Mitsubishi Heavy Industries Technical Review Vol. 63 No. 2 (June 2026)

World's First 2-Stand HYPER UC-MILL with Advanced Strip Temperature Control for Electrical Steel Production and Strip Thicknesses Down to 0.2 mm

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This article presents the successful commissioning of the world's first twin-stand HYPER UC-MILL for producing high-permeability non-grain-oriented electrical steel and advanced high-strength steel. The reversing mill features a newly developed small work roll diameter 6-high configuration equipped with driven work rolls and high-torque MH spindles, providing exceptional reduction capability and precise shape control. Induction strip heating, Minimum Quantity Lubrication, and an advanced strip-temperature prediction and guidance system enable stable thin-gauge rolling with high yield and minimal waste. The HYPER UC-MILL's compact work-roll design, reduced edge loading, and efficient torque transmission establish it as a benchmark technology for both new installations and cost-effective modernizations, ensuring reliable production of high-grade electrical steels and ultra-thin cold-rolled products.

1. Introduction

Electrical steel can be categorized into grain-oriented (hereinafter referred to as GO) and non-grain oriented (hereinafter referred to as NGO) types. GO electrical steel exhibits anisotropic behavior, meaning its magnetic properties are optimized in one direction. GO electrical steel is primarily used in transformers due to its high efficiency in directing magnetic flux. In contrast, NGO electrical steel is utilized in rotating machinery such as motors and generators, where magnetic properties are required in multiple directions.

Primetals Technologies, a Mitsubishi Heavy Industries group company and a global leader in supplying plant solutions for electrical steel production, has developed advanced process technologies that substantially improve manufacturing performance, yield, and product quality.

The production of high-grade GO and NGO electrical steels is essential for high efficiency electrical machinery, particularly in the automotive and energy sectors.

High-permeability electrical steel is essential for generators in wind turbines because it significantly reduces core losses and enhances the efficiency of energy conversion from mechanical to electrical energy, thereby optimizing the overall performance and reliability of the wind turbines.

The rapid expansion of e-mobility requires electrified vehicles (hereinafter referred to as EVs) with lightweight body structures, optimized crash performance, and reduced greenhouse gas emissions across the entire vehicle life cycle. This drives demand for new generations of advanced high-strength steels (hereinafter referred to as AHSS) featuring high deformation resistance and reduced sheet thicknesses. At the same time, the automotive industry requires ultra-thin NGO electrical steels with 3.2–3.4% silicon and thicknesses between 0.2 mm and 0.5 mm. These so-called NGO EV grades impose stringent requirements on dimensional accuracy, surface quality, mechanical properties, texture evolution, and magnetic performance.

Electric traction motors rely on copper coils, permanent magnets, and laminated steel cores. The laminations consist of thin, lacquer coated isotropic electrical steel sheets designed to provide high permeability and high magnetic induction. Efficient energy conversion requires two key characteristics: low core losses and high magnetization. As the use of silicon steels in automotive

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applications continues to increase, steel producers are investing heavily in advanced rolling mill equipment and automation systems to modernize their production facilities.

Figure 1 illustrates the projected global EV sales, forecasting a 70% market share for electric vehicles and over 60 million new EVs sold per year by 2040. Modern electric vehicles, which can contain between 30 and over 100 electric motors, require approximately three times more electrical steel than traditional combustion engine cars. This significantly increases the demand for developing and producing electrical steel with superior magnetic properties.

Cold rolling of high silicon electrical steels presents significant challenges, primarily due to the material's inherent brittleness at typical cold rolling temperatures. The combination of high rolling loads, strip tension, and shear stresses in the roll bite can initiate and propagate edge cracks, leading to strip breaks, equipment damage, and production downtime. Despite these demanding conditions, strict quality requirements for strip thickness, flatness, and surface condition must still be met. Requirements that are becoming increasingly stringent as delivery gauges decrease to 0.2 mm and even below. Achieving high yield must be combined with efficient use of process consumables, which places considerable demands on the mechanical, electrical, and process design of the rolling mills.

Traditionally, electrical steels were produced on reversing 20-high mills. The introduction of small work roll diameter 6-high mills enabled stable production of high-grade NGO and, depending on strength and thickness, high-permeability GO steels. More recently, integrating the 6-high Hyper Universal Crown Control Mill (hereinafter referred to as HYPER UC-MILL) into tandem mill layouts has enabled high volume, energy-efficient production of advanced electrical steel grades.

Key technologies for high efficiency cold rolling include induction strip heating, Minimum Quantity Lubrication (hereinafter referred to as MQL^{TM}) for optimized roll gap lubrication, and advanced strip temperature control systems. Together with the HYPER UC-MILL's small diameter work rolls, edge-oriented intermediate roll shifting, and high-torque drive system, these innovations ensure precise thickness control, excellent flatness, and superior edge profile quality—enabling stable production of ultra-thin gauges.

Primetals Technologies supports both established and emerging steel producers with a comprehensive portfolio of cold rolling solutions and deep metallurgical, mechanical, and process expertise. Close cooperation with customers enables the continuous development of next generation electrical steel products.

The following sections present the key technologies incorporated into the new two stand HYPER UC-MILL.

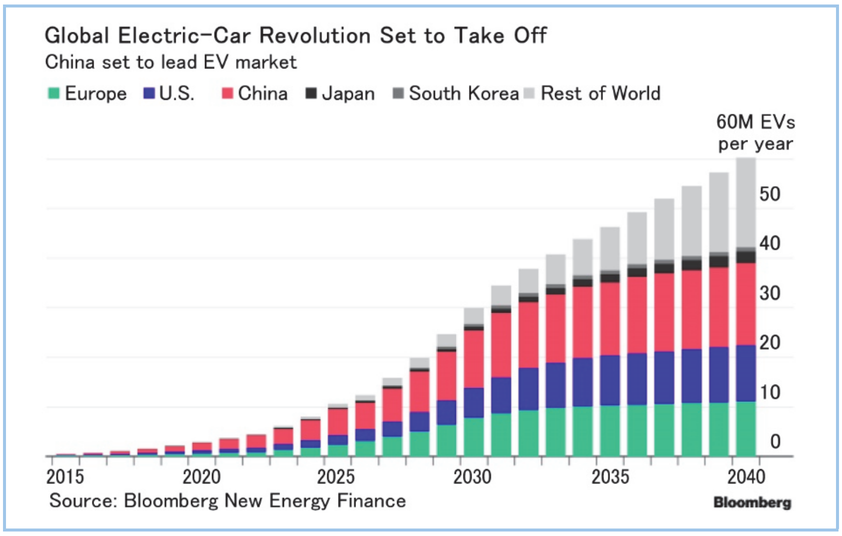


Figure 1 Forecasts of annually sold electric vehicles worldwide

2. Double HYPER UC-MILL reversing cold mill

Primetals Technologies developed and supplied the world's first 2-stand HYPER UC-MILL reversing cold rolling mill to thyssenkrupp Steel Bochum. This new flagship cold mill is dedicated to producing high-grade electrical steel and advanced high-strength steels, with an impressive annual production capacity of 475,000 tons (**Figure 2**, **3**).

PLANT DATA

Mill type	2-stand, 6-high HYPER UC-MILL
Annual capacity	475,000 t
Main drive power	2 x 3,000 kW per mill stand
Roll force	22 MN
Rolling speed	max. 1000 m/min

Figure 2 Plant data of thyssenkrupp Steel's new double cold reversing mill

Figure 3 Plant data of thyssenkrupp Steel's new double cold reversing mill

With its back-and-forth (reversing) operation, the double reversing mill can roll particularly thin strip with an end-product thickness down to 0.2 millimeters. Featuring a highly versatile mill solution, the plant is, on the other hand, also capable of handling heavier gauges i.e., products that meet the highest possible strength requirements. Highly skilled operators supported by advanced automation solutions are the driving force behind achieving these extraordinary strip dimensions. This mill ensures that thyssenkrupp Steel is well-prepared to deliver thinner and lighter steel of very high quality – exactly the type of steel needed in electrical vehicles.

Several factors contributed to thyssenkrupp Steel's decision to select Primetals Technologies as its supplier, one of them being strong references. Primetals Technologies is the global market leader in cold-rolling solutions for silicon steel—covering 20-high, 6-high reversing mills, and 6-high tandem mills—and holds a 90% share of the worldwide market.

Another important factor is the unique features of HYPER UC-MILL technology. With this solution, it is possible for operators to influence the edges of the strip – the most common area for cracks – in a very flexible way.

Investing in two twin-stand reversing mills provides several advantages over a continuous tandem mill, including lower initial capital expenditure (CAPEX), a smaller footprint, and increased availability.

The work roll diameter of a 6-high UC-MILL (**Figure 4**), typically ranging from 300 to 340 mm, is widely applied in electrical steel production. This mill configuration features driven work rolls and an axially shiftable intermediate rolls that can be positioned according to the actual strip width. In combination with dedicated work roll and intermediate roll bending systems, the UC-MILL enables precise and flexible shape control. The use of cylindrical work rolls ensures stable strip shape and allows compliance with the most stringent flatness requirements.

Figure 4 illustrates the design and advantages of the UC-MILL concept: the tapered roll geometry and edge-oriented intermediate roll shifting effectively eliminate undesired contact areas while providing superior control over strip crown and flatness.

During cold rolling of high strength or high silicon materials, the strip thickness profile typically exhibits pronounced thinning at the edges, commonly referred to as *"edge drop"*. This phenomenon is primarily caused by longitudinal variations in work roll flattening. For electrical steel production, minimizing edge drop is critical, as reduced edge drop improves lamination factors and directly contributes to lower core losses.

The most beneficial mill stand technology for producing the upper range of AHSS and high-grade NGO electrical steel represents the 6-high HYPER UC-MILL, which is a further development of the well-established UC-MILL technology.

Although the UC-MILL can process lower range of AHSS and middle grade electrical steel, the growing demand for harder AHSS and thinner electrical steels with high silicon content led to the development of the HYPER UC-MILL. To apply smaller diameter work rolls, a comprehensive study of the influence of work roll diameter on the shape-control capability, Hertzian stress between rolls and the reduction ratio was carried out. Rolling loads can be reduced and higher reduction ratios can be obtained by using work rolls with smaller diameters. This study showed that the highest reduction ratio is achieved with work rolls having a diameter approximately 20–30% smaller than those of the standard UC-MILL.

To accommodate smaller work roll diameters while maintaining excellent shape-control capability, the diameter of the intermediate rolls was increased to ensure sufficient mill rigidity and operational stability. In parallel, a new gear-type main drive spindle capable of transmitting significantly higher torque to small-diameter work rolls was developed. This spindle design—referred to as the MH Spindle—provides up to 2.7 times the torque capacity of a conventional universal-joint (UJ) spindle (**Figure 5**).

These advancements led to the development of the HYPER UC-MILL, a next-generation mill type that combines reduced work roll diameters with high-strength spindles to enable reliable rolling of high-strength materials and premium electrical-steel grades.

Figure 6 presents a visual comparison of the roll configurations in a standard UC-MILL and a HYPER UC-MILL. To preserve the highest level of shape-control performance despite the smaller work roll diameter used in the HYPER UC-MILL, the intermediate roll diameter is correspondingly increased.

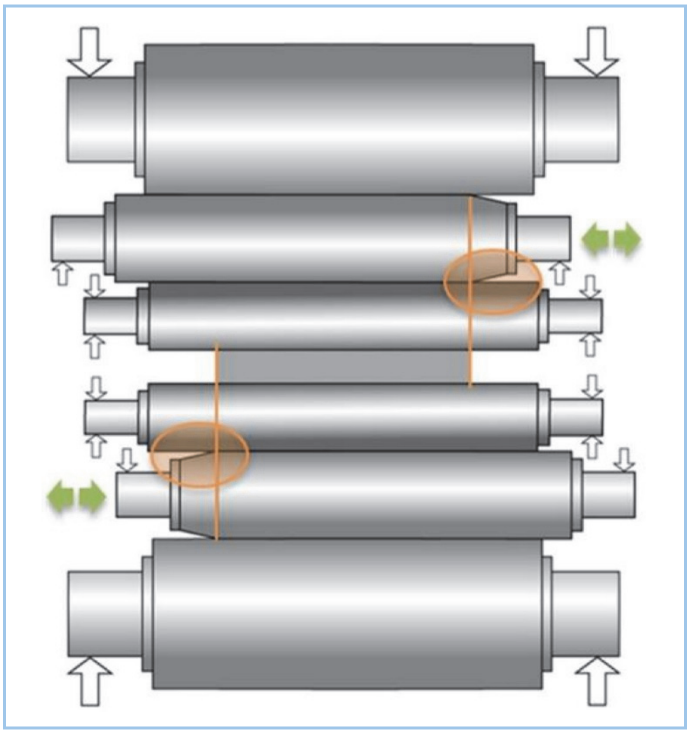


Figure 4 Core design of a 6-high HYPER UC-MILL

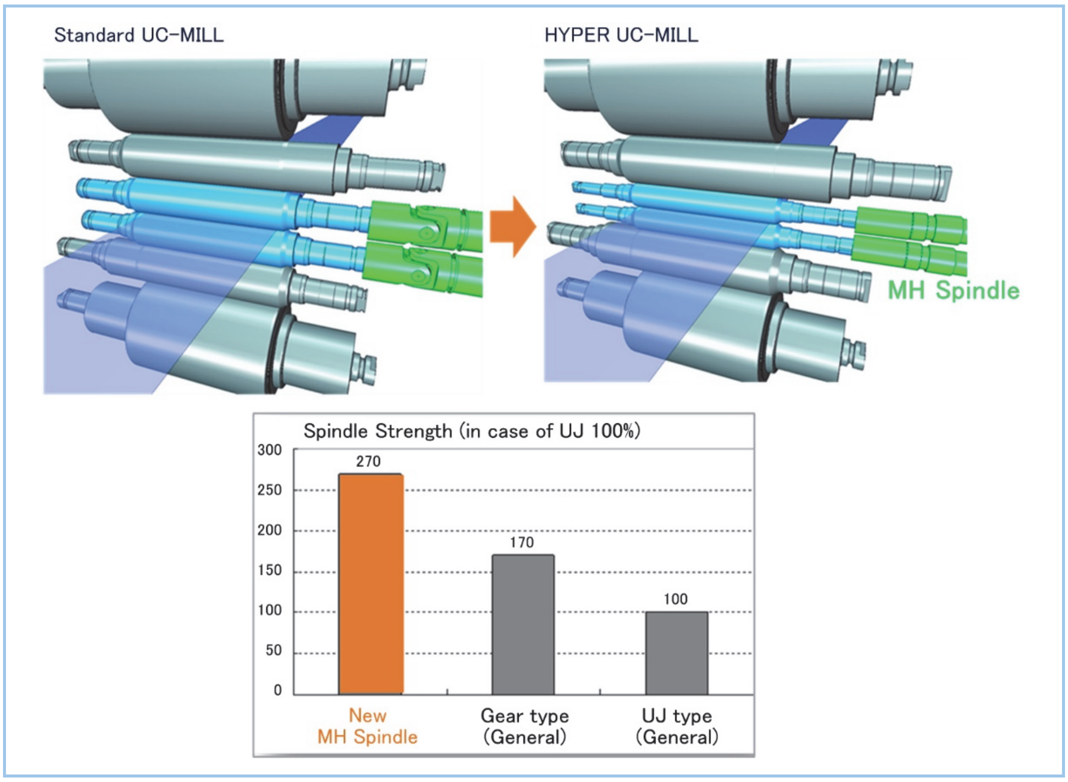


Figure 5 New MH Spindle provides significantly increased torque capacity

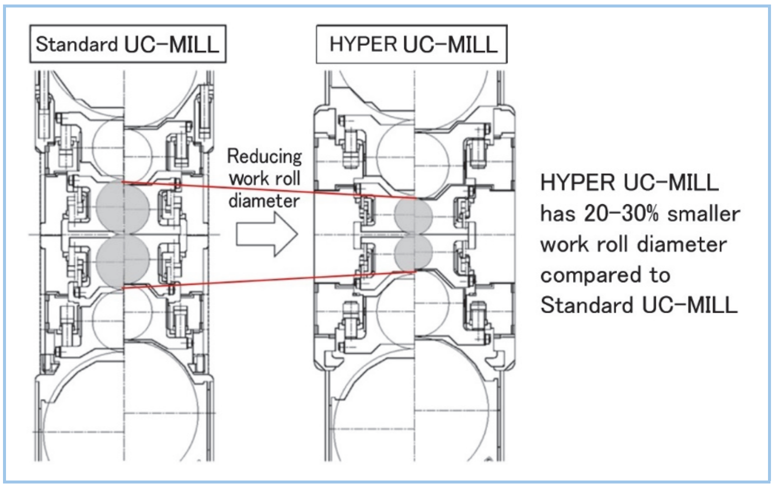


Figure 6 Roll arrangement of Standard UC-MILL and HYPER UC-MILL

3. Strip heating prior to cold rolling

Cold rolling of high-silicon electrical steel (Si ≥ 2.5%) is characterized by an increased risk of strip breaks. The main reason is that the high brittleness of high-Si steels at typical cold rolling temperatures. The high brittleness of the strip material in combination with high rolling loads (strip tension, contact pressure and shear stresses in the roll bite) during cold rolling can lead to generation and growth of edge cracks which can lead to strip breaks and significant production downtimes and delays.

It is well established that increasing the strip temperature prior to cold rolling significantly reduces material brittleness (1). In the first pass of a reversing mill, the strip is typically processed at room temperature (approximately 20–30 °C). Room-temperature brittleness strongly depends on the silicon and aluminum content of the steel: higher Si levels (≥ 2.5 %) and Al levels (≥ 0.5 %) markedly increase brittleness and, consequently, reduce ductility and formability during cold rolling. Edge cracks are mainly caused by restricted dislocation sliding, which - in combination with high rolling loads - promotes deformation twinning and premature fracture initiation.

Figure 7 presents the ductile-to-brittle transition temperature (hereinafter referred to as DBTT) curve determined using a servo-hydraulic high-speed testing machine (1) for a 3.4 % Si NGO electrical steel at various strain rates. At typical cold rolling strain rates (see blue curve, 100 s^{-1}), the DBTT is located near room temperature (approximately 22 °C).

This implies that cold rolling at room temperature poses a significant risk of strip breaks due to low fracture elongation and high brittleness of the material. Decreasing the deformation rate—i.e., reducing strip speed and/or pass reduction - or more practically increasing the strip temperature enhances ductility and formability. Consequently, the likelihood of edge-crack propagation and strip breaks is substantially reduced.

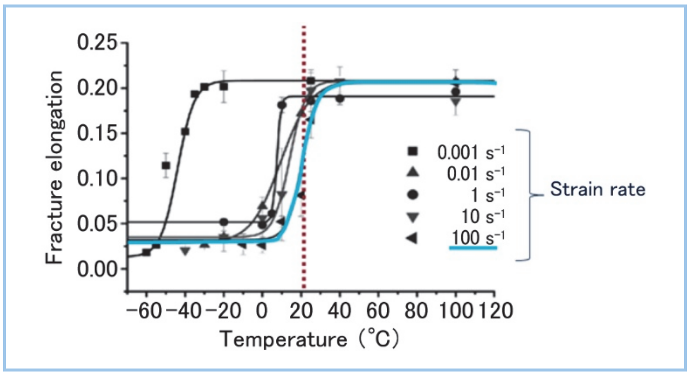


Figure 7 Ductile-to-brittle transition temperature (DBTT) for a 3.4% Si steel (1)

4. Strip temperature prediction and guidance

As outlined above, strip temperature plays a crucial role in ensuring stable and reliable production of high-permeability electrical steels, particularly during threading and the first rolling pass. Elevated strip temperatures can also be beneficial in subsequent passes, provided they are maintained within an optimal process window. This requires controlled strip-temperature management throughout the entire reversing-mill pass schedule. If the strip temperature becomes too low, the increased brittleness of the material - combined with the applied rolling loads - substantially raises the risk of edge cracking and strip breaks. Conversely, excessively high strip temperatures may cause elevated work roll surface temperatures and reduced roll-shell hardness, potentially resulting in heat streaks or other surface defects.

A product-specific strip-temperature guidance strategy is therefore essential. Relevant actuators for influencing and controlling strip temperature include strip cooling, work roll cooling, strip speed adjustments, pass-schedule optimization, and induction strip heating (shown also in Figure 10).

An advanced strip-temperature model significantly improves both the setup calculation and dynamic control of temperature evolution and accounts for the complex deformation behavior of high-silicon electrical steels. **Figure 8** shows an example of the strip-temperature profile during the first pass of a double-reversing mill with prior induction heating. As illustrated, conventional emulsion lubrication on the entry side of Stand 1 undesirably cools the pre-heated strip, causing unnecessary energy losses and increasing processing costs.

MQL prevents this unwanted temperature drop because entry-side lubrication is achieved by spraying atomized pure rolling oil directly onto the work-roll surface. This pure oil lubrication approach avoids the intensive strip cooling effect typical of recirculating emulsion systems and therefore preserves the desired strip temperature as it enters the first pass.

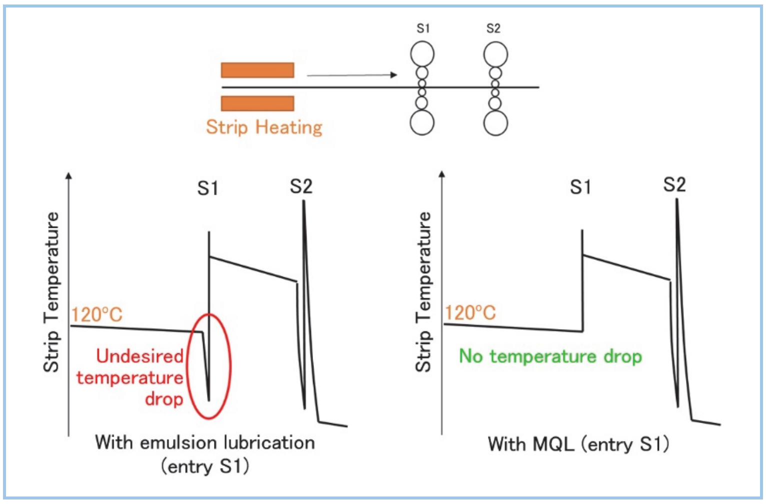


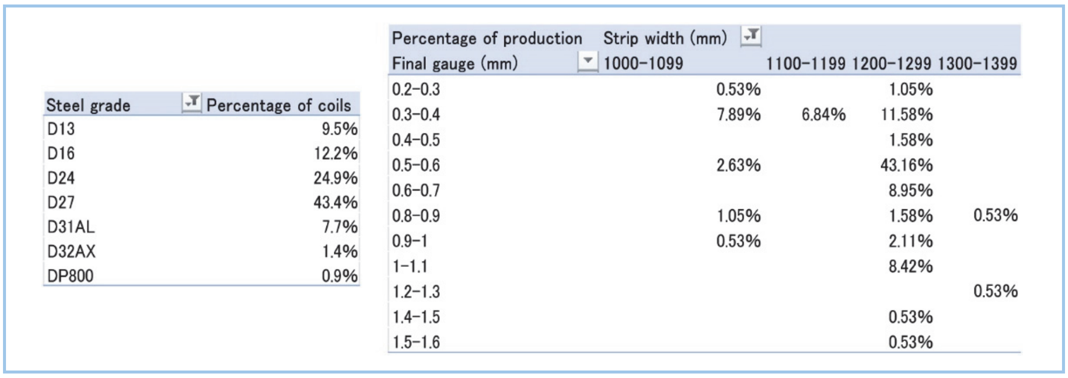
Figure 8 Strip temperature evolution with emulsion lubrication versus MQL during first-pass heating

5. Operational highlights

5.1 Fast introduction of new products

Thanks to the mill's high flexibility and user-friendly operating concept, the introduction of new products can be carried out quickly and reliably. Remarkably, silicon-steel grades were rolled successfully from the very first day of operation, without the typical need to begin commissioning with commercial or soft grades. As a result, progressively lighter gauges and steels with higher silicon contents were introduced in rapid succession and at reasonable rolling speeds, without requiring extended stabilization campaigns. **Figure 9** illustrates the product matrix achieved within the first weeks after reaching the initial "ready-for-operation" milestone, including steels with more than 3 % Si and final thicknesses below 0.3 mm.

Shape control is straightforward due to the mill's simple setup principle, which uses intermediate roll shifting based on strip-width requirements. Flexible and accurate process models provide reliable setup values across a wide range of grades and dimensions - even for products that have never been rolled before.



Steel grade	Percentage of coils
D13	9.5%
D16	12.2%
D24	24.9%
D27	43.4%
D31AL	7.7%
D32AX	1.4%
DP800	0.9%

Percentage of production	Strip width (mm)			
Final gauge (mm)	1000–1099	1100–1199	1200–1299	1300–1399
0.2–0.3	0.53%		1.05%	
0.3–0.4	7.89%	6.84%	11.58%	
0.4–0.5			1.58%	
0.5–0.6	2.63%		43.16%	
0.6–0.7			8.95%	
0.8–0.9	1.05%		1.58%	0.53%
0.9–1	0.53%		2.11%	
1–1.1			8.42%	
1.2–1.3				0.53%
1.4–1.5			0.53%	
1.5–1.6			0.53%	

Figure 9 Product mix within the first month of operation

5.2 Lubrication and cooling

The mill is equipped with a highly flexible set of actuators designed to control roll-gap friction, roll and strip temperatures, and overall rolling conditions. Their activation depends on the product grade, rolling direction, pass number, and pass schedule (**Figure 10**). Conventional roll-cooling and roll-gap lubrication systems serve both lubrication and temperature-control functions and contribute significantly to stable strip-flatness control.

Additional actuators - such as MQL, and strip cooling - can be selectively activated according to the required lubrication and cooling strategy. This configuration effectively decouples roll-gap lubrication from strip-temperature management, enabling independent optimization of both frictional behavior and thermal conditions. Maintaining low friction is essential for achieving ultra-thin gauges, while precise strip-temperature control is critical for preventing brittleness and ensuring stable rolling performance and final product quality - key requirements in silicon-steel production.

Multiple temperature-measurement devices are installed throughout the plant to track strip temperature continuously and keep it within the desired process window (explained in chapter 4). The combination of MQL and induction strip heating ensures an adequate initial strip temperature during the first pass, thereby preventing strip-break events caused by low incoming coil temperatures. In both entry and exit sections, thermo-optical systems capture real-time two-dimensional temperature maps, enabling accurate temperature evaluation across the strip length and width.

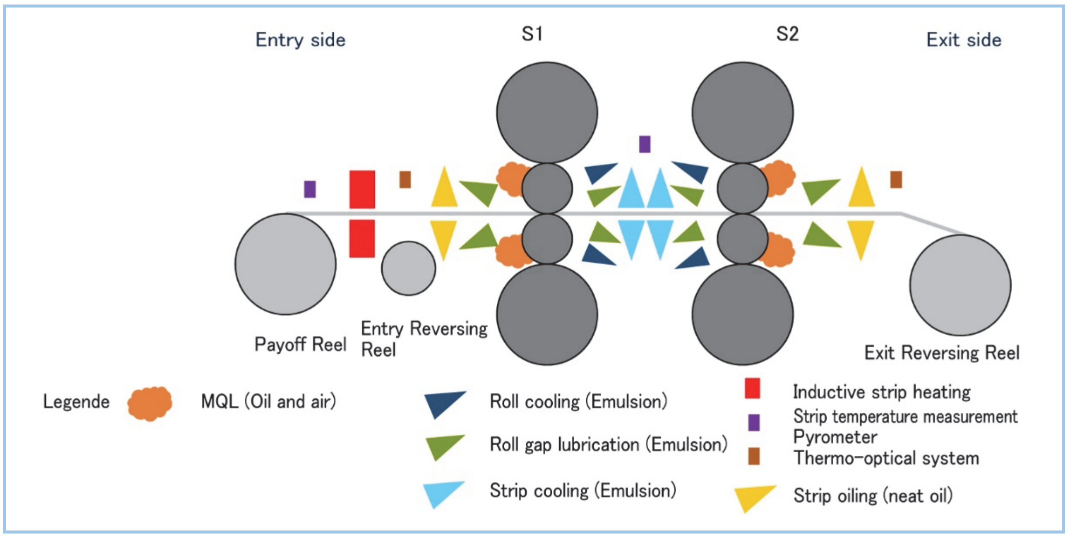


Figure 10 Schematic of lubrication and cooling actuators (each available equipment shown, only a selection is active in each run)

5.3 Shape control

Edge loading - one of the most critical factors in silicon-steel rolling - is controlled by the contour of the intermediate roll and by precisely positioning the intermediate roll chamfer. This ensures an optimal balance between rolling pressure and strip tension in the edge region. The strategy can be applied independently for each pass or run, allowing fine-tuned edge-load management throughout the rolling schedule.

For strip-shape control, advanced flatness models determine the optimal combination of flatness actuators - including work roll and intermediate roll bending, intermediate roll shifting, and multizone cooling - for every individual pass. All actuators are fully integrated into the control strategy. Once the ideal setup is calculated, closed-loop feedback control compensates for deviations caused by variations in incoming material properties or changing mill conditions, ensuring consistently high strip flatness and product quality.

6. Conclusion (Summary)

This paper presents the latest mill-stand technologies and innovations successfully implemented at thyssenkrupp Steel's new twin-stand HYPER UC-MILL. The HYPER UC-MILL represents a new generation of 6-high cold rolling mills featuring reduced work roll diameters, direct work roll drive, and exceptionally high torque-transmission capability. This technology not only sets the current benchmark for modern tandem and reversing mills but also provides a cost-effective solution for revamping existing facilities. Its outstanding reduction performance, superior shape-control capability, minimized edge loading, and standardized roll inventory make the HYPER UC-MILL an optimal platform for producing high-strength steels and thin-gauge cold-rolled products.

The integration of induction strip heating effectively addresses the challenges associated with the intrinsic brittleness of high-silicon electrical steels at room temperature. By enabling precise thermal control, the system significantly reduces the risk of edge cracking and strip breaks, resulting in a more stable and efficient production process. The combined application of induction heating and MQL further enhances rolling conditions by maintaining the desired strip-temperature level while ensuring highly efficient roll-gap lubrication. This synergy is essential for achieving excellent surface quality, reducing rolling loads, and improving overall process robustness.

HYPER UC-MILL is a registered trademark of Primetals Technologies Japan Ltd. in Japan.

References

(1) J. Kwon, H. Huh, and J. Kim (2017), 'Evaluation of the Ductile-to-Brittle Transition Temperature of a Silicon Steel Under Various Strain Rate Conditions With a Servo-Hydraulic High Speed Testing Machine', Met. Mater. Int., vol. 23, no. 4, pp. 736–744