The Next-Generation HSM Process

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ABSTRACT

An enhanced strip production concept with Danieli Inductive Heating technology ensuring conventional Hot Strip Mill answers market demand for ultra-thin gauge, high quality and premium grades.

Thick-slab rolling using conventional Hot Strip Mill holds the leading position when it comes to high production capacity, wide and flexible product mix, and premium grades such as automotive exposed and electrical steel.

The modern HSM production faces a triple challenge in the current dynamic market: achieving sustainability, enhancing quality with tight tolerances and uniform properties, and answer market demand for thin-gauge, hot-rolled coil.

The competing in-line casting and rolling technology is a step ahead in many aspects.

The Danieli Quali-HSM® breakthrough process innovation is the answer to those challenges, merging the advantages of both conventional rolling and inline casting and rolling process routes.

The result is the production of HRC at high and uniform temperatures, at a constant speed and down to ultra-thin gauge of 1.0 mm.

Keywords: Green energy, Flexibility, Thin and Hard Grades, Silicon Steel, Digitalization

INTRODUCTION

The Quali-HSM technology is engineered to produce ultra-thin, high-strength steel grades with exceptional surface quality and uniform properties.

The core of this innovation lies in the integration of inductive heating (IH) modules within the finishing mill, enabling high finishing temperatures, stable rolling conditions, and a uniform process

The typical 7-stand finishing mill is divided into a 2+5 arrangement, optimizing the footprint and enhancing energy efficiency.

This configuration creates the opportunity to include the following equipment inside the Finishing Mill:

- Induction Heating: a heat-on-demand tool used when rolling thin gauge, placed 5 stands from the end-of-rolling, finding a sweet-spot between process advantages and expenses, both operating and capital ones,
- Additional Descaler Box: an additional descaling point reduces tertiary scale on the final surface,
- Crop shear: installed further downstream compared to a traditional HSM, to reduce the risk for cobbles by improving the shape of the head-end threading the last stands,
- Additional thickness and profile gauge: installed after H2 for additional open- and close-loop automation controls.

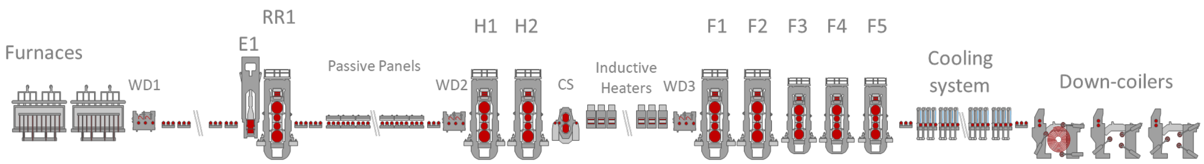

Figure 1 - Quali-HSM Technological Layout

This patented[1] configuration makes it possible to thread the last 5 finishing stands with a bar uniformly reheated to the desired temperature and rolling it at the most convenient constant speed, with no need for detrimental speed ramps as typically done in the previous generation HSMs.

In those plants, the reliance on speed-up and the crop shear positioned 7 stands from end-of-rolling, constitute major causes for cobbles when rolling thin gauges. These problems are overcome in the Quali-HSM.

The optimal control over the thermo-mechanical process is thus achieved, yielding profile and flatness almost identical to in-line-casting-and-rolling plants.

BENEFITS

Temperature Efficiency

In the traditional HSM, the loss of temperature in the production of thin gauges can only be compensated by the speed-up. This established practice however is detrimental when producing advanced grades, since the thermo-mechanical conditions of each portion of the strip are different, and the control of thickness and flatness actuators is challenging. The result is high variances in the mechanical properties and the profile, plus an increased risk of cobbles.

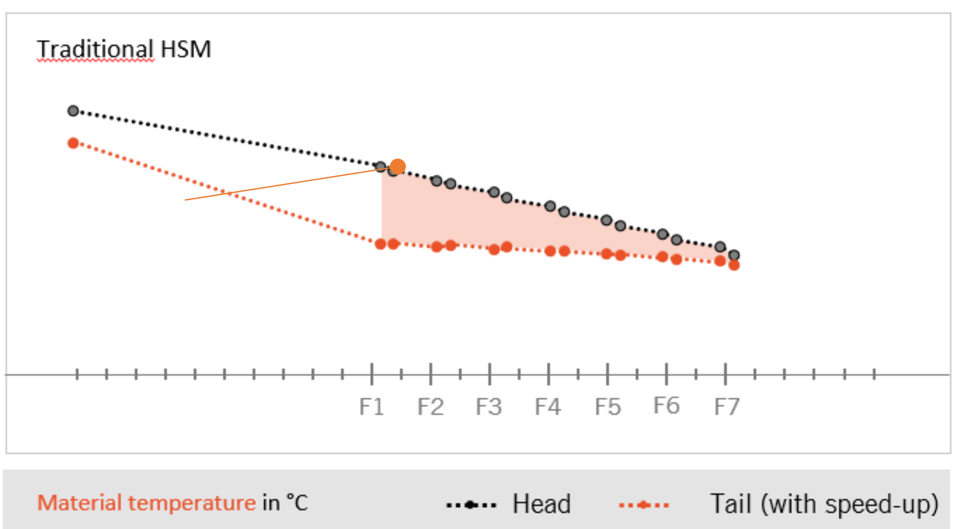

Figure 2 - Traditional HSM Temperature chart[2]

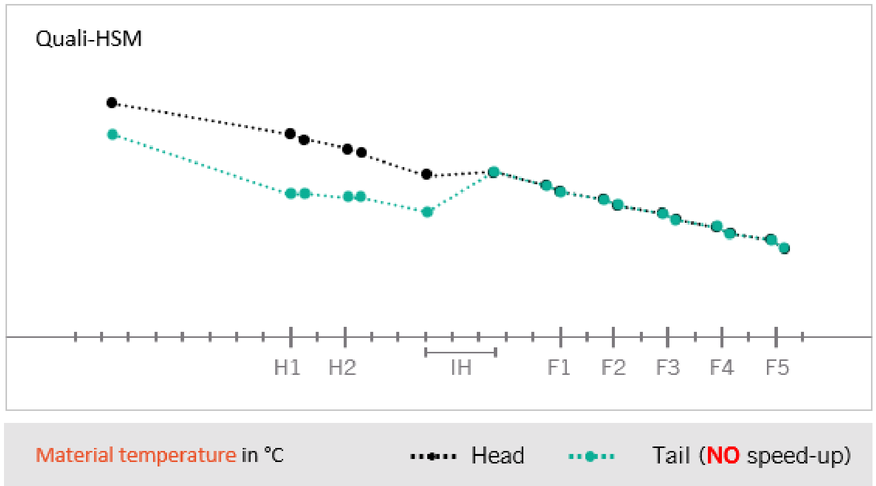

Figure 3 - Quali-HSM Temperature chart

In the Figure 3 the Quali-HSM solves this problem by presenting constant thermo-mechanical conditions in the last 5 finishing stands: a 30% increased uniformity of product properties is achieved[3].

Positioned strategically within the finishing mill, IH ensures high finishing temperatures and stable rolling conditions. This technology allows for precise control of the strip temperature, which is crucial for producing high-quality steel with uniform properties.

An additional benefit is the option to utilize lower drop out temperatures from the furnaces. The process minimizes the risk of oxidation and scale formation, leading to better surface quality, which is essential for producing high-quality steel.

Environmental Impact

The Quali-HSM technology not only improves production efficiency but also contributes to environmental sustainability, making it a greener alternative to traditional HSM.

- Reduced Energy Consumption: Quali-HSM consumes 20% less energy, resulting in lower operational costs. The use of induction heating and optimized rolling schedules contribute to the overall energy efficiency of the process.
- Lower CO_2 Emissions: The technology's efficiency translates to a 20% reduced carbon footprint, aligning with global sustainability goals. By reducing CO_2 emissions, the Quali-HSM technology helps steel producers meet regulatory requirements and improve their environmental performance.

The following charts indicate the required energy (rolling mill only) and CO_2 emitted to produce a 1.5mm x 1,600mm NGO 3% Si Steel.

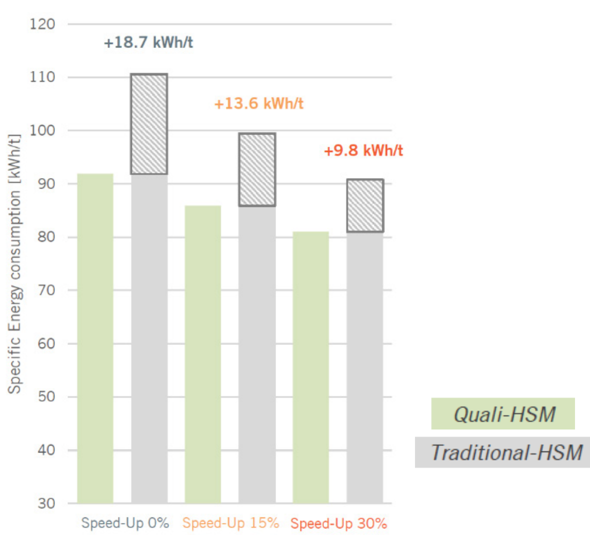

Figure 4 - Energy Consumption Comparison

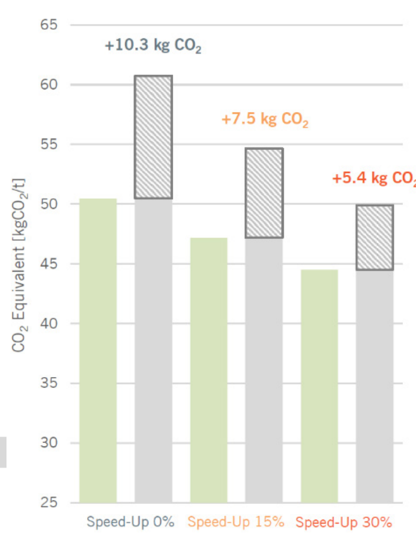

Figure 5 - CO_2 Emissions Comparison

Control Efficiency

Advanced control systems ensure tight tolerances and precise crown control, resulting in superior product quality. The ability to maintain tight tolerances is particularly important for applications that require high precision, such as automotive and electrical steel.

The production control starts with the pre-setup, which is calculated when the product enters the production queue. It's based on planned target data, including strip geometry and rolling strategy.

The second step is the setup calculation when the slab is discharged from the furnace, using latest available information and adaptations from previous products. An example block diagram of the setup calculation is reported in Figure 6.

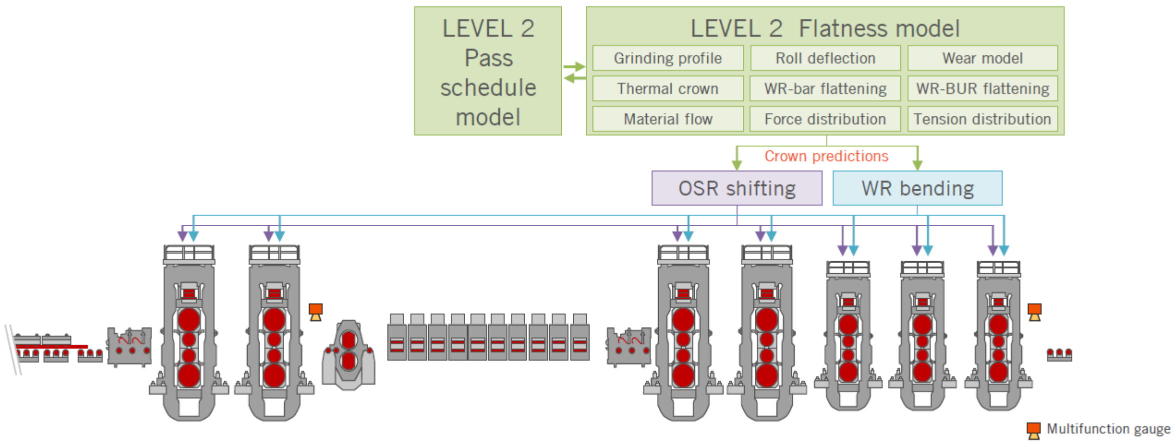

Figure 6 - Quali-HSM Setup Block Diagram

As commonly adopted in the majority of modern HSM, the setup is re-calculated at specific events, for example the end of the roughing stage.

Exclusive of the Q-HSM layout however is the opportunity for a re-calculation inside the finishing mill thanks to the presence of an additional internal multi-function gauge and enough time before threading the next stand: see the block diagram at Figure 7.

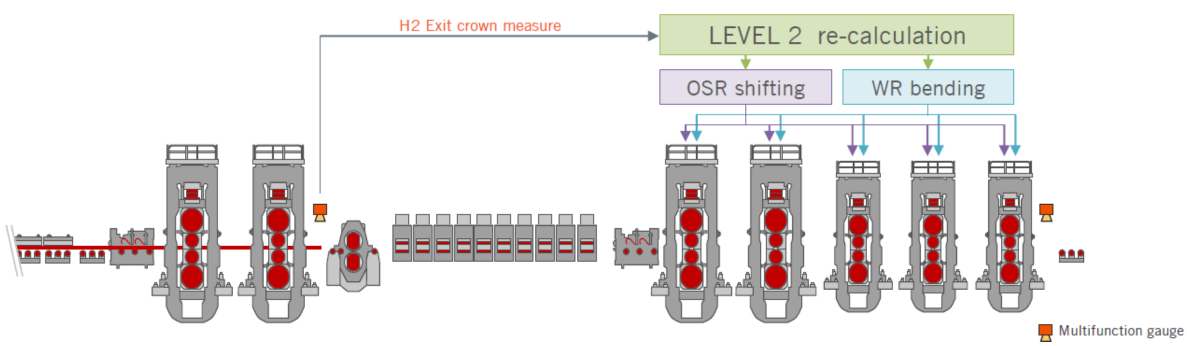

Figure 7 - Quali-HSM Setup Re-Calculation Block Diagram

The above control strategy coupled with the induction heating allow for a vastly improved control of the transfer bar.

This highly dynamic control is the key to achieve the highest uniformity in the final product, overcoming known issues like the skid marks originated in the walking beam furnaces.

In fact, a patented technology[4] was developed for the correction of the skid marks.

The skid marks are localized temperature profile defects on the bottom side of the transfer bar which affect negatively the final strip thickness tolerance. See for example the Figure 8 for an explanation of the phenomena.

The red line is the measure of the pyrometer at the entry of the FM and the skid marks are identified by the by the gray band. The lower temperature at the skid mark is related to a defect in thickness and profile of the strip at the exit of the mill.

The pyrometer reading is not precise enough to be used alone for the compensation, and the force readings of the RM last pass are difficult to track down to the FM.

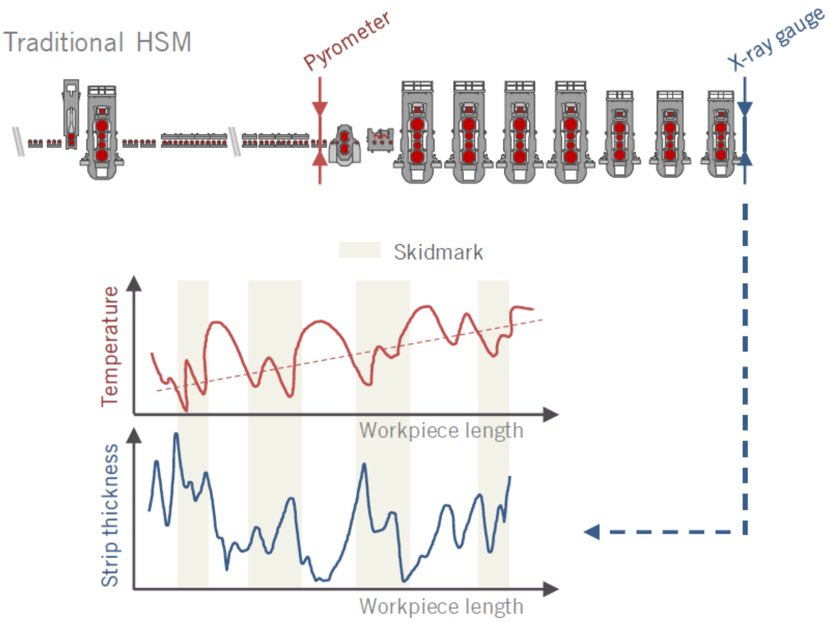

Figure 8 - Traditional HSM Skid Mark Compensation

In the Quali-HSM, a dynamic compensation of these defects can be achieved with the induction heaters, utilizing the input data from both the pyrometer A and the load cell of H2, see Figure 9.

These two inputs are combined to perform a fine tuning of the compensation. Both the thermal profile (solid red line) and corresponding final thickness/profile (solid blue line) are improved; tighter tolerances in final strip thickness, as good as **1/5** Euronorm are possible.

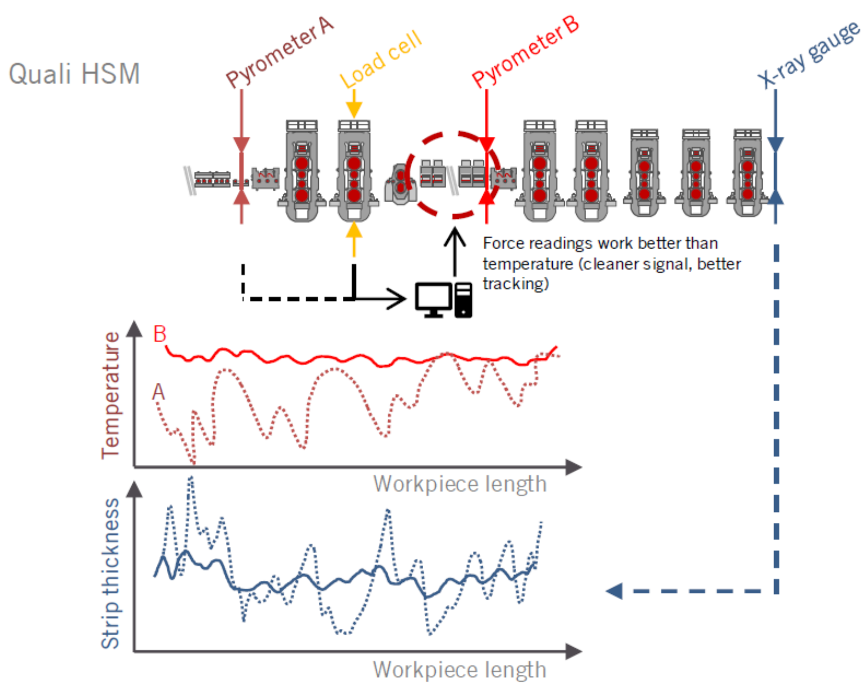

Figure 9 - Quali-HSM Skid Mark Compensation

Surface Quality

Surface quality is further improved by installing an additional descaler unit just 5 stands away from end-of-rolling, which will reduce the final layer of tertiary scale by 30% and minimize the risk for imprinted scale.

In Figure 10 we can see the difference of the scale layer thickness between the traditional HSM (dotted line) and the Quali-HSM (solid blue line).

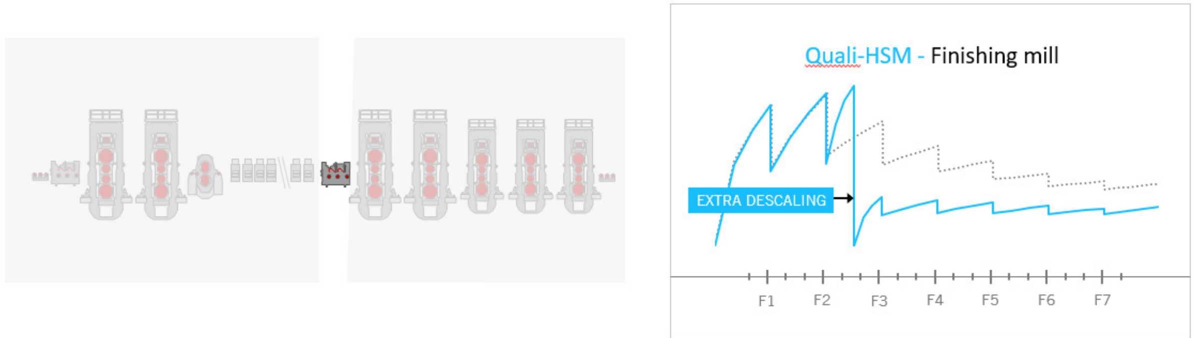

Figure 10 - Scale layer thickness comparison

The descaling concept of the Q-HSM result in a thinner scale layer at the negligible cost of a 0.14% yield loss increase.

The thinner scale layer grants a speed increase of 15÷20 % at the pickling line.

Market Opportunities

One of the standout advantages of the Quali-HSM technology is its economic efficiency. The ability to produce ultra-thin and hard strip opens new market opportunities, particularly in segments where traditional HSM face challenges.

- Thin Gauge HRC: The technology targets the market for hot rolled coils with thicknesses ≤2.0mm, a segment typically not well served by traditional HSM. This market segment is particularly lucrative due to the higher value of thin-gauge steel products.
- Premium grades which are demanding in terms of final rolling temperature, such as electrical steel or ultra-low carbon steel, are benefitting from a tool which can boost the final rolling temperature above 920 °C even when rolling thin gauges, which becomes an opportunity to sell on the market new products out-of-range for the traditional HSM, such as 1.5 mm Silicon steel, see Figure 11.
- Thermo-mechanic process: the Quali-HSM is a configuration well suited for thick thermo-mechanically rolled products; in this production mode induction heating is not used and is shifted offline.
- High Productivity, in excess of 5 million tons per year.
- Added Value Mix: The production of high-strength, thin-gauge steel adds significant value. The ability to produce high-quality steel with tight tolerances and uniform properties makes the Quali-HSM technology attractive to industries such as automotive, construction, and electrical.

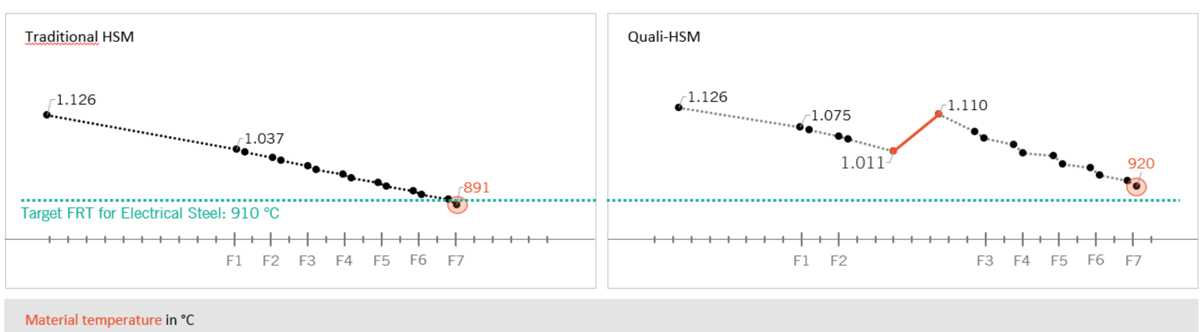

Figure 11 - Comparison of temperature trends for 1.5mm Si Steel

Light & strong grades, Superior quality and the capacity to supply products for Cold Rolled Substitution are the major competitive advantages granted by the Quali-HSM technology; a concept extremely comfortable in rolling Thin Gauges which are a very profitable market niche.

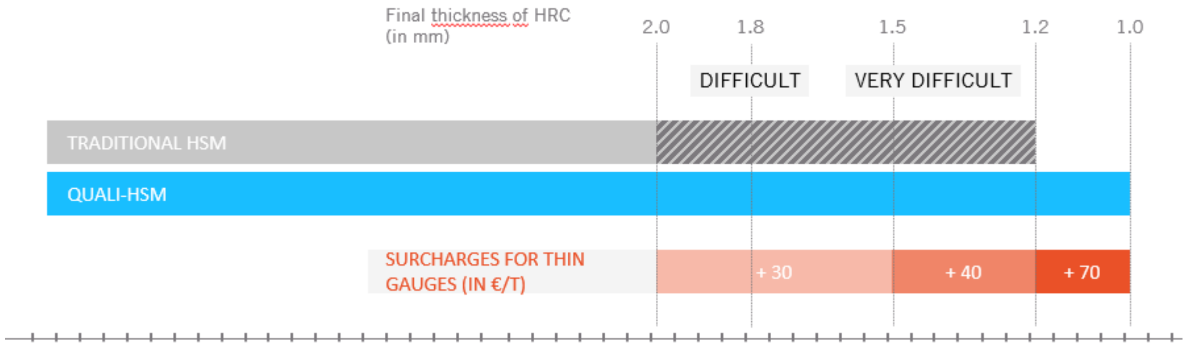

Figure 12 - Typical Surcharges for thin and ultra-thing gauges, LC grade

Induction Heating Technology

The need to heat the material through the rolling process requires a powerful tool combining high efficiency and control capabilities.

Danieli started developing a 100% in-house design since late 2000s and supplied the first LFH unit in 2012 and the first TFH unit in 2015.

These inductors have been extensively modeled in the R&D department before validation with real scale industrial prototypes and instrumented plates.

Industrial applications have successively confirmed the accuracy of the models

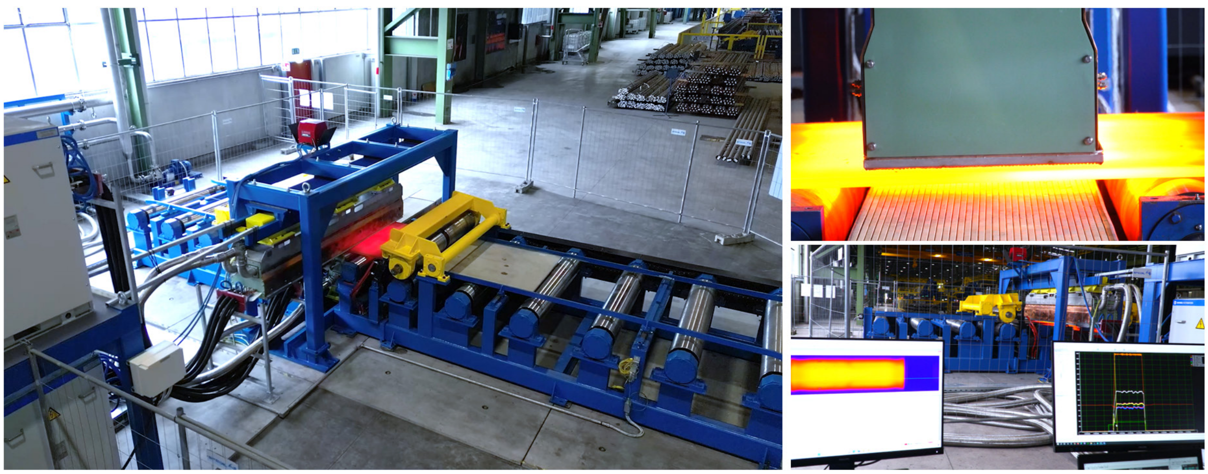

Figure 13 - TFH Inductor during real scale testing

It is known that a transfer bar can be heated by means of two possible induction heating technologies: the longitudinal flux technologies and the transverse flux technology (see figure below).

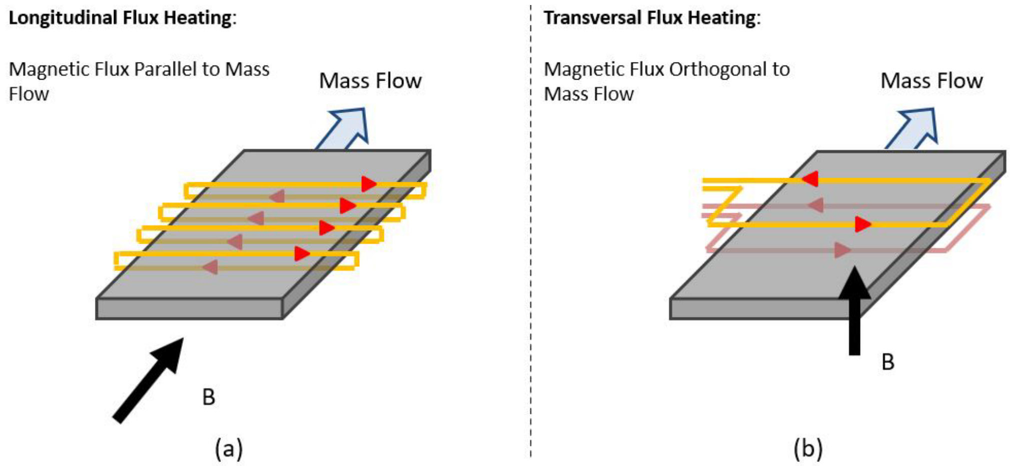

Figure 14 - (a) Longitudinal Flux Technology (b) Transverse Flux Technology

In the longitudinal heating flux technology (LFH), the magnetic flux (B) generated by the coil is parallel to the mass flow, while in the transversal heating flux technology (TFH) it is orthogonal.

This implies that these two different technologies provide two different heating patterns on the slab: while in the LFH most of the power is delivered on the slab surface, in the TFH it is delivered uniformly across the section, hence reducing the issues of an excessive superficial temperature. Furthermore, the TFH inductors allow an additional grade of freedom in slab heating, which is the possibility to manage the temperature on the slab edges.

The Danieli patented[5] TFH inductor optimized design combines the high efficiency on the slab heating with the flexibility to selectively heat the slab edges[6]: it is the perfect tool for the Quali-HSM process.

Benchmark Between Processes

The Quali-HSM technology has been tested and proven through various production cases, demonstrating its capabilities in producing high-quality steel. For instance, the production of non-oriented electrical steel (NGO) with 3% silicon content showcases the technology's ability to maintain consistent temperatures and achieve desired material properties.

A significant comparison can be drawn between the Quali-HSM and the previous generation HSM equipped with Inductive Heating upstream the finishing mill. Both concepts achieve the end-of-rolling temperatures and the same minimum gauge, but the traditional layout requires a higher number of modules.

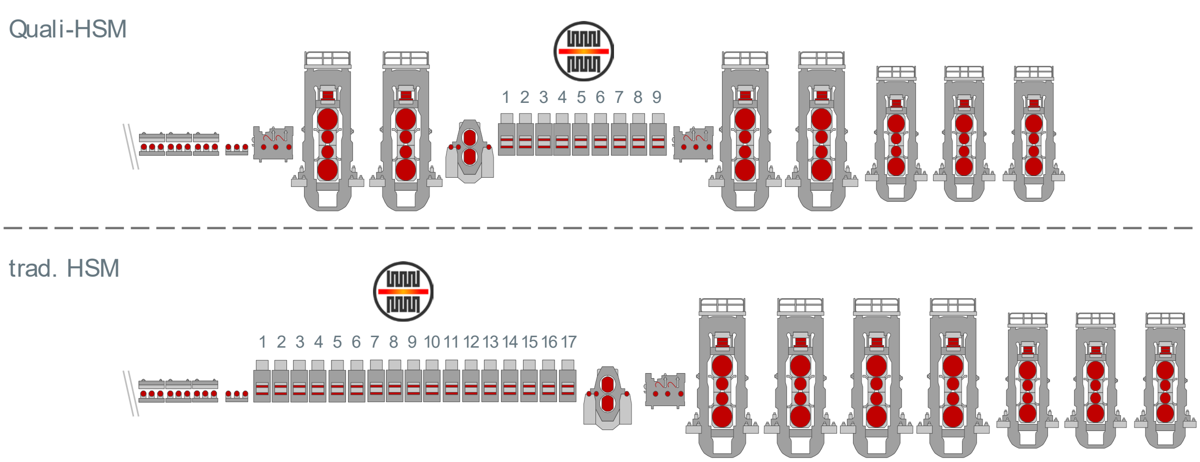

Figure 15 - Comparison of Induction Heating configuration

The production of a 1.5 mm x 1.600 mm, for a 3% Si NGO Steel, requires 9 induction modules on the Quali-HSM and 17 modules on the Traditional HSM.

This 89% increase means the traditional HSM needs additional 30MW of IH power to accomplish the same task.

The higher number of modules results from the less efficient utilization of energy: introducing heat to a material with higher temperature leads to significantly higher radiation losses. In other words, the Quali-HSM layout is more thermally efficient, having the last inductor 15 m closer to the last finishing stand.

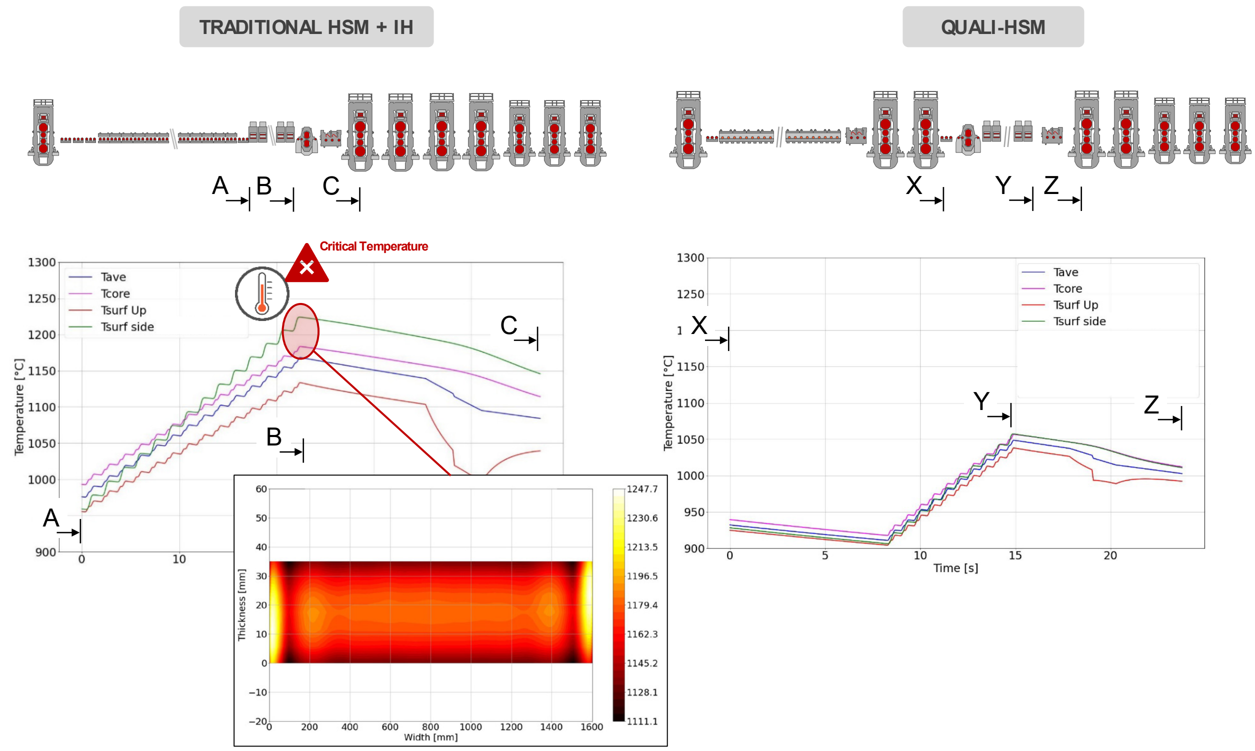

Figure 16 - Temperature Charts of IH area

The above comparison shows it clearly, the Quali-HSM solution is better suited for Thin Gauge Electrical Steel production than its traditional counterpart, being able to achieve the necessary temperature at end-of-rolling with less modules (9 versus 17) and by reheating to a safer temperature level.

The traditional HSM solution reaches temperatures higher than 1,200°C, posing the risk for scale remelting; a highly detrimental phenomenon for FM rolling.

In addition, at F1 entry the Q-HSM exhibits a better uniformity of temperature across the thickness compared to the traditional HSM (see Figure 17).

This ensures a higher uniformity of mechanical properties, which is a key parameter in the production of Si Steel.

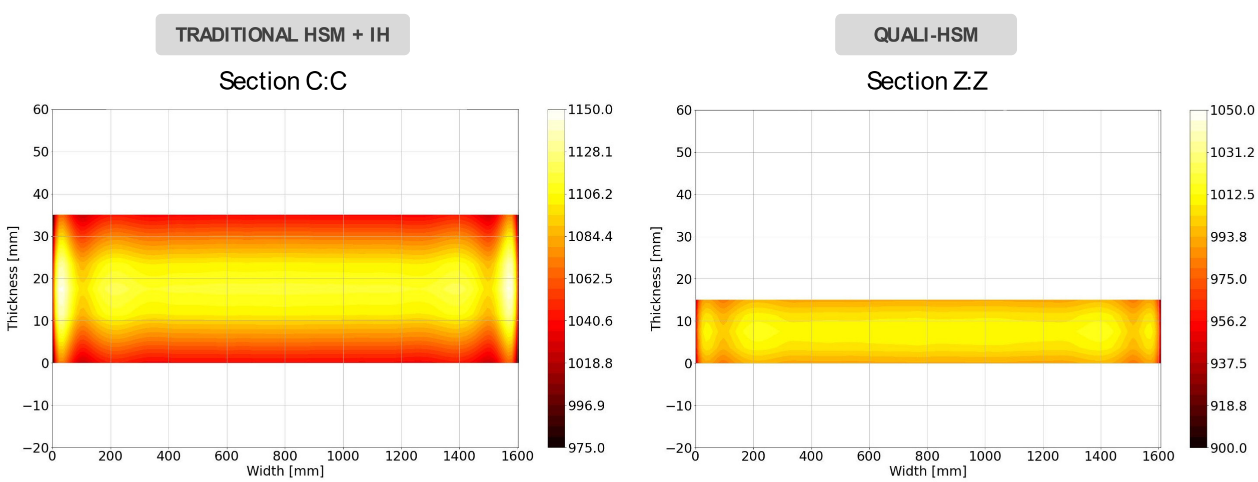

Figure 17 - Temperature modeling at entry of first stand after IH

CONCLUSION

The Quali-HSM technology represents a significant advancement in steel production, offering enhanced quality, efficiency, and environmental benefits. By leveraging innovative features such as induction heating, precise control systems, and advanced scale management, Quali-HSM sets a new benchmark in the industry.

The ability to produce high-strength, thin-gauge steel with exceptional surface quality and uniform properties makes the Quali-HSM technology a valuable asset for steel producers.

The economic benefits, including operational and capital expenditure savings, further enhance its appeal.

Environmental advantages, such as reduced energy consumption and lower CO2 emissions, align with global sustainability goals and regulatory requirements.

The traditional HSM technology has not evolved significantly over the past 50 years, and therefore it’s now obsolete when faced by the challenges of today’s steel production.

Trends in the automotive industry require increasing volumes of thin and hard grades for light vehicles, coupled with the booming market of electrical steel.

Mass production of these steels in a traditional HSM forces the producer to accept several compromises.

As the example of many successful companies attest, the market rewards those with a vision, who decide to differentiate from the status quo.

Danieli's Quali-HSM is a break-through technology which is posed to represent a game-changer in the steel industry: an industry that needs to evolve.

REFERENCES

1. Benedetti G.; Bobig P.; Bulfone M. Plant and Method for Producing Flat Rolled Products. Patent Pending.
2. Simulation from Danieli Wean United Technology Department - “TRoll” model.
3. Modeling from Danieli Wean United Technology Department - “QMPE” model.
4. Benedetti G.; Bobig P.; Bulfone M.; Franzil G. Plant and Method for the Production of Flat Rolled Products. Patent Pending.
5. Minen M.; Guastini F. Transverse Flux Induction Heating Apparatus. US 10638553, 2016.
6. M. Minen at al. Development of a High-Power Density Transverse Flux Inductor for The Danieli Universal Endless Process. HES - 19 - Heating by Electromagnetic Sources proceedings, 191-195.

