used to determine the effects of a surface pre-oxidation stage, followed by reduction stage before Zn coating. The work was successful and identified an adequate process window to enable industrial use of this approach. An industrial version is currently under construction in a galvanising line.

Driven by car weight reduction and increasing car safety requirements, the steels used for the ‘body in white’ have significantly increased in strength over recent years, mostly by using multi-phase microstructures. The achievement of such microstructures requires modification of the austenite to ferrite transformation by adjusting quenching rate and temperatures, selecting the right aging processes and adjusting alloy composition.

Steels for galvanising require higher alloy content than those for continuous annealing lines (CALs) due to the fact that the heat cycle during galvanising (reheating/soaking over the pot temperature) is not optimum for the required strength-elongation requirements. In addition, good Zn wettability and adherence requires the surface to be oxide-free. This means avoiding the development of an oxide film during annealing and fast cooling by using HNX as the gas coolant. Unfortunately the cooling rate is only about 100°C/sec for 1mm strip thickness, whereas in continuous annealing it can reach as high as 1000°C/sec using cold water.

One of the solutions to get around this silicon problem consists of fully oxidising the steel surface between 650°C and 750°C with a mixture of O2 and N2, resulting in an iron oxide film, also containing some manganese oxide. The other oxides from the alloying elements such as Si and Al, which are not soluble in iron/manganese oxides, are rejected at the steel/oxide interface. Then, following oxide reduction, the oxidised alloying elements do not totally cover the surface but are located in nodules, which enables better wettability and coating adhesion. This full oxidation treatment is already practised on these steel grades in some plants using direct fired furnaces. However, these furnaces have the disadvantage of lower heat efficiency than radiant tube versions and require good control of the combustion gas composition. In addition, it is known that, depending on their design, direct fired furnaces may give hotter strip edges, which may affect the oxidation.

To evaluate the benefits of using a radiant tube furnace the management and control of the surface oxidation during a full process cycle has been studied using the hot dip simulator at the laboratory at CRM, Liege, and are described below.

As the product mix may only contain say 10-15% of steel grades requiring pre-oxidation, any industrial plant must be still able to cope with the remaining ‘normal’ grades. This implies that an industrial pre-oxidation section within a galvanising line must be small, flexible and with easy atmosphere change. Following a successful outcome from the experiments, a dedicated section has been implemented in an industrial furnace dedicated to an automotive galvanising line. This is described later.

<table>
<thead>
<tr>
<th>Grade</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Al</th>
<th>Si/Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiTRIP</td>
<td>0.2</td>
<td>1.5</td>
<td>2.2</td>
<td>&lt;0.4</td>
<td>&lt;0.1</td>
<td>0.68</td>
</tr>
<tr>
<td>DP 980</td>
<td>0.15</td>
<td>0.70</td>
<td>1.83</td>
<td>&lt;0.4</td>
<td>&lt;0.1</td>
<td>0.38</td>
</tr>
<tr>
<td>CQ</td>
<td>0.052</td>
<td>0.010</td>
<td>0.17</td>
<td>0.03</td>
<td>0.04</td>
<td>0.059</td>
</tr>
</tbody>
</table>

Table 1 Steel composition (wt%)
PRE-OXIDATION AND REDUCTION CYCLE

The management and control of the total surface oxidation in a full radiant tube furnace cycle has been studied using the hot dip simulator at CRM, Liege, to simulate the process and heat cycle [4].

Two high-strength steels were investigated: a SiTRIP grade and a DP980 grade. A conventional low carbon CQ grade was also tested for comparison. The steel compositions are summarised in Table 1.

Figure 1 is a schematic of the furnace and process, and Figure 2 [2] shows the simulator which has very specific features that allow it to simulate industrial cycles:

- The full treatment can be done in a single step (without going to room temperature after the oxidation process) thanks to special valves that allow for two separate atmospheres. The sample moves up and down to be in contact with the desired atmosphere (either oxidising or reducing) before dipping.
- As the simulator has cold walls (IR furnace), the atmosphere is cold and hydrogen escaping from the reduction section does not react with oxygen in the oxidising zone. Therefore a relatively correct oxidation step can be simulated.
- An oxide sensor is installed to measure the oxide thickness formed.
- The pot area has a Zn circulation system to avoid the defects due to the oxidation of the zinc surface.
- All data are recorded in real time to ensure that the cycle has been done correctly.

The parameters tested consisted of:

- Oxidation temperature: 650°C, 700°C and 750°C
- Oxidation time 1.5sec, 3sec and 6sec
- O2 content 0.5%, 1% and 2%
- Conditions after oxidation: 1%H2/DWP -5°C, annealing 60 sec at 800°C for Si TRIP and DP980 and 850°C for Si TRIP only

For comparison, the steels were also tested using the classical cycle as used for lower strength steels without pre-oxidation: 1%H2/DWP -5°C (high dew point practice) before soaking, and 5%H2 /DWP -30°C (typical of no use of water injection).

Sample characterisation consisted of oxide thickness measurement by OTTM (an online sensor, based on reflectance spectroscopy that allows the continuous measurement of this iron oxide layer for most steel grades including AHSS) [1,5], glow discharge optical spectrometry (GDOS), and identification of the oxide type by XRD on uncoated samples, analysis of surface chemistry after oxidation and before dipping with GDOS. Wetting was estimated visually and Zn adhesion was tested by 2T bend tests followed by adhesive tape.
RESULTS
The results have demonstrated the efficiency of a pre-oxidation step in the range of 650-750°C to improve zinc wetting and the coating adhesion on AHSS, especially containing Si. The main findings can be summarised as:

- The oxide thickness formed on AHSS between 650°C and 750°C for 1 to 6 seconds and with 0.5 to 2% O₂ is quite constant.
- The oxide thickness is self-regulating in the correct oxide range (≈1g/m²) over a wide process window thanks to the formation of Fe₂O₃ for high oxidation conditions (higher temperature, oxidation time or oxygen amount). This is because Fe₂O₃ formation slows down the oxidation kinetics.
- The oxide formed on classical low carbon steel consists of FeO. A 1g/m² thickness is obtained with less than 0.5% O₂ which means that pre-oxidation on this type of steel should not be used.
- A significantly better zinc wetting of AHSS was observed with the oxidation/reduction process, especially the SiTRIP grade, in comparison with classical annealing conditions (5%H₂/DWP-30°C).
- Good wetting, however, does not guarantee good adhesion. This means that adhesion tests must be done to evaluate the efficiency of the process.
- Oxidation at higher temperature can delay Fe oxide reduction at 800°C in atmospheres containing 1%H₂/DWP-5°C. Stronger reducing conditions during annealing are therefore recommended (5%H₂ minimum for 800°C).
- When soaking at 850°C, coating adhesion is always good if an oxidation/reduction process is applied, even with only 1%H₂. This indicates the efficiency of carbon for iron oxide reduction. Such a high annealing temperature, however, increases the decarburisation of the extreme surface.
- The injection of water vapour leads to good zinc wetting and coating adhesion on DP980 but is not efficient for SiTRIP. The oxidation/reduction is expected to be a more robust process for AHSS equal or higher to DP980 than simple dew point management (although results may also depend on the exact steel composition used).
- Due to the high dew point, decarburisation is quite significant and, even when correct iron oxide reduction occurs, the oxide formed does not represent an effective barrier to minimise carbon depletion. The higher the dew point and the soaking temperature, the higher is the carbon depletion.
- Oxidation and soaking temperatures, as well as dew points, must be limited as much as possible to avoid internal selective oxidation and steel grain de-cohesion during deformation.

- Table 2 Quality of coating for SiTRIP
- Table 3 Quality of coating for DP980

Fig 3 Implementation of pre-oxidation chamber in industrial furnace for automotive CGL
A summary of the results is shown in Tables 2 and 3 (red is poor, green is good).

PRE-OXIDATION CHAMBER IN INDUSTRIAL FURNACE

A dedicated section has been designed and built in an industrial furnace dedicated to an automotive galvanising line. The general design is as shown in Figure 1 and includes the following patented main features:

- It is short, about 5m long. This allows easy purging of the atmosphere during the transitions from classical steel to AHSS. No heating is necessary due to the low total heat losses.
- Separate sections in the vertical leg for similar action on each side of the strip. No contact with rolls means no difference in reaction time for both sides.
- Circulation of \( N_2+O_2 \) at about 600°C, controllable on each side separately.
- Oxide measurement with selected pyrometers or a more dedicated system like the OTTM will be used[5]. The sensors will be located after the chamber, eventually on each side or even scanning the width.
- Double water-cooled sealed rolls at entry and exit of the chamber to avoid oxygen entry to the furnace.
- Pressure control of the chamber and furnace to limit the oxygen flowing in the other part of the furnace.
- Dew point control in chambers before and after the section. This is done by using steam boilers and dedicated injection points. In addition, specific actions are undertaken to control the CO content in the chamber to minimise the sooting risk [6].
- When classical steels are run, all the seal rolls are open and the furnace operates in a classical way. The chamber becomes a simple connection section between the two sections of the annealing furnace.

Figure 3 shows a drawing of the chamber in the furnace. Figure 4 is a 3D schematic.

Industrial trials are foreseen on two new lines to be provided to an Indian client in about one year’s time.

Michel Dubois is with CMI Industry Metals, Seraing, Belgium and Louis Bordignon is with CRM Group, Liege, Belgium. MS

CONTACT: michel.dubois@cmigroupe.com

REFERENCES

Now you can download all previously published technical papers FREE of charge

It is time to Visit: www.millennium-steel.com
REBAR measurement like never before with PROFILEMASTER® Systems from ZUMBACH

ZUMBACH Electronics, a leading supplier of non-contact measuring technologies for the metal and steel industry, introduces its newest PROFILEMASTER SPS 80 gauge for in-line measurement of any rebar type. Sophisticated capabilities allow the measurement of rebar products in hot rolling processes. With a unique processing feature, the full contour of a rebar is captured and the cross-section is extracted in such a way that core diameter, rib height, width and height among other characteristics can be measured and monitored.

The PROFILEMASTER SPS 80 is specially designed to measure the rebar in the rolling mill without having limitations in terms of rolling speed. Since many rolling mills produce rebar in more than one strand, ZUMBACH's PROFILMASTER can handle up to three strands simultaneously with one single gauge. Every individual strand is measured and related statistics can be generated.

ZUMBACH's experience of supplying measuring systems into the metal and steel market helped us designing a solid and reliable system for such applications and will help our customers producing rebar products with higher quality and higher efficiency.

The PROFILEMASTER family consists of various models and depending the product size, ZUMBACH offers the

Fig 1 PROFILEMASTER® SPS 80 gauge with main REBAR screen
best suitable model that will accommodate the complete range of products. 

PROFILEMASTER® systems are available with four up to eight laser/camera modules measuring continuously the cross-section of the moving product. A powerful PC-based processor combines the captured line images of the individual cameras to yield the momentary cross-section of the profile. All relevant dimensions such as width, height, angle and radius or other geometric quantities are computed to characterise the full cross-sectional picture. An operator-friendly graphic display of this data allows the monitoring of the product during the whole process. The nominal values for the profile can be directly imported from CAD design files, which allows easy and problem-free configuration of the device.

CUSTOMER BENEFITS/ MAIN FEATURES

- REBAR measurement irrelevant to rolling speed
- Multi-Strand measurement of rebar up to three strands in one measuring gauge
- Provides 100% inspection in real time
- Reduces start-up time
- Increases the repeatability and precision of your end product
- Improves process control
- Reduces scrap and production costs
- Saves raw material and post-processing costs
- Detects process problems at an early stage
- Industry 4.0 ready – OPC UA (integrates in a seamless way to your network or higher-level systems)
- Simple cleaning requirements, giving short maintenance needs
- Logging of all production data for QC department
- Makes post production measurements irrelevant
- Reliable operation in harsh conditions, product temperatures up to 1,200°C MS

Offering The Most Suitable Dimensional Measuring Solutions

Regardless of Shape, Size, Speed or Temperature, We Measure It All!

Static, Oscillating, Rotating, Full Profile Capture, We Do It All!

25 – 29 June, 2019
Düsseldorf, Germany
Booth # 5F22
Additive manufacturing at SMS group – philosophy and products

Additive Manufacturing is being exploited at breathtaking speed. Now design engineers are not restricted by any manufacturing constraints such as having to consider the geometry of the input stock, so can start out from the function the component is going to perform and can immediately examine the 'printed' result in the form of a real component.

SMS group has already made great achievements in this challenging technological field and is well positioned for the future in terms of the technology, maximising its benefits and providing new products and related services for its customers.

A revolution in manufacturing is taking place. Additive Manufacturing (AM), or 3D printing as it is popularly known, is being exploited at breathtaking speed. AM means producing an object based on digital 3D design data by adding material layer by layer. For many years SMS group has been very active in this field with a young and dedicated R&D team advancing and promoting this innovative technology within the company. The team does not limit its activities to investigating which new and optimised components could possibly be produced by AM, members also dedicate a great deal of their time to introducing a new way of thinking in the company’s design and engineering departments.

A further role of the project team is to communicate the knowledge and the potential and benefits of AM within the SMS group. We organise design workshops for SMS engineers and are in direct contact with the design departments and do not miss out on any opportunity to share information about AM with our colleagues so that they can see the great potential it provides.

As a manufacturer of plant and machinery for the steel and non-ferrous metals industries, SMS group focuses on components made primarily of metallic materials because the machines and equipment are subjected to extremely high loads during operation. With AM, however, we are not restricted by any manufacturing constraints. We do not have to consider the geometry of the input stock, eg, a forging blank, or the specific requirements posed by machining processes such as milling or drilling, therefore we can start out from the function the component is going to perform.

We adopt a creative technological approach to designing and can develop the ‘perfect’ shape for the product function. For instance, we have stopped thinking in terms of rectangular, machined bores in cooling channels as AM designs can be produced with the optimum profile.

The project team has already implemented a great number of innovative solutions, which impressively demonstrate what advantages AM processes provide.

The most important benefits include:

- Significant weight reduction of dynamically actuated components
- Functional features are directly manufactured into the part during the 3D printing process
- Improvement of energy efficiency as a result of optimised flow patterns and minimised weight
- Dramatically shortened delivery periods
- Possibility to produce products virtually anywhere in the world
- Customised solutions.

ADDITIVE MANUFACTURING TECHNOLOGIES

The number of AM techniques available today is quite large, however, for the time being two main techniques are commonly used for plant and heavy machinery applications.

Selective laser melting in a powder bed In selective laser melting, high-purity homogeneous metal powder is selectively melted by a laser, layer by layer at robotically controlled defined positions. In this way, the component is gradually built up to produce the finished object. With the powder bed technique it is possible to produce components of complex and hitherto unprecedented structures, which would not be feasible by conventional processes.

For plastics-based components, the selective laser sintering (SLS) process is available. This technique is very similar to the powder bed process using metals, the basic difference being that it uses a special plastic powder instead of metal.

Laser melting deposition process (LMD) In laser metal deposition, metallic powder or wire is fed via nozzles and melted by lasers at defined spots. The unit that
accommodates the laser and the nozzle may be actuated by a robot. Laser metal deposition achieves high build-up rates, but it is more limited than selective laser melting in terms of ‘fineness’.

**AM EXAMPLES AT SMS**

**Spray heads for forging plants** A very impressive example of the use of AM parts is the spray heads for cooling and lubricating the dies in drop forging plants.

A forging press cycle is:
- Loading
- Pressing
- Ejecting
- Cooling

The forging press opens after each stroke. Die contact has to be kept as short as possible in order to minimise thermal stresses and speed up the onward movement of the work piece. Die cooling has to be performed during this extremely short time window therefore it is essential that the spray head reaches its operating position as rapidly as possible.

The arms carrying the spray heads have to be moveable in such a way that cooling can be accomplished extremely quickly between the forging strokes, while minimising cooling of the work piece. Additionally, the arms have to be of a very sturdy design and easily accessible to facilitate spray head replacement. These requirements make die cooling and lubrication extremely challenging processes, especially with the design of conventional spray heads.

These are characterised (see Figure 1) by the following attributes:
- In certain presses, up to four spray heads are needed
- They are manufactured from solid metal components
- They are expensive
- Significant manufacturing effort is involved in drilling the channels that distribute the cooling and lubrication fluids within the spray head
- Sometimes they feature fluid channels running with sharp rectangular turns which can lead to particles such as scale accumulating in the channels
- One head typically weighs between 2kg and 15kg
- Malfunctions in the press may damage the dies
- In order to allow the heavy spray heads to be retracted and moved out quickly and accurately, the head carrying arms have to be of very sturdy design.

The experts of SMS group were not happy with this situation and so began studying the potential of AM at a very early stage. Drop forged parts come in all kinds of shapes, and die cooling and lubrication have to be adapted to the shapes of the dies. This means that the spray nozzles have to be in the correct position and...
the spray angle and impact have to be adjusted to meet the specific requirements of the die. As the spray heads have to accommodate the layout required by the die shape, their design varies considerably.

SMS group R&D activities have brought about revolutionary results, developing a new generation of spray heads has developed a process capable of producing these new spray heads by 3D printing from either plastic or metal. This groundbreaking solution is significantly less costly for the press operators and the new spray heads (see Figure 2) weigh only one-tenth of conventional ones, significantly reducing the wear of the head carrying arm.

Another key advantage for the operator is the possibility of producing customised spray heads on demand, i.e., spare heads are available in virtually no time, without incurring the high costs of keeping them physically in stock. It also allows operators to easily redesign and optimise the spray heads for a specific application. Figure 3 shows the new sprays in operation.

SMS group is already developing weight-saving designs for supporting arms operating at higher actuation speeds. This patent-pending technology is currently the most easy-to-use method to design a spray head for drop forging presses. Without any modification of the geometry, this component can be manufactured in plastics or metal (aluminium or stainless steel). The new spray heads are designed by means of smart computer software. Based on the nozzle positions, the software fully automatically computes the optimal spray head geometry for the 3D printer.

Commercial use Formal market launch is expected soon. The spray heads have passed field testing and have been successfully used under plant operating conditions. In these applications, most of the connections of existing cooling systems could be reused so minimising retrofitting issues. Spray heads made of polyamide performed perfectly, reaching a maximum temperature of approximately 50°C during continuous operation. During a test at our customer, Bharat Forge in Germany, a temperature of only 14°C was measured. This low temperature is due partly to the constant cooling effect by the compressed air used for scale removal and partly due to the specific process in place at that facility, which makes it extremely unlikely for the spray heads to touch the red-hot work piece.

For Bharat Forge, the spray head was specifically designed to allow switching between water and a graphite-based spraying fluid. The nozzles can be switched closed, which guarantees that no unwanted fluid leaks out. All the controls are compressed-air actuated. Bharat Forge intends to establish it as standard equipment at the site. Benefits include:

- The spraying pattern is much more homogeneous
- The dies are cleaner and fluid consumption is lower
- Handling is easier than with the conventionally manufactured spray heads
- Accumulations of material which frequently occurred inside the conventional spray heads, have not been found. This is due to the flow-optimised design of the fluid channels.

In order to guarantee a long service life of the plastic spray heads, under certain operating conditions it may be necessary to program dedicated protective measures that will be triggered by the process control system in the event of a failure. Should parts remain in the dies as a result of a failure, an air curtain will be activated, cooling the surroundings for about 60 seconds without producing a cooling effect on the dies. In the event of stickers (forgings that have got stuck in the upper die), the spray heads are immediately removed from the forging area to avoid contact with the forgings.

FUTURE, INTEGRATED DEVELOPMENTS

As spray heads are integral parts of the cooling and lubrication systems in drop forging plants the technology needs to be integrated into the overall system, in order to achieve maximum efficiency. Three higher-level aspects and harmonised design will be the focus of developments.

Automation The lightweight spray heads can be automatically placed in the correct position in fractions of a second by way of a linear movement. All spray heads will be connected to the cooling system via a standardised terminal board which will make the replacement of a spray head extremely easy and fast.

Spraying system The spraying system consists of the tank, valves and the supply lines for all required media. It handles all switching operations which can be used to fully exploit the potential of the new technology, i.e., the possibility of switching on and off individual nozzles at very short intervals and provide optimal die cooling, while saving on spray fluids. The latter is a unique feature of the new spray heads. By switching individual nozzles quickly on and off, it is even possible to create a sweeping effect. Quick-response valves guarantee direct switching of the valves via dedicated control signals, and sensors feed back information about the conditions inside the press. This information may also be used to optimise the control process.

Controls The simple, vision-based controls adjust to the current product and optimise the spray pattern or spraying situation in a fraction of a second during running operation. The customer may choose between a spray head
made of plastics or metal. If the plastic version is used, it is recommended that a circuit breaker be implemented to protect the spray head in the event of a failure. This function is already included in the SMS system as standard.

It is planned to also print current-conducting elements and sensors. This will make it possible to actuate the valves electrically and generate condition messages of the systems. The gained added value and the potential for process optimization make the 3D-printed spraying system for drop forging operations a technology ready for Industry 4.0. By integrating thermosensors, it will become possible to obtain an exact thermal image of the product during forging and a clear documentation of the production process, which in principle can also be used to react to changing conditions in real time.

OTHER EXAMPLES OF AM PRODUCTS AT SMS

Annular gap nozzles In a copper wire rod mill, annular gap nozzles are used for wire cooling and water removal. The conventional component consisted of six parts and the air gap adjustment required the use of a shim, and setting up and properly adjusting the component involved a great effort by our customer.

Our task was twofold: first, the component design was to be simplified and second, the adjustment was to be accomplishable without the aid of a shim. We produced a nozzle by AM which requires only 35mm of installation space – versus the previous 65mm – weighs only 0.85kg instead of 2.5kg and is of a monolithic design that does not require preassembly or adjustment of the nozzle prior to its installation (see Figure 4).

The new nozzles are already successfully in operation at BIRLA COPPER in India (see Figure 5). They are less noisy than the previous ones and meet or even exceed all performance specifications. As we have manufactured the nozzles from a high-strength, wear-resistant material, they can remain in service much longer than their predecessors.

A new roll cooling header for wire rod mills featuring a contour-adapted design with integrated nozzles has been performing excellently. By using Alumide, a blend of aluminum powder and polyamide powder, the new component is now lighter and cheaper than the conventional solution. A comparison between the two is shown in Figure 6 and the installed header is shown in Figure 7.

EAF steelmaking We have been able to reduce the size of the SIS (SMS Injection System) injectors used for fuel and oxygen injection in steel melting by 60%. The injectors also now come in one piece compared to eight individual parts previously. A section through an injector is shown in Figure 8, illustrating its complexity.

Tube manufacture Tube welding plants made by SMS group will in future be able to produce tubes with...
PRODUCTS AND APPLICATIONS

CONCLUDING REMARKS

The activities and projects mentioned above illustrate the direction in which AM is heading. There are several driving forces. Design engineers can now avail themselves of ‘printers’ to print the parts they design and immediately examine the result in the form of a real component. Digital 3D design coupled with robotics and ever more sophisticated printers are responding to the growing demand for AM components. This, in turn, is spurring the development in printer technology, for instance, the first hybrid machines combining AM and milling are already available on the market.

SMS group has already made great achievements in this challenging technological field and is well positioned for the future in terms of the technology, maximising its benefits and providing new products and related services for its customers. **MS**

_Nina Uppenkamp, Robert Banse, Sarah Hornickel and Axel Roßbach are with SMS group GmbH, Mönchengladbach, Germany_

**CONTACT:** thilo.sagermann@sms-group.com
Safe and efficient robotic removal of high strength steel straps from coils

To cope with the remarkable increase in recent years in the demand for high strength steel strip, coil producers have had to use higher strength steel straps to hold the coils securely during transport within the steelworks or to customers. Because of the higher coil locked-in stresses and the more highly stressed straps, strap removal is a particularly challenging task, when cut, the straps can whip and raise concerns over equipment damage or personnel safety. There is also the possibility of the coil partially and rapidly unwinding. To address these issues Tebulo Industrial Robotics has developed a new robotic de-strapper specifically designed for the safe de-strapping of high strength steel coils.

The increase in demand for high strength steel in recent years, particularly in strip form, can be explained by the fact that this material offers substantial cost reductions in its many product applications, through weight savings (thinner sheets) and its capacity to improve product performance. Specific examples are in the automotive sector, other areas of transport and the offshore oil and gas sectors.

High strength steel (HSS) is a generic term for steel qualities that are stronger than ‘standard’ steel qualities, but in recent years steel producers have developed (and continue to develop) ever more ‘high strength’ and ‘ultra-high strength’ grades.

Steel strip is typically coiled after rolling into 30-40 tonne coils which usually require three to five straps per coil to hold the coils secure during transport within the steelworks or to customers. HSS grades, however, because of their higher strength (and hence residual or locked-in strength) require either more straps (up to 12 per coil) or the use of higher strength/thicker steel straps to hold the coils securely. HSS straps are under considerable tension so their removal is a particularly challenging task. When cut, the straps can whip and raise concerns over equipment damage or to personnel safety. There is also the possibility of the coil partially and rapidly unwinding.

Tebulo is an industrial robotics company which produces tailor-made robotic solutions for material handling, welding, hot and cold marking and/or tagging of coils, sheets or slabs. To address safety issues over coil de-strapping, some years ago Tebulo developed a robotic de-strapper which detects the straps over the full width of the coil, and removes them. It comprises a robotic arm similar to those used in car manufacture with the de-strapping tool attached, and uses bespoke software. The robot sits at the side of the process line as shown in Figure 1.

Because the size (diameter/width), position, number of straps and position of the strap lock varies between coils...
The robot head detects these and adjusts accordingly. The first machine was supplied for a pickling line in Canada in 2004 and many units have been supplied worldwide since. Although the system has been very successful, this particular design is unsuitable for HSS coils with the thicker and stronger straps.

This relates to the fact that the material typically has a double breaking force compared to traditional strapping materials and, when cut, the HSS strapping material shoots away with explosive force due to the extremely high internal tension of the strapped roll of steel. The time was right, therefore, to optimise and further develop the de-strapper for safe removal of these new high strength straps.

**ROBOT HEAD DEVELOPMENT**

**Cutting tool** In the development of the new de-strapper head, our engineers searched for the optimal balance between a blade with the proper geometry, the correct cutting angle, cutting forces and minimum wear and tear. To determine the correct cutting and deformation behaviour, we started by recording the process on a high speed video. Subsequently, we created a complex mathematical cutting model and conducted force analyses which eventually led to the new design with a substantially improved cutting head.

In order to cut the new HSS straps the single blade knife has to somehow slide underneath the straps. This is quite a challenge since these new straps are extremely tightly wrapped around the steel coils. The cutter blade angle (the angle by which the blade slides under the straps) was modified so that it slips under the strap, but the angle is not so sharp that it is too weak. As soon as the cutter slides under the strapping material, the strap is lifted and cut with minimum damage to the coil. Blade material has been changed and is now produced from a higher strength material and includes a unique hardening process such that the wearable parts now have a lifespan of the cutters used for standard strength steel coils.

**Strap clamping** For extra safety the cutting tool now has two clamping units instead of one, preventing the strapping from shooting away as the strap is cut. The strap is clamped to the coil. The new de-strapper uses laser technology in conjunction with bespoke software to detect the straps such that as soon as the strap is cut, it is automatically pulled away and transferred to the strapwinder.

**Overall design** To flexibly carry out the three functions of sliding under the strap, cutting and holding in a single movement, much greater force is required, so we modified the hydraulic system to create it. Also, design of the entire construction has been improved and stiffened with very little weight increase. Figures 2, 3 & 4 show various views of the de-strapper in action.
OPERATION
Coil measurement, strap detection and first strap removal takes about 50 seconds. Removing each subsequent strap takes about 30 seconds.

DISPOSAL OF WASTE MATERIALS
In the industry there are two main disposal systems: strap choppers and strap re-coilers. Tebulo has traditionally preferred coilers (strapwinders) as they have fewer wearing parts and require lower maintenance. The strapwinder is a device that collects the cut straps and coils them up and compresses them for recycling. The strap is pushed out of the winder and it either falls onto a conveyor that transports the strap to a scrap container or it is collected in a bin which is emptied by another robot into the scrap container.

For the new de-strapper the strapwinder has been upgraded (strengthened) so has to cope with the higher coiling forces needed to process the very high strength steel straps into a compact waste material package. An additional design change has minimised the risk of the cut straps getting caught within the strapwinder's press area where the strap is wound and compressed and which might otherwise cause a stoppage or safety issue. Also noteworthy is the fact that the new strapwinder design is very low maintenance and has a minimum of wearing parts. The new design may be used for standard straps as well as for high strength steel straps, although the former de-strapper remains available in our product range for the removal of conventional straps.

FIRST MODELS
Each new de-strapper comprises a clamping and cutting unit, laser system for the detection of the number and exact position of straps and to perform a diameter measurement. Each machine is specifically tailored to customer requirements and may be equipped with various options. These include a scanning functionality for roll material shape recognition, coil detection, width scanning detection, bar code scanning and camera for access control or product number identification.

The first two new de-strappers, including control units, hydraulics and robot tools, were delivered to a high strength steel producer in Finland in the middle of 2018.

With this new de-strapper on the market, we expect that the use of HSS for straps will significantly increase, since strap removal can now be handled in a safe and affordable manner. MS

Henriëtte van Norel is Director of Van Norel Management Consultancy, Maarn, The Netherlands, working on behalf of Tebulo Industrial Robotics.

CONTACT: Henriette@vannorel.com
Marking & Labelling  
De-Strapping of High Strength Steel Straps  
Product Handling & Specials  

Slab Marking & Labelling  
Inner Coil Welder  
Sample Plate Handling

www.tebulo-ia.com

‘Making Heavy Industry Lighter’

24 June – 28 June 2019
Düsseldorf, Germany
Please visit us
Hall: 4  Stand No. “4A-15”
Optimal use of available floor space at a new storage location for steel coils

Use of mathematical modelling of a new steel coil storage/distribution warehouse has generated storage space for 300 additional coils and results in an 8-10% greater potential throughput than pre-modelling designs indicated.

Authors: Daan Merkstein and Stevo Akkerman
Systems Navigator BV and Tata Steel IJmuiden

Major investment decisions in the business sector are often accompanied by major uncertainties. For logistics projects, these uncertainties often relate to the dependencies between different parts of the logistics systems. Additionally, arrival patterns are, in practice, not nicely distributed according to an exponential distribution. There is variability over time in the various production processes, and one has to deal with peaks and failures. A simulation model of the logistics process can clarify this uncertainty by simulating the entire process, with all dependencies and relevant parts of the logistics included in the model.

A good example of an application for a simulation model is the LA warehouse project of Tata Steel IJmuiden. In collaboration with Systems Navigator BV, Tata Steel started the construction of a simulation model in early 2018 to analyse and optimise the logistics of a planned new steel coil warehouse. The coils are stored in cradles in the warehouse, but certain cradles are only suitable for some of the roles, so it is important to choose these cradle dimensions well and to place them smartly on the available floor space.

THE COMPANIES
Tata Steel produces, manufactures and distributes high quality steel for products in various industries, such as automotive, packaging and construction. At Tata Steel in IJmuiden more than 9,000 employees work on an annual steel production of almost 7Mt/y.

Systems Navigator is an independent software consultancy firm with headquarters in Delft, The Netherlands, and is a global leader in advanced decision support technology. Since 2003, our employees have been working around the globe for a wide range of customers on the most challenging projects. We assist our customers in making better decisions on where to spend their capital by demonstrating the impact of change through simulation modelling that can calculate a wide range of future scenarios.

Our Dropboard platform for planning and scheduling helps companies optimise their operations, improve customer service and maximise the use of their assets. Systems Navigator is a distributor of Arena and Simio simulation software and is the creator of Scenario Navigator.

© Fig 1 Phase three of the LA warehouse under construction
a coil and ensures that it does not roll away. However, certain cradles can only be used by coils that meet certain conditions in terms of width, diameter and weight. In addition to these technical limitations, it is not advisable to make all cradles suitable for every coil size since each cradle must then be suitable for the largest coils, which means that space is lost if only a small coil is placed on it.

In addition, as illustrated in Figure 3, coils can be stored on top of other coils to maximise space utilisation. To stack these coils, they have to meet certain stacking rules, which are based on the width, diameter and weight of the coils on the cradles and the corresponding coil that needs to be stacked.

In order to maximise warehouse capacity and efficiency, it was important to smartly decide on the number, the size and the placement of the cradles before storage operations commenced because, if it turned out to be wrong, adjusting it later would mean that parts of the warehouse would have to be emptied and operations stopped.

In order to do this, the possible changes in the characteristics of the coils that will be stored and the variability of the incoming stream have to be considered. Thus the aim should be to create a layout in which as many potential incoming streams with different types of coils can be efficiently dealt with.

WHY SIMULATE?

There are many factors that influence the quality of a layout, such as:

- Order of arrival of the coils
- Availability of trains and employees
- Variation in the type of coils that enter the warehouse
- Coil dispatch priority
- Prioritisation of the cranes
- Dimensions of the different cradles
- Number of cradles
- Placement of cradles in the warehouse
- In which order/batch size the coils enter the warehouse

Optimising a problem with so many complex variables and factors is a seemingly impossible task, which is why
the project team opted for an approach using discrete event simulation.

**THE SIMULATION MODEL**

The solution space of possible warehouse divisions has been researched by drawing up a set of layouts with specific characteristics and comparing them by simulation. From an analysis of these simulation results, a conclusion can be drawn that optimises the solution.

The simulation model for the LA warehouse was made in the software package Simio. Simio works on the basis of discrete event simulation and is object-oriented, allowing intelligent objects to communicate with each other and exchange their information. For example, if a coil is to be picked up, this pick-up request is communicated to the cranes which will then decide between themselves which crane will pick up the coil. Thus there is no need for an overlapping process that does the steering of the processes. Simio works with a 3D environment where real distances, times and speeds are taken into account and thus realistic object movements and transport times are guaranteed. An example of the model output is shown in Figure 4 which shows coils in the warehouse and the rail transport line. The coils that are blocked by a stacked coil are coloured red in the visualisation. The stacked coil has to be moved first, before the blocked coil (on the cradle) can be moved to an outbound modality.

**NO OUTPUT WITHOUT INPUT**

In any simulation model the value of the output relates to the value of the inputs (garbage in, garbage out). For many investment projects there is historical data of a process that is somewhat similar to the process that is being simulated. For example, historic ship arrivals at an oil terminal can be an excellent representation for future ship arrivals when this terminal invests in an additional quay or storage tank.

For the LA warehouse project, the project team looked at a dataset of coils that were stored at the Tata Steel site in 2017. With this dataset as a basis, the project team analysed the coils that would potentially have gone to the LA warehouse if the warehouse had already been available. In this way a representative set of 90,000 coils was compiled. Other parameters in the model included technical specifications of the warehouse, train loading and truck loading. Accompanying restrictions and transport-out schedules to Tata Steel’s customers were also examined.

**DETERMINING THE CRADLE TYPES**

The cradles are mounted on notched rails in which they are fixed (see Figure 3). This determines a specific number of possible cradle types depending on the number of notches that are left between the cradle. The distance between the two rails determines the possible width of the cradle.

From the data analysis, a scatter plot of the width/diameter of the coils from the dataset was produced, as shown in Figure 5a.

The first step was to determine which range of width/diameter groups performed best. Ultimately, it was decided to analyse six different combinations of width and diameter. For each of these six combinations the optimal group sizes were determined using the expected inventory level of these groups. By minimising the lost space (that quantity where a roll is smaller than the largest roll that would fit on the cradle), the optimal dimensions of the groups, given the number of groups, were found.

To determine the expected stock level per width/diameter adjustment, the analysis takes into account the number of arrivals and the residence time of the rolls in...
storage. According to Little’s law, the product of these two values gives the expected average required stock level per cradle type:

\[
\text{Expected number of coils in storage in the warehouse} = \text{Number of incoming coils per day} \times \text{average duration of stay in the warehouse}
\]

One can analyse the outcomes of the simulation on various chosen performance indicators, such as the number of coils that were not available, the average initial investment and the efficiency of the cranes. The analysis showed that a combination of 4 width groups x 3 diameter groups gave the best layout. This is illustrated in Figure 5b.

By analysing and improving the six optimised layouts with specific characteristics a number of times, the solution space can be reduced after each iteration. After about 10 iterations an optimised cradle solution was found and this advice was delivered to Tata Steel in the form of a layout ready for submission to the constructor.

**ADDED VALUE**

To test the added value of the simulation model, the initial cradle setup, (made on the basis of common sense and experience), was simulated and analysed. The results showed that in the optimised layout, 50 additional cradle positions fit in the warehouse, resulting in approximately space for 300 additional coils because of a higher stacking potential. This results in an additional 8-10% potential throughput. Additionally, and possibly more importantly, the final layout is also better able to accommodate greater variability in arrivals and potential future changes in coil dimensions.

**CONCLUSIONS**

The LA warehouse has been in full production use since October 2018 and is performing to expectations. The project has demonstrated that the use of a simulation model is an excellent way to obtain answers and advice for complex investment logistics systems projects, even before the construction of the project has started. The model is currently being developed further so that it can be used to support operational planning issues, such as assigning parking places for incoming trains, setting priorities for tasks, the deployment of operators, and the analysis of the use of space.

Daan Merkestein is Consultant at Systems Navigator BV, Delft, The Netherlands and Stevo Akkerman is Manager Logistic Projects at Tata Steel Ijmuiden, The Netherlands

**CONTACTS:** daan.merkestein@systemsnavigator.com
stevo.akkerman@tatasteeleurope.com

---

*Fig 5a Scatter plot of width and diameter*

*Fig 5b scatter plot with, as an example, a colouring based on 12 distinct cradle groups (3 width groups x 4 diameter groups)*
Supply to China?

The next edition of Millennium Steel China will be published in November.

Stay ahead of the competition

For further information please visit: www.millennium-steel.com
Index of Advertisers

A
AUMUND ......................................................... 41

B
BWG .................................................................. 88

C
John Cockerill ................................................. 8

D
Danieli ................................................................ 2-3
Danieli Corus ................................................... back cover

E
Edwards Vacuum ............................................ 57
Edwards Vacuum .............................................. 58-59
Maschinenfabrik Gustav Eirich ....................... 22
EVERTZ .............................................................. 66

F
Fontaine Engineering .................................... 4
Fontaine Engineering ...................................... 96-97

G
GSB .................................................................. 35

L
LAP Laser ....................................................... 95
Leybold ............................................................... 60

M
Magnesitas Navarras .................................... 23
Midrex ................................................................. 12

N
Nuova Carpenteria Odolese ......................... 84

R
Redecam Group ............................................ 17
Refratechnik ................................................... 31

S
Sarralle .......................................................... 48
Schrägheiztechnik ............................................ 123
Showa Denko ............................................... 42
SMS ................................................................. 10

T
Tebulo ............................................................ 116
Tenova ............................................................... 6
Thermo Fisher Scientific ............................... 73

V
Velco ............................................................. 47

W
Paul Wurth ................................................... 27

Z
Zumbach ......................................................... 106-107
Modern Stockyard Technology

Eco-Friendly Solutions

• Fully enclosed stockyard solutions
• Reduction of dust pollution
• Reliable and field proven technology for various kinds of plants

SCHADE Lagertechnik GmbH
sales@schade-lagertechnik.com • www.schade-lagertechnik.com
Danieli Corus, based in The Netherlands, covers all of the BOF Steelmaking technologies within the Danieli Group. With the integration of the Danieli Linz Technology specialists in the IJmuiden office, development of equipment for oxygen steelmaking will be greatly accelerated by sharing knowledge and experience between both disciplines. In addition to BOF Process Control technology, which brings the highest level of process automation and efficiency, the portfolio includes the latest converter designs. These come in the range of 85 to 350 tonnes tapping weight and are equipped with the innovative Daniella suspension system. A first joint development is the application of wet scrubbing technology proven in blast furnace ironmaking to replace existing BOF off-gas scrubbers that are known to have operating and maintenance issues.

For improved BOF shop operation and maintenance, we offer a comprehensive set of upgrades. One such an upgrade is the converter relining machine, which allows for the quickest and safest possible relining of the converter vessel.

We offer you the world benchmark in BOF steelmaking. Our solutions allow for optimized operations at the lowest cost per ton of steel and minimum interruptions for maintenance.