The review of whole production cycle from thermomechanical treatment and wire rods calibration, to application of 4.0 strategies for process control

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In 2022 It has been completed in Feralpi Siderurgica the R&D project WireAccuracy4.0 starting in 2018 also with the support from Italian funding Scheme FRI of MISE (Italian Ministery of Economical development).
This project involved several applications of new strategies and component in whole production cycle and it has been a great opportunity of development of the production facilities of Feralpi Siderurgica involving improvement of productivity, steel quality, process reliability and involving new products lines.
In particular the project involved several plants developments including new devices in steelmaking area, Revamping of the continuous casting, improvement of rolling mill with new billets welding machine, thermomechanical treatment, new wire rods calibrator and new exit line.
These plants improvements have also been coupled with new solutions Industry 4.0 including increased capability of products tracking, new sensors developments and capability of process simulation to develop new control systems for on-line advanced process control.
In particular improvement of on-line simulation process of EAF and Ladle treatment have been developed in order to support the production process with guidelines based on process technology.
These developments addressed to increase the level of quality also in applications for civil constructions through a modern production of Wire Rods from billets casting to rolling.
For this reason Feralpi Siderurgica has followed a route of global improvement of its production cycles following the most advanced approaches for reliable Wire rods production.
This procedure of production cycle global improvement has been followed by Feralpi Siderurgica also
through improvement of internal skills promoting collaboration between the different technical department (R&D – Process Technology, Production, Quality, Automation) and also promoting the creation of advanced programs of training (Technical Graduates Program)

KEYWORDS: CONTINUOUS CASTING, SIMULATION, PROCESS CONTROL, SOLIDIFICATION MODEL

INTRODUCTION - Feralpi Siderurgica

Feralpi SiderurgicaFeralpi Siderurgica is part of Feralpi Group that is a group with 3 steel plants where active production cycle based on electrical steelmaking route and devoted mainly to production of conventional Steel and special steel for automotive.

Following are the main numbers reached by Feralpi Group and Feralpi Siderurgica for 2021:

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Feralpi Siderurgica

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SMS

A. Ventura, D. Ressegotti
Rina CSM

- Turnover :	1,93	525.6 M€/yea
- Employers :	1826	385
- Production :	2,62 Mton/year	1,1 Mton/year
- Society n° :	20 (7 Countries)	
- Products :		

Feralpi Siderurgica is a Steelmaking plant sited in Lonato del Garda (Italy) since 1968, and it is devoted to production of conventional Steel for constructions in terms of Billets, Bar, wire rods, electrowelded mesh and others.

Fig.1 - Feralpi Group and Feralpi Siderurgica (Lonato Site).

In this paper the activity included in the R&D project WireAccuracy4.0 are described. In particular the main directions of Feralpi productions improvements have included implementation of new equipments in rolling areas as new calibrator, implementation of thermomechanical treatment and exit line coupled with improvement in continuous casting for the production of billets with 150 mm side.

These developments in the production facilities to improve quality and productivity have been coupled with advanced approaches of data management following the advanced Industry 4.0 strategies including systems for product and production tracking, advanced data measurement, on-line control system for detailed process control and adaptation in order to improve the capability of project management and data analysis.

The scopes of these improvement have been to reach as main benefits in following terms:

- Product quality and wire Rods dimensional accuracy
- Productivity to increase capability on market satisfaction
- Repeatability and reliability of process management and control
- Capability on data management and analysis following a view of w

The project WireAccuracy 4.0

Feralpi Siderurgica has concluded in 2022 the project WireAccuracy4.0 started since 2018 the project WireAccuracy4.0 - Actions through process to obtain the product WireRod with thermomecanical treatment, bars and derivates with new steels through production plants modifications and control system Industry 4.0 with a duration of 48 months.

The main objective of the project is the development of new products wire rods with increased dimensions accuracy with also thermomecanical treatment and other products and improvements of production performances of whole production cycle through technological plants modifications, metallurgical studies and development of control system of single production phases.

The project is co-funded by R&D Funding Frame : "MISE - Bandi grandi progetti R&S a valere sulle risorse del Fondo rotativo per il sostegno alle imprese e gli investimenti in ricerca (FRI)"

In WireAccuracy4.0 have been implemented different actions in whole production site to cover the all possibilities of actions of improvement as:

- Technological improvements in production plant on each phase to increase efficiency and effectiveness
- Implementation of improved views systems of each production phase to improve capability of process control
- To implement an integrated view of the whole production cycle (tracking product/process) in order to :
  - obtain correlations between practices adopted and Process performances and product quality obtained
  - manage dependencies between the different phases to manage abnormal situations, corrections and alerts fucntions

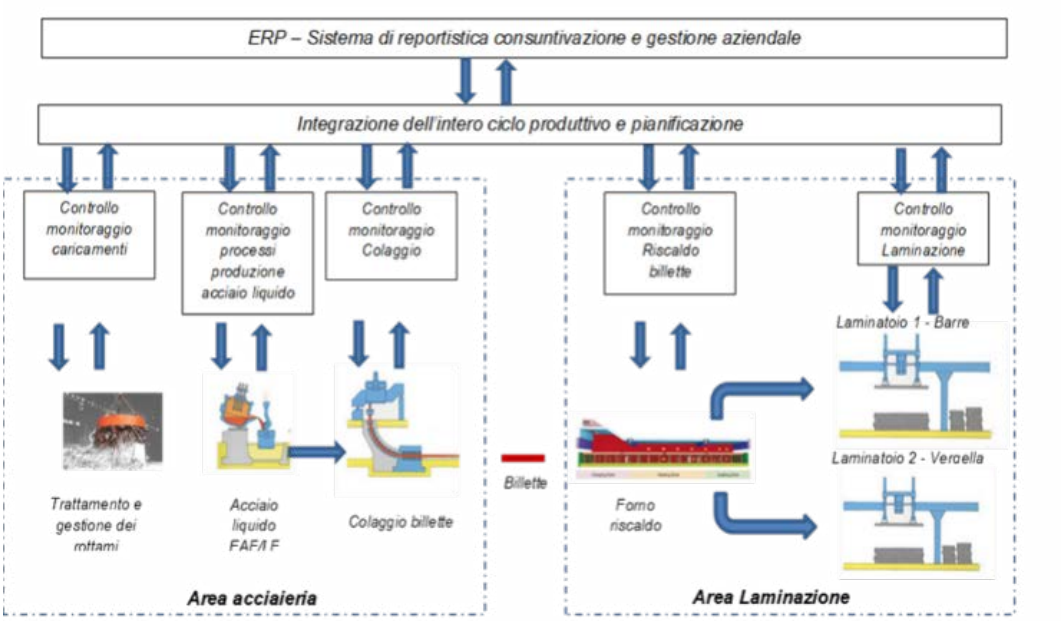

Fig.2 - Feralpi Group and Feralpi Siderurgica (Lonato Site).

The project cover the whole production process including as main actions (Figure 3) :

- Steelmaking: Development of process simulators for definition of operating practices, revamping of the continuous casting machine for billets 150 mm, improvements in ladle treatments and preheating.
- Rolling: Revamping of rolling for wire rods with implementation of Thermomechanical treatment and profile calibrator, implementation of billets welding machine for continuous rolling, revamping of the rolling exit line
- Industry4.0 solutions: Implementation of data analysis systems starting by process and product tracking, new control system for Steelmaking and rolling, solution for data integration in single steelmaking and rolling areas and for the whole production, solution for automatic production scheduling and for e- business.

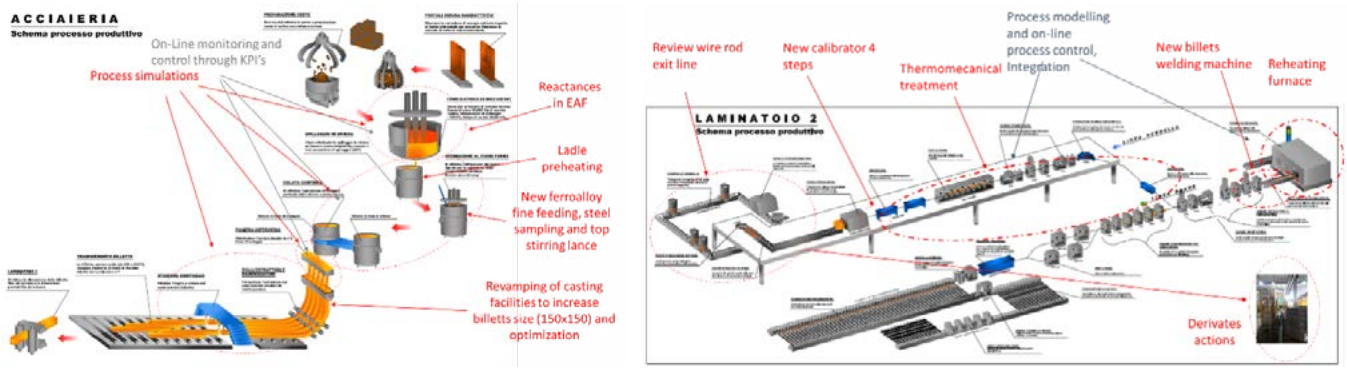

Fig.3 - Main actions in Steelmaking Area Main actions in Rolling Area.

Studies and design of the systems

Studies assessment of the different topics has been realized to enable the Basic design of the solutions to be adopted for process and plant improvements icluding:

- Subsequent dimensional calibration of the wire rod to improve dimensional accuracy for subsequent treatments
- Obtain improved mechanical properties thanks to a more fine grain distribution

Metallurgical aspects

In particular the main action involved the review of rolling facilities for wire rod to obtain new characteristics of actual products with improved production process aimed to obtain (Figure 7) :

- Thermomecanical Treatment for wire rod through rolling at lower temperature respect the conventional.

The process to be realized includes different steps of rolling and cooling in subsequent phases, accuracy in control of times and events on the process, capability to fine control the process to be realized is necessary.

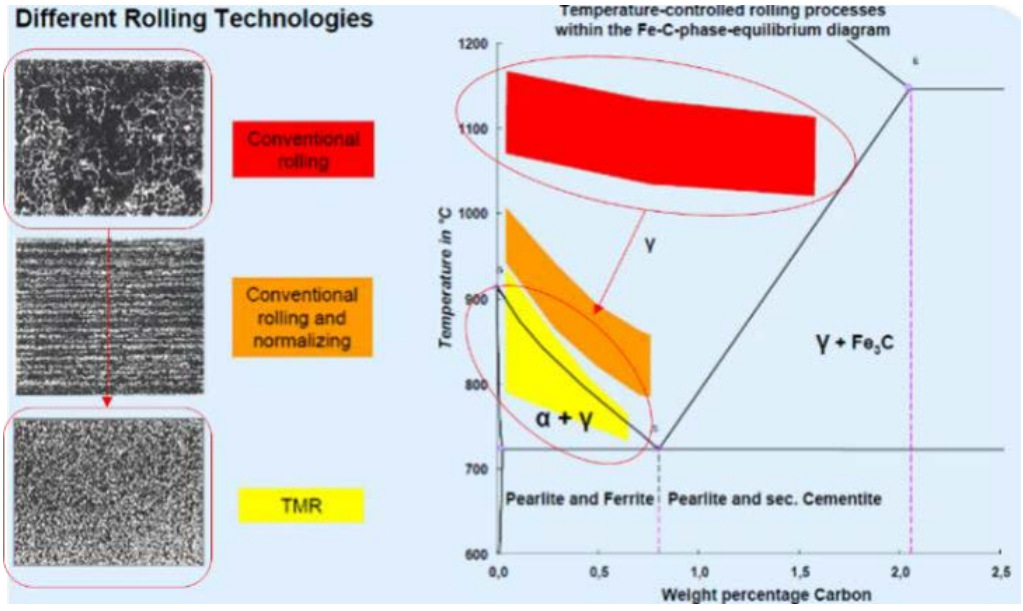

Fig.4 - View of TMT metallurgy.

Furthermore to obtain the necessary products for rolling is necessary to guarantee also the quality of the billets produced and available for rolling.
In this way a continuous route of product and process quality assurance has to be realized involving the whole production chain from steelmaking to rolling including (Figure 5) improved control of production cycle, plant improvements, optimization of process parameters for whole cycle, complete tracking of the product in the factory

Feralpi started a strategy to realize mathematical process simulators in-house with following scopes :

- To design processes operating practices
- better control mathematical models implemented
- To improve internal processes competences

Simulation EAF/LF Treatments

Regarding the EAF and LF treatments process simulators have been developed in order to be able to design new operating practices.
The systems developed with Matlab/Simulink code realize a dynamic mass and energy balance of the process (Figure 9) able to estimate from the designed operating practice and material charged:

- Time evolution of the reactions, energies in input/ output masses, chemical compositions for steel, slag, off- gas.
- Process summary in terms of : performances, consumptions of energies/materials, time, final composition and temperature of Steel and slag.
- Estimation deoxidation and reactions evolution in ladle treatment as desulphurization (Figure 11)
- estimation of ladle additions necessary (Figure 12)

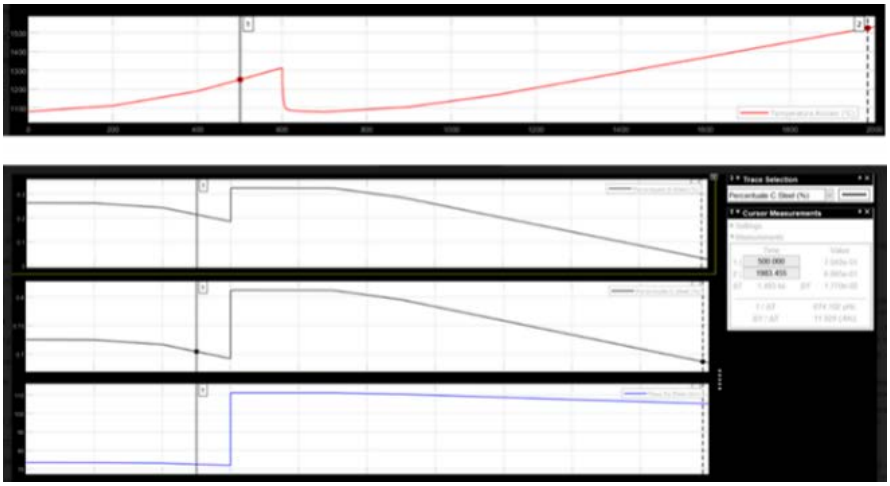

Fig.5 - Example of result output input.

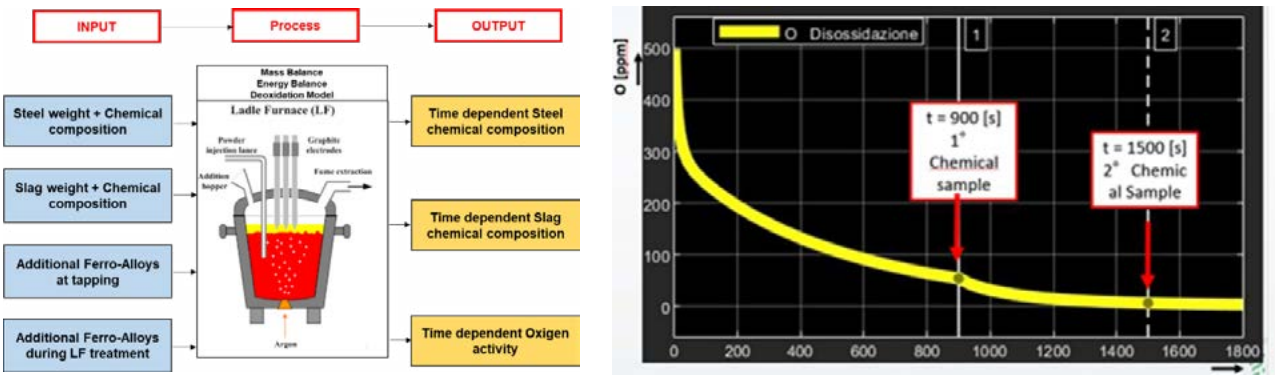

Fig.6 - Scheme of process modelling in LF, Estimation of evolution of O2 in ladle.

Tundish/Castings

Simulation of fluidynamic of steel in tundish has been realized with Rina CSM including:

- Study of stationary conditions of present tundish
- Study of the period of ladle change and tundish emptying
- Analysis of result and definition of correct practice

By this approach the probability of inclusion passage in mold depending by particles dimensions has been obtained in different configurations.

Furthermore studies and simulations has been realized in continuous Casting and solidification process with the partner Seamthesis in order to evaluate the critical aspects having effects in billets quality to obtain as output :

- Temperature of the different areas of the billets along casting line (Figure 8)
- Solidified shell formed during casting
- Metallurgical length and position of crater
- Evidence of strain forces occurring in relevant sections as unbending.
- Probability of cracks formation

Thermomechanical treatment

SMS has developed a tool for prediction of results of the treatment in rolling to be used to assess the optimal cycle of cooling and times for wire rod rolling and has used in input the configuration of the plant to evaluate the optimal design of the plant and practices to be used (Figure 8).

The objective of the activity has included:

- Simulation of the temperature regulation
- Guidelines for production scheduling
- Reduction of the water consumption
- Reduction of the number of production steps/Phases

With improvements of the product quality thanks to :

- Improvement of mechanical properties
- Optimal regulation of temperature in real time
- Uniformity of scale formation
- Improved repeatability of products characteristics.

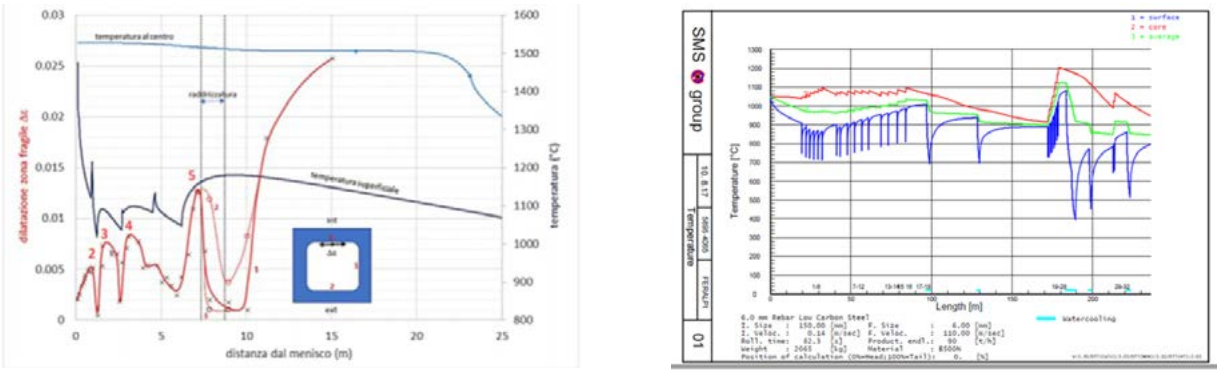

Fig.7 - Simulation of billets solidification evolution and temperature prediction during billets rolling.

Industry 4.0 - On-Line Control systems

Main control systems of process implemented are:

- Expert Systems for EAF Process
- System for trough process steelmaking treatment
- On-line control of heating on the 2 billets reheating furnaces

EAF Monitoring/Control system

For EAF Process monitoring and management Feralpi has developed with Rina Centro Sviluppo Materiali the system EAFPro including several funcions (Figure 27) as :

- Data acquisition and monitoring
- Data analysis
- Process Simulation
- Autoadaptation and Expert functions
- Online alerts Guidelines and control rules

For EAF the main on-line control functions presented as included in the system EAFPro are :

- Detection of acoustic emission to manage the Foaming agents injection (Coal) (Figure 28)
- Estimation of Slag Oxidation Status (SOS) to manage the O2 Injection (Figure 29)
- Summary control chart to evaluate abnormal Process/ Production conditions (Figure 30)

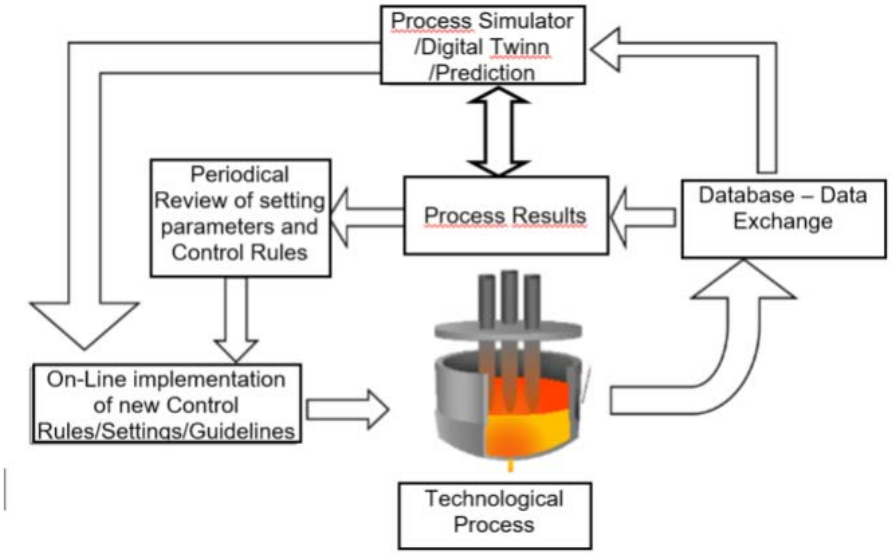

Fig.8 - Shcme of logic functions of expert system for process control based on process simulation.

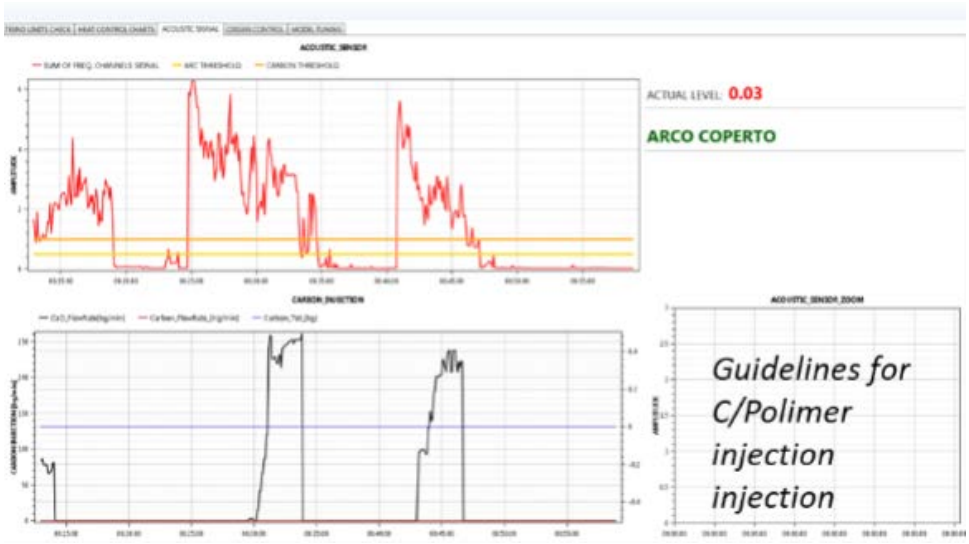

Fig.9 - View of acoustic signal used for control of solid injections in EAF for slag foaming.

Ladle treatment Monitoring/Control system

A monitoring/prediction system of steel temperature in ladle has been implemented including:

- The steel temperature estimation in ladle starting by each tapping by EAF start (Figure 31)
- The estimation of steel temperature in ladle takes into account of the temperature variations due to energy losses in l adle, electrical energy inputs, materials additions gas stirring inlet.
- The temperature estimation is compared with real temperature samplings and adaptation to real samples is realized.

- Steel and slag composition evolution during LF Treatment following the LF additions

Main scopes of the through process system includes :

- Reduction of necessary samplings in LF
- Reduction of irregular temperatures in LF and CC
- Availability of alerts based on ranges of acceptability of ladle temperatures depending by process phase and process conditions (Figure 32).

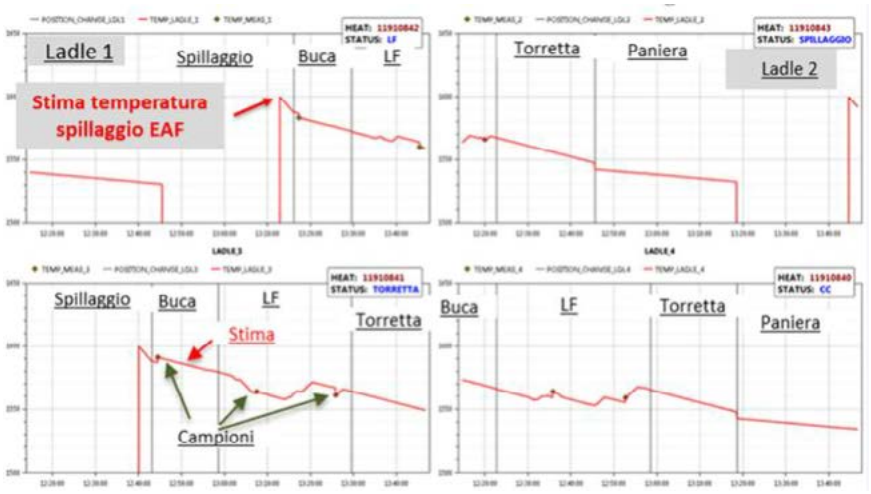

Fig.11 - View of steel temperature estimation through process for 4 ladle in cycle.

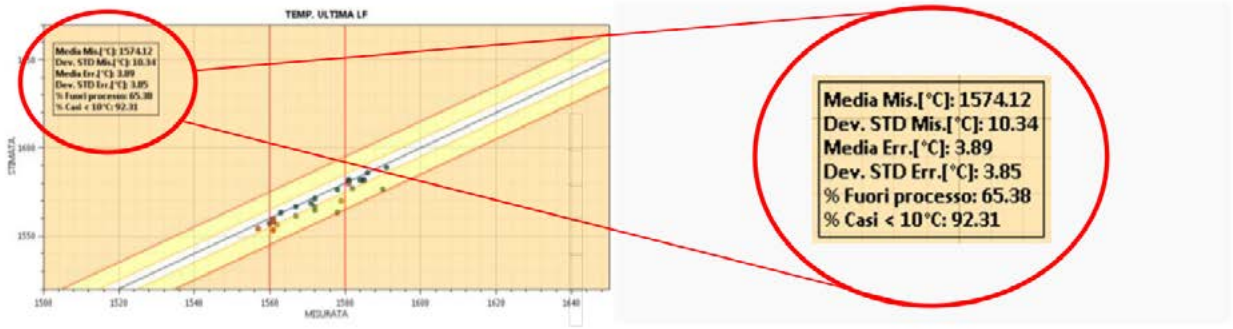

Fig.12 - Accuracy of steel temperature prediction in LF.

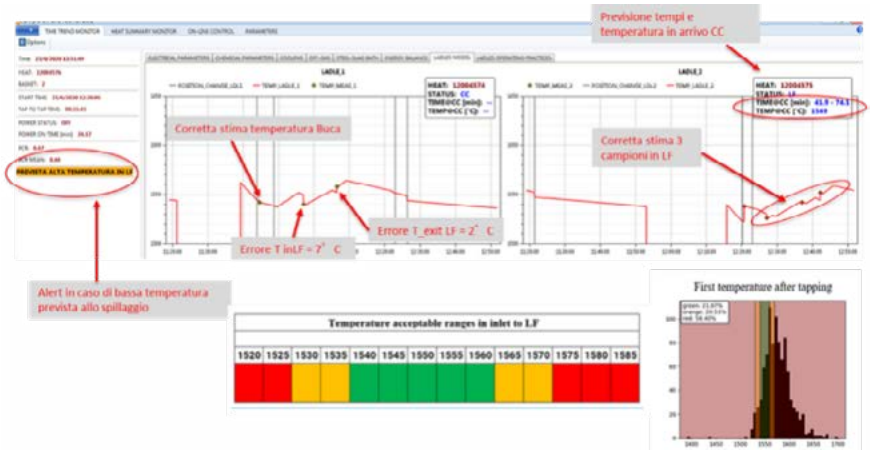

Fig.13 - Alert functions on steel temperature.

Further system implemented is the capability to evaluate the % of sterile content in scrap charged depending by process monitoring.
This system is able to follow trend variation of sterile content depending by period and different stocks charged and it is presently under testing/Calibration after first trials.
Process data integration is followed also in rolling area and for whole production cycle.

Technological developments

Steelmaking/Casting

With Primetals have been realized the new Billets Casting machine with the scope to increase produttivity, obtain new billet size 150 x 150 and improve billets quality with following actions:

- Design of the new machine
- Process simulation for new practices
- Testing and practices assessment.

New equipments implemented (Figure 14) :
- New mold oscillation system
- New mold design with foot rolls
- New secondary spray cooling
- New billet extraction/Unbending

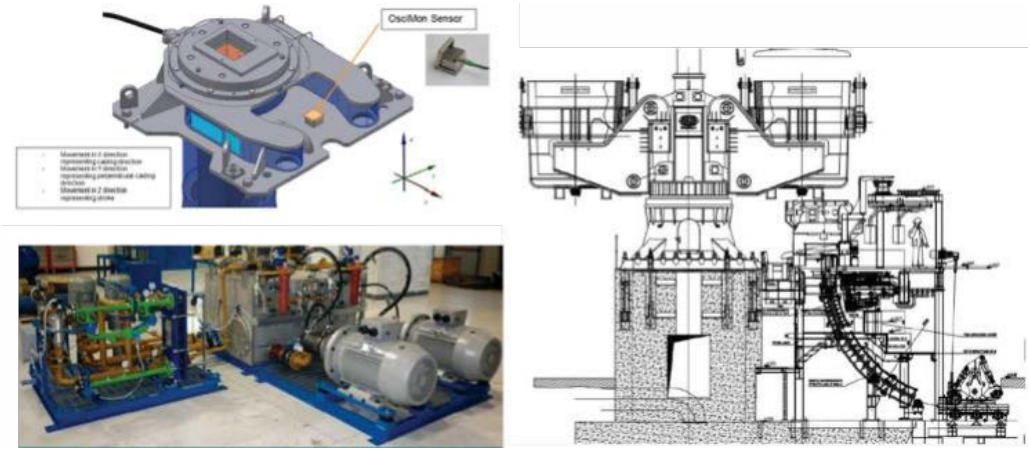

Fig.14 - Main improvements in casting machine.

New equipment have been implementad for wire ferroalloy additions in LF

The aim are:
- to guarantee uniformity and repeatibility of the process
- more accurate knowledge of quantity of additions realized
- improved capability to regulate the additions.

Fig.15 - New wire additions in LF.

New system for ladle preheating has been implemented and the activity has included (Figure 16):

- Design of the system
- Realization and installation
- Testing

The main results obtained with this application include:

- Improvement of stability of ladle preheating
- Reduction of energy consumption for ladle preheating

Fig.16 - New system for ladle preheating.

System Sampling/Stirring in LF

The system includes (Figure 17) :

- System for sampling steel in LF
- Implementation of porous column to substitute the function of porous plugs when necessary for bath stirring

The main objectives are:

- Increase reliability snd frequency of steel chemical sampling
- Improvement bath stirring and uniformity of steel conditions in LF. Both these system will reach following benefits
- Improvement of product quality in terms of composition, cracks and inclusions reduction.
- Increased productivity for optimization of samplings when necessary.

Fig.17 - New station sampling/Stirring in LF.

Technological developments – Rolling - Thermomechanical treatment and calibration

Thermomecanical treatment/calibrator for rolling

About the implementation of Thermomecanical Treatment preliminary evaluations have been realized with some main potential supplyers (SMS, Danieli) than SMS has been selected for the final solution.

Different paths have been designed for different wire rods diameters (Figure 18).

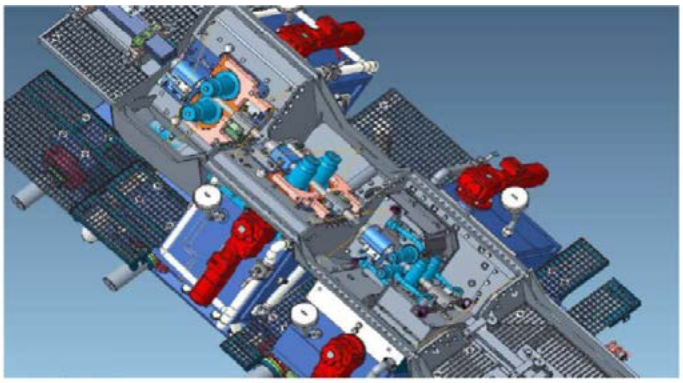

Fig.18 - Disposition of new wire rot calibrator Meer Drive SMS.

Billets welding machine

For the billets welding machine the activity had included :

- Design of the system by SMS.
- Realization and installation of components
- Testing of the new billets welding machine coupled with exit line

With this equipment the billets is welded face to face with the previous billets in rolling and the subsequent in reheating furnace exit.

In this way it is realize a continuity of the rolling process that is realized endless.

The benefits with this approach have been:

- Increase productivity due to delete of interbillets time
- Reduction of metallic loss due to avoidance of start and final billets
- Reduction of damages due to equipments.

Fig.19 - Disposition billets welding machine.

Exit /Finishing line

About the review of the wire rod exit line to rolling mill 2 following phases have been developed :

- Basic design and technology provider selection
- Detailed design
- Site preparation and modification of rolling path line
- Installation and commissioning

Fig.20 - New Exit Line and shear for wire rods.

Systems Industry 4.0

Tracking systems

Several systems of tracking have been applied as :

- Ladle tracking
- Wire rod rolling tracking
- Product tracking

Tracking systems – Ladle tracking

Ladle positions tracking has been realized in pilot scale to validate the possibility of detect ladle number with this device including :

- Point of emission of optical signal
- Point of detection of signal

Main aims of this equipment are:

- To follow the real history of the process
- To track the ladle history use , and maintenance necessities.
- To give right informations to the process simulator EAFPro through process to enable to follow and control the process.

Tracking systems – Wire Rod sections measurement

The activity has included the implementation of systems for optical measurement of wire rod sections to detect quantity of material passing and equivalent section and couplig with on-line profile detected (Figure 21, 22).

Main activities :

- Design of main points of detection
- Application of the detection devices
- Design and realization of summary view to obtain following main points:
  - Detection of equivalent section and quantity of material rolled
  - Evaluation of acceptability respect expected values
  - Coupling with other measurements and alerts in case of abnormal values
- Billets Labeling system and process parameter tracking it has been designed and installed.
- Products automatic labeling including spools and bandles
- Integration of these informations in the automation system to assign parameters of production to the correct billets with these parameters.

Fig.21 - Profile and section measurement.

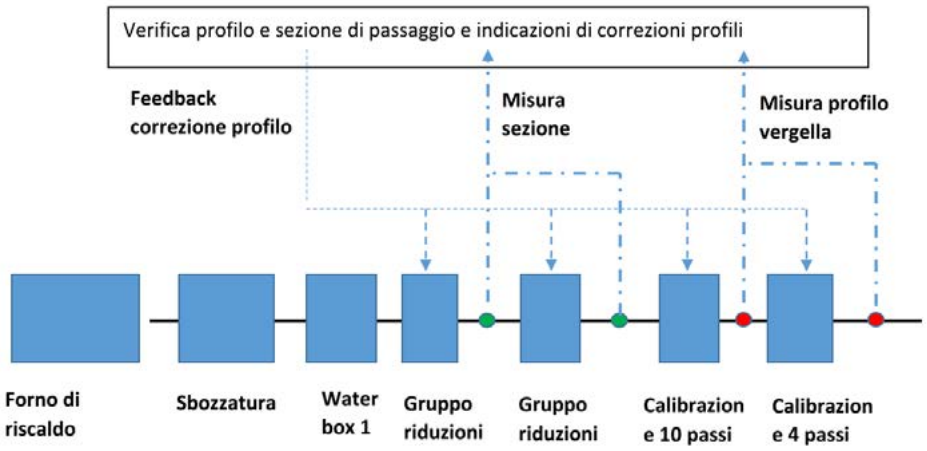

Fig.22 - Rolling measurement combinations.

CONCLUSION

In modern steel production, the continuous improvement is still a driving force for both increase the production efficiency but also to follow the market opportunities developing new products when necessary.

To follow this approach the innovation play a key role for technological development and, when possible, enabling the activation of R&D projects can be useful to obtain the support of funding schemes necessary to lower the level of risks characteristics of new developments.

Feralpi Siderurgica has followed a route of global improvement of its production cycles following the most advanced approaches for reliable wire rods production and for product quality including:

- Development of new products (as wire rod obtained after thermomechanical treatment
- Implementing improvement of technological devices as the case of revamping of continuous casting
- Developing solutions Industry 4.0 in terms of data acquisition, process and product tracking, capability to processes simulation, data analisis in terms of KPI's and processes integration.

The scopes of these improvement have been to reach as main benefits:

- Improvement of product quality and wire Rods dimensional tolerance accuracy
- Improvement on productivity to increase capability on market satisfaction
- Improvement on repeatability and reliability of process management and control
- Improvement of capability on data management and analysis following a view of whole process integration

Thanks to this approach, new developments are now implemented and became part of the production cycle while further steps seems necessary for the development activities prosecution.

These results obtained thanks to the Passion for Steel and collaboration between the different technical areas of Feralpi Siderurgica including Steelmaking and Rolling Production, Maintenance, Automation, Quality, IT, R&D and strong commitments from the Direction.

Furthermore, the cooperation also with technological partners and research provider (Universities) has enabled performances improvements for Industry, development of new technologies, transfer of knowledge and increasing of internal competences.

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