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 ever increased. These changes are not only influencing our way of life, but will also affect the way we work, and are and are often referred to as Industry 4.0, where new technologies will increasingy 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.

Authors: Andrea De Luca, Alessandro Ardesi and Luca Cestari
Danieli & C. Officine Meccaniche SpA and Danieli Automation SpA

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 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 (300-800kt/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 Mi.DA technology 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 ▷

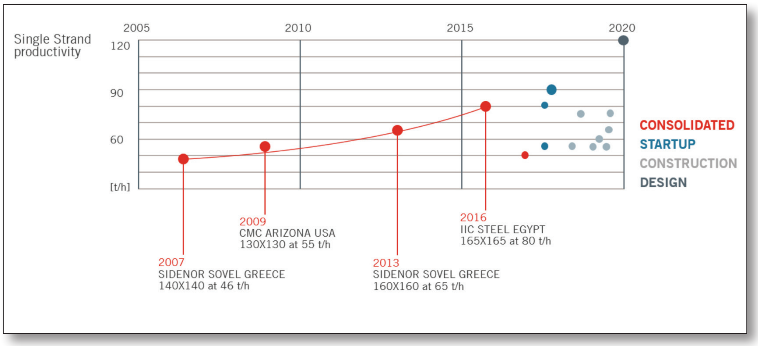

Fig 1 **Mi.DA milestones and future developments**

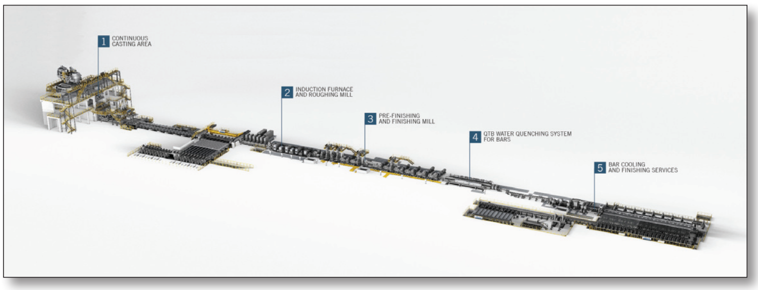

Fig 2 **Mi.DA typical plant layout**

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 140x140mm 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, boosting the plant productivity up to 800kt/yr**[4].** Some of the milestones are shown in *Figure 1.*

Today's scorecard for this technology are 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%

The typical Mi.DA plant layout is shown in *Figure 2* and consists 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 DRB

DIGI&MET VISION AND MISSION

Over the past 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 increasingy 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**[5]**.

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**[6]**.

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 usage 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 the 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 challenging so-called 'Green Metals' 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.

Q3Intelligence 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 analytics 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.

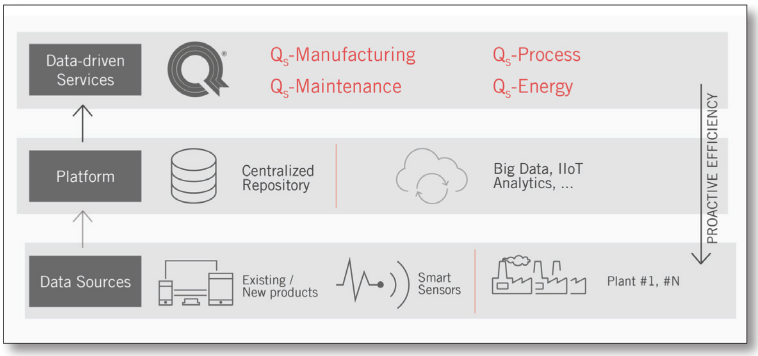

Fig 3 **Data-driven approach towards digital smart plant**

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 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 the Q-MELT furnace control package. Melt Model is based on a statistical approach to identifying 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

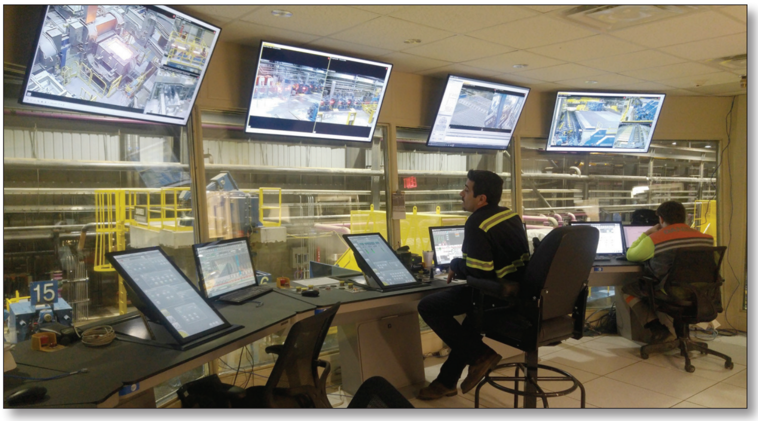

Fig 4 **Integrated 3Q digital pulpit for endless casting and rolling**

of conveyors, being thus perfectly integrated in Danieli Endless Charging System (ECS).

At the start of a heat, the fingerprint of the key process variables (off-gas CO, CO_2, H_2O, total O_2 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 tip design to 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 continuous caster and rolling mill. For the specific requirements of the Mi.DA process, 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, including:

- **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 key performance indicators (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 focused 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 great contribution, supporting automatic identification and localisation of materials, assets and workers, therefore improving plant efficiency and 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

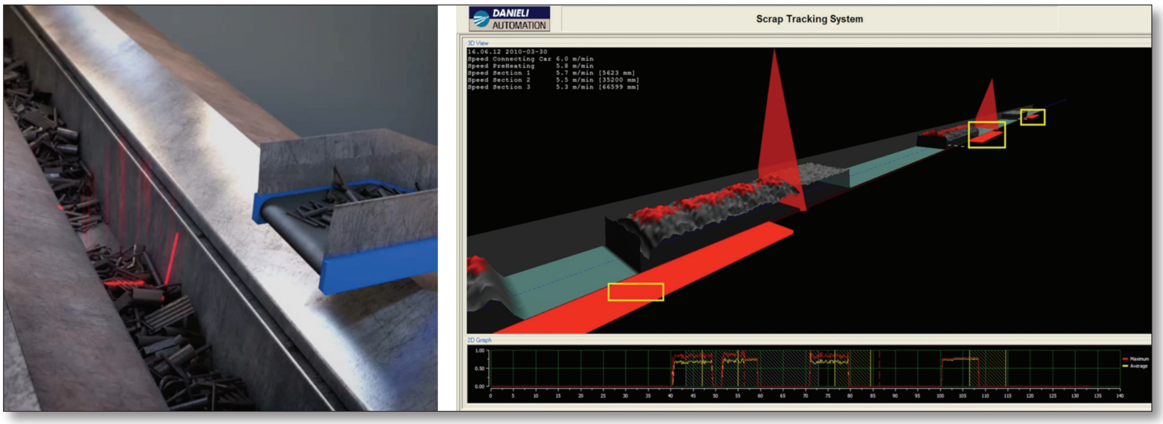

Fig 5 Q-STS Automatic scrap tracking system for ECS continuous charging

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 specific 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, 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 an automated patented machine-vision solution (Q-ETS). It is based on a unique 2D pattern printed on panels to guarantee increased reliability of reading even with a limited field of view from the camera. There are several successful reference applications. 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 through all 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 the casting machine process control system, 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 significantly improved efficiency, availability and utilisation of the plants, as well as to leverage high rationalisation opportunities through the integration of new systems.

According to the DIGI&MET 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 in the ladle, 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 a 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, of the information about CO, CO_2, temperature and H_2O 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 O_2 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 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 also has 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,

Fig 6 **Smart sensing and instrumentation from melting to hot rolling**

Fig 7 **Q-ROBOT MELT**

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*.

Fig 8 **Q-ROBOT CAST**

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-based automated solutions are also an important support for workers in executing regular and repetitive tasks. The design of these solutions, aiming at improving both plant efficiency and safety, takes into consideration the safety constraints represented by the fact that, in some cases, operators and robots must share the same spaces.

Robotic applications have been efficiently implemented by DANIELI with custom solutions in primary and secondary metallurgy stations, where tasks like automatic temperature and chemistry sampling are handled with the proven Q-ROBOT MELT technology, which makes use of an innovative and smart solution for fast automated cartridge change (*see Figure 7*).

In continuous casting, Q-ROBOT CAST (*see Figure 8*) is the family of solutions that is provided to automate operation in the casting platform by replacing human operators in dangerous tasks, such as ladle shroud insertion and removal, nozzle opening by means of oxygen lances, powder addition, sampling and measurements in the tundish**[9]**.

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, a roll wear early 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 on 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 a 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 & 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.

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 a utilisation

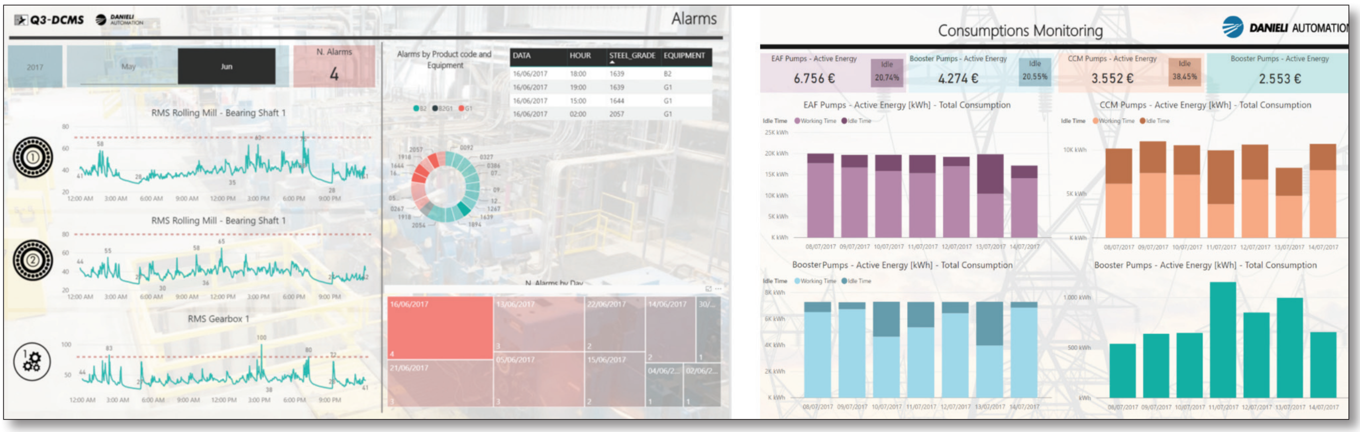

Fig 9 **Q3Intelligence dashboards: Condition and energy consumption monitoring**

of the permissible power that is as high as possible, without exceeding the contractual limitations and avoiding price peaks and penalty charges.

All 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*.

CONCLUSIONS

Mi.DA endless casting and rolling is, today, a proven technology, the best available in the market to fulfil 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. They support 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, they enhance 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. **MS**

REFERENCES

1. A. De Luca et al, *Energy Saving: the High Speed Solutions in Danieli CCMs*, AISTech Proceedings 2016.

2. A. Miconi et al, *Danieli Power Mould: Key Technology in Evolution for High Productivity, High Quality and Energy Savings*, AISTech Proceedings 2015.

3. K. Keller et al, *The New Micromill Danieli (MI.DA.®) at CMC Steel Arizona – An Innovative Process for the Most Competitive Production of Rebar Product*, AISTech Proceedings 2010.

4. M. Fornasier e al, *Productivity Record @75 tph in a Single Endless Line for Bars*, ECCC Proceedings, 2017.

5. A. Merluzzi and G. Brunetti, *Metals industry: Road to digitalisation*, 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 22-26 May 2017.

6. ESTEP Platform, *Roadmap Integrated Intelligent Manufacturing (I2M)*, Created by the Working Group Integrated Intelligent Manufacturing (I2M) of ESTEP, 2016.

7. M. Piazza et al, "EAF process optimisation through a modular automation system and an adaptive control strategy", in *La Metallurgia Italiana*, n.9, 2016.

8. M. Appio and A. Ardesi, *HiPROFILE innovative defect detection package to increase production quality*, ESTAD Proceedings 2017.

9. P. Demetlika et al, *Q-Robot CAST for Ladle Area: reaching new levels of automation and safety in continuous casting*, METEC and ESTAD Proceedings 2015.

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

CONTACT: info@dca.it