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A HOLISTIC VIEW ON THE SIEMENS VAI SOLUTIONS FOR ENERGY SAVING AND ENVIRONMENTAL PROTECTION POTENTIAL OF A PLTCM[1]

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Abstract

Energy conservation and the minimization of emissions are the key factors for environmental protection in today's highly industrialized world. CO_2 regulations and the limits imposed on the steel industry for this purpose are already stringent and have a significant impact on the competitiveness of steel producers, particularly those operating their plants in old economies. The pickling and cold-rolling operations that are part of integrated flat-steel production plants are mostly perceived as having a low potential for energy-saving or energy-recovery measures, when compared with those processes in the chain that entail high temperature levels upstream and downstream. But there are still a number of resources within these production units that can provide remarkable contributions to energy savings and also reduce the emission output to zero. Today's highly productive and high quality linked pickling and cold-rolling facilities (PLTCM) are certainly a classic example of how energy-saving measures can be optimized to the limits of the state-of-the-art technology. Many of the measures in place are not immediately obvious: but there are a number of small processes that can provide a substantial contribution to the goal of keeping overall energy consumption and emission output as lean as possible. In addition to measures already in place, there are new and quite promising developments: for example, roll lubrication systems in tandem cold mills have a remarkable potential to further decrease primary energy input and reduce oil consumption. There are other developments in the tandem mill and pickling line to come, with very similar goals. This article provides a brief outline of SIEMENS VAI solutions in the field of pickling and cold rolling that meet the goal of making these processes even more energy-, material-, and emission-saving, and therefore more environment-friendly.

Keywords: Energy saving; Cold rolling mill.

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INTRODUCTION

In our highly industrialized world, energy savings and minimization of emissions are seen as key factors for environmental protection. The already obligatory and upcoming CO_2 regulations and limits imposed on the steel industry will have considerable relevance for the competitive position of steel producers.
As part of integrated flat steel production facilities, cold rolling and pickling plants are technologies with a long history. The basic mechanical principles and parameters of these processes were established long ago. This could give the impression that the technology has reached the state-of-the-art, with low improvement potential. In the 1970s, the introduction of automation systems laid a strong foundation for improvements in strip quality, yield, increased production capacity, and energy efficiency. The primary parameters off-gauge and flatness could be controlled very quickly and consistently.
Today, a suitable automation system acts as the backbone of every cold mill. In addition to automation systems, drive technology has also undergone continuous development, enabling today's use of AC motor technology throughout plants in combination with suitable inverter systems – which provide many advantages, from compact design to fast response and efficient use of energy.

Today's challenges in cold rolling

To deal with the changing demands of their end users, steelmakers are forced to operate highly flexible production systems. New steel grades like DP, TRIP, and CP will be a considerable part of cold rolling mill product mixes. These new grades are characterized by excellent forming properties and highest strength properties.
In addition to these advanced high-strength steel grades (AHSS), other grades like HSLA or Si grades are challenging to work with in production, especially on continuously operating lines. As in the cold rolling process, these new grades are difficult to subject to welding, scale breaking, pickling, and side trimming.
The main focus of today's development can be seen in:

- increased yield
- reduced energy consumption
- improved process stability
- widened operational ranges
- efficient and fast self-diagnostic systems
- improved process models
- reduced emissions.

To satisfy these requirements, the demand for close cooperation between plant operators and suppliers will increase so that, on the one hand, they share their operational expertise on optimizing processes, and on the other, they are able take all environmental aspects into account.

ISSN 1983-4764

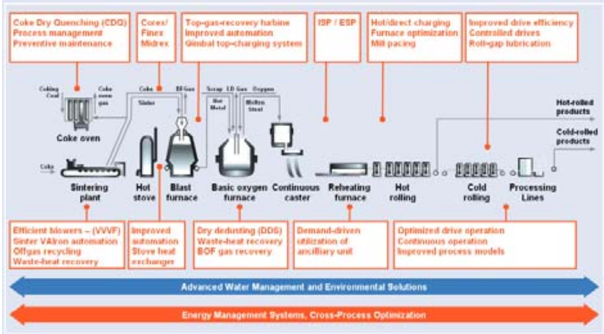

Figure 1: Siemens VAI solutions for energy savings and environmental technologies.

Environmental factors

Within a steel work the major sources of emissions and the primary energy consumers are the coking plant, sintering plant, blast furnace, and steelmaking plant. Compared to the facilities working at high temperature levels, the pickling and cold rolling processes are mostly seen as having a low potential for energy savings and emission reduction. Despite these preconditions, there are still a number of sources inside pickling and cold rolling lines that can provide substantial contributions to energy saving and also minimize to zero the emission output. Many of these measures are not immediately obvious, but there a number of small processes that can provide a substantial contribution to keeping the overall process, in terms of energy and emissions, as lean as possible.

Figure 2 shows a brief overview of potential measures to improve a linked pickling and tandem cold rolling mill (PLTCM) with respect to environmental factors.

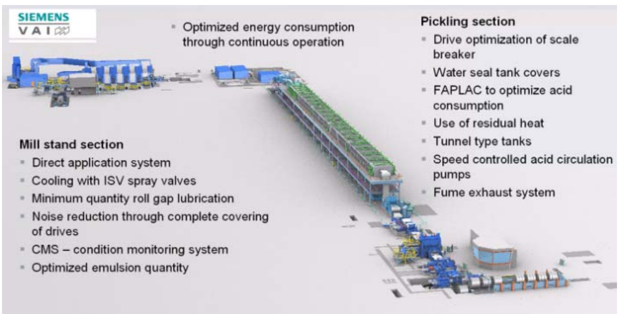

Figure 2: Green potential of a PLTCM.

Compared with discontinuous operating lines, continuous operation in principle ensures tightly stabilized process conditions and high process efficiency for a wide range of cold mill products such that stringent product-quality specifications can be met. Continuously operating cold mills provide the capability for output optimization with reduced strip-head and tail-end losses, contributing to better overall yield.

The continuous operation of a PLTCM eliminates threading and unthreading operations and enables substantial capacity increases compared to batch operation. Additional benefits are higher quality and yield as well as lower operational costs. Figure 3 describes the high improvements and savings obtained by converting an existing pickling line and an existing batch mill to a PLTCM.

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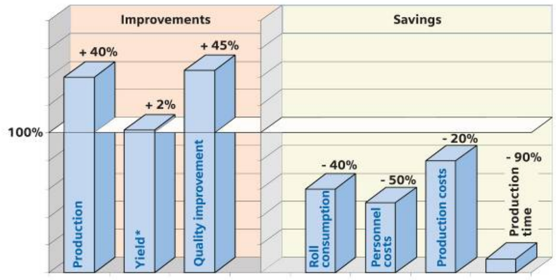

Figure 3: Savings and improvements after converting an existing pickling and tandem mill to a PLTCM.

From an environmental point of view, the 40 percent reduction in roll consumption and the two percent increase in yield (resulting in less scrap) should be emphasized. Siemens VAI has introduced a number of modernization packages for the purpose of upgrading plants to continuous operation. A detailed description of Figure 3 and some of the modernization packages can be found in Fabris, Georges and Stabauer.[1]
The following sections briefly describe some of the concepts implemented in SIROLL, with a focus on reduced emissions, reduced energy consumption, and improved process models.

Direct use of reversing power flows and highly accurate models for scale-breaker drives

A precise knowledge of the entire scale-breaker system and the measurements derived help improve plant performance, reduce energy costs, and cut emissions.
At the entry side of the process section, the scale breaker is used to elongate the strip up to three percent in order to remove strip waves and to crack the scale for an improved pickling process. The purpose of the scale breaker is to multiply bend the strip around small rolls under high strip tension.
At the entry side the tension must be increased, because the tension level in the preceding aggregates is significantly lower, and typical strip tensions just after the scale-breaker stand are 500, 650, and 900 kN. In the subsequent process section, a lower tension level is again required. Bridle units on the entry and exit sides of the scale breaker are used for setting the required tension.
The high tensions required for an efficient scale-breaking process require high installed power in the electric drives. In addition, due to the scale-breaking effect, the dust burden is relatively high.
In many cases, scale-breaking setups are configured based either on experience or on expensive but still approximate offline calculations.
To acquire a better understanding of the scale-breaking process, precise predictions of the strip-bending line (strip curvatures), reaction forces at the bending rolls, required strip tension levels, resulting tension losses, and required motor powers of bridle-roll drives are required.
Together with the Johannes Kepler University Linz, Siemens VAI has developed a holistic model of the scale-breaking process [2].
The new model is based on an intensive analysis of the scale-breaking process using numerical methods (FEM) for a better understanding of the physical effects and the interaction of the various parameters. These investigations were the foundation for a

ISSN 1983-4764

new modeling approach based on the principle of virtual work and parametric shape functions (PSF) for curvature and strain distributions. Using this method leads to a drastic reduction of degrees of freedom and therefore of computational costs, while the results of FEM and PSF show a high accordance.
With this new model, a very accurate prediction of tension loss can be achieved, which is essential for the design of the scale-breaker drives.
In order to fulfill the customer's needs and preferences, Siemens VAI offers several drive systems for scale-breakers. For each of these systems, a very accurate design tool has been developed.
Using the strip levels at four significant points in the scale-breaker system, the required drive torques can be calculated. Figure 4 shows the beneficial results of this mechatronic calculation tool. The diagram at the top displays the strip tension levels before and after each bridle roll and in the scale-breaking unit itself. The bottom diagram shows a comparison of required motor powers for two drive concepts. Due to the direct use of reversing power flows, the required installed power for the electro-mechanical drive concept (see Figure 4) is significantly lower than for an electrical drive concept.
The generic model facilitates a deeper understanding of the operation mode of a scale breaker. This precise knowledge of the system provides the basis for minimizing the installed power requirement and helps to improve plant performance and reduce energy costs.

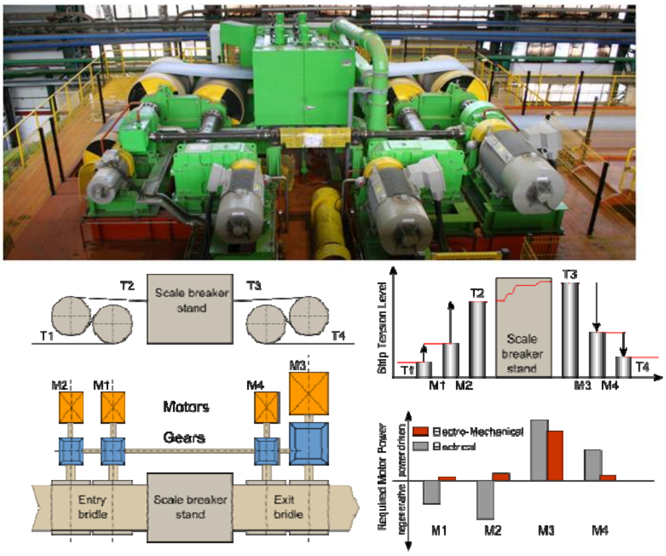

Figure 4: Scale-breaker design, tension level, and required motor power.

A highly efficient scale-exhaust system using wet or dry system processes cuts dust emissions. In addition to the scale breaker, several other machines in the entry area of a pickling line are equipped with exhaust systems, including at the anti-coil break roll, the flattener, and typically at the first bridle unit.
Using all these measures, dust emissions can be minimized in the bay.

Application of residual heat usage in the pickling process section

The pickling process itself is energy intensive and, from an environmental point of view, critical due to the use of acid: and so the goal is to run a highly efficient process with a minimum of emissions.
The efficiency of the pickling process is dominantly defined by:

ISSN 1983-4764

- Scale layer: thickness, composition, distribution
- Acid concentration (free HCl)
- Iron ion concentration
- Temperature of pickling liquor
- Initial strip temperature
- Elongation value performed by scale breaker
- Intensity of turbulence and flow parameters.

The Siemens VAI acid jet system provides a high turbulence flow around the strip inside the tank; the turbulence intensity can be controlled by variable-speed circulation pumps. For high-speed pickling, each tank is equipped with a jet pump actuated exit to entry (horizontal) acid re-circulation system, which ensures a minimum of acid drag out into the wringer-roll tanks.

Thanks to a perfect gas-tight water seal between tank and its lids, acid fumes are drawn off from the wringer-roll tanks and cleaned in a one- or two-stage scrubber to ensure minimum emissions to the environment.

Acid flow from circuit to circuit is in n-stages counter cascade and allows for natural as well as forced cascading. The rinsing section, typically a five-stage counter-cascade type with a high pressure ramp, ensures the lowest possible chloride residuals on the strip surface after it leaves the process section.

The use of residual heat is a common energy-optimization measure. In the pickling lines, Siemens VAI recovers heat of the condensate in two areas of the acid-circulation systems. One measure is the preheating of the fresh acid delivered by the acid regeneration plant, and the other is the preheating of the last rinsing stage during restart after a line stop.

All of these approaches provide a highly efficient pickling process, which becomes even more effective when integrating the fully automatic pickling liquor analysis and control system (FAPLAC) with plug-and- play functionality into the overall control and model architecture of SIROLL CM, which is illustrated in Figure 5.

The highly advanced measuring setup and process models provide the basis for very accurate control of pickling liquor utilization through the use of reproducible acid concentration measurements. These measurements are the basis for product requirement-dependent and stable yet quickly adjustable pickling conditions.

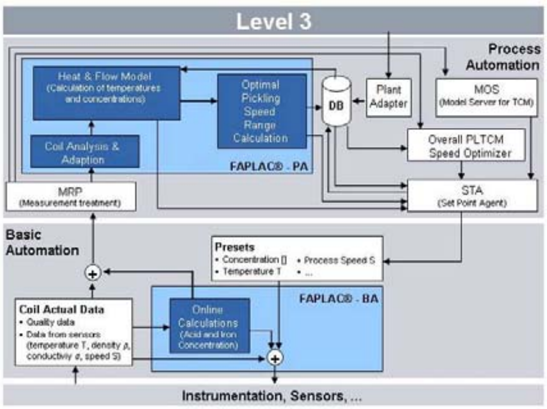

Figure 5: FAPLAC.

From an environmental point of view, FAPLAC is the best system for optimizing the feed of fresh pickling liquor and minimizing the discharge of used pickling liquor.

In addition, FAPLAC enables reduced operating costs and provides state-of-the-art pickling process automation.

ISSN 1983-4764

Mill stand area

The main energy consumers of a PLTCM are located in the mill stand area. The mill's main drives are the biggest motors installed in a PLTCM and the flow of emulsion is also of remarkable volume.

Precise models of cold-rolling process as a key factor for energy-optimized design of rolling mills

The pass schedule calculation is performed to define the thickness and tension distribution across the different passes in a tandem mill.
Today, mill productivity and product quality are the parameters that are optimized by the underlying model. Mill productivity is primarily defined by minimized rolling times and maximized yield.
To obtain the highest product quality, the forces adequate for correct flatness and required surface quality are calculated, considering different constraints like maximum motor load.
For this purpose, Siemens VAI has developed a powerful multi-variable optimization algorithm, where one of the variables to be optimized can be required energy.
Based on the results of the pass schedule calculation, the flatness actuators are calculated to achieve the mill's optimal flatness performance. The flatness pre-adjustment defines the initial set-points for the flatness automation system.
It's a matter of fact that with more accurate set-points, the quality of the products will increase and therefore yield can also be increased, which leads to a more energy-efficient pickling line tandem cold mill.
The pass schedule calculation and the flatness pre-adjustment have a strong impact on the quality of the process model. For this reason, Siemens VAI puts emphasizes in their process model development, with the following highlights:

- Rolling model: for modeling the rolling process of very hard and thin material, a non-circular arc model is used. This model is online-capable and very flexible in order to handle new steel grades.
- Roll stack deflection: a change of roll shapes can be computed online with no model adaptations.
- Roll temperature crown and wear model: provides a description of wear and the effects of asymmetric temperature fields.
- Roll gap model: for online calculation of roll pressure distribution within the roll gap.

Figure 6 gives an overview of the available toolkit from Siemens VAI that is used for accurate modeling of energy-optimized rolling processes.

SIROLL CM Design and Layout Tool Box				
Pass schedule program for cold rolling mills & throughput calculation	Roll gap analysis and roll stack deflection program for CMs	SmartCrown roll profiling program for CMs	Skewed drum shear layout for CMs	Drum shear layout for CMs
Strip tension simulation	Looper layout program	Roll stress analysis program	Reel motor Layout	Logistic simulation tool
Mill housing analysis program	Thermal work-roll crown simulation for CMs	Spray header layout	Leveler program for CMs	Pass schedule program for skin-pass mills

Figure 6: SIROLL CM design and layout toolbox.

ISSN 1983-4764

Roll gap lubrication for minimization of rolling-oil consumption and emulsion flow rates

With the roll temperature crown and wear model tool, Siemens VAI is in the position to precisely predict the heat behavior of rolling mill components, for example, work rolls. This knowledge is essential for the optimal design and arrangement of lubrication headers. In a recent installation, the emulsion flow rate of an existing line was reduced by more than 50 percent with an unchanged temperature level of the work rolls. It must be mentioned that this drastic reduction was primarily possible due to the non-optimized arrangement of the old solution: so this value is not generally valid.

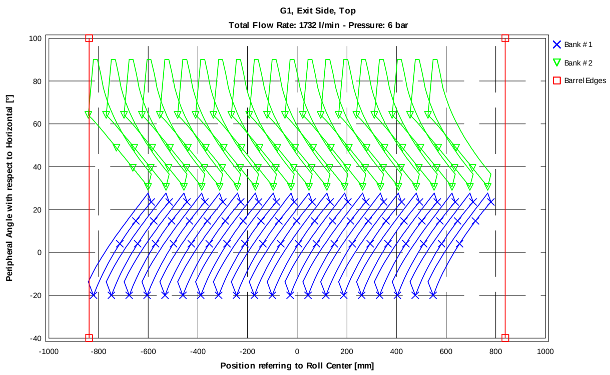

Figure 7: Optimized spray pattern.

New and quite promising developments are ongoing for roll-lubrication systems that have a remarkable potential for reduction of oil consumption and primary energy reduction.
The exact knowledge of the tribological behavior in the roll gap creates the foundation for the optimized design of a lubrication system. For this purpose, in 2009 Quaker Chemical Corporation, voestalpine Stahl GmbH, Johannes Kepler University Linz, and Siemens VAI combined their knowledge to develop of better lubricant and cooling solutions for industrial applications. Through this unique cooperation between three highly experienced, well-known companies in the steel industry and a university institute with an extraordinary expertise on rolling process modeling, steel producers will benefit in terms of application expert advice on customized oils and emulsions. The advantages of using the new oils and emulsions are higher mill productivity, an extended product range, improved surface quality, and lower energy costs required for rolling.

Strip blow-off system to minimize emissions to the bay and the loss of emulsion

The strip blow-off system situated at the exit of the last mill stand removes all remaining emulsion from the strip surface to ensure a dry strip surface during coiling. The liquid removed through the air blast from the strip surface is captured in the surrounding exhaust system and collection pans and drained back into the emulsion return line.

ISSN 1983-4764

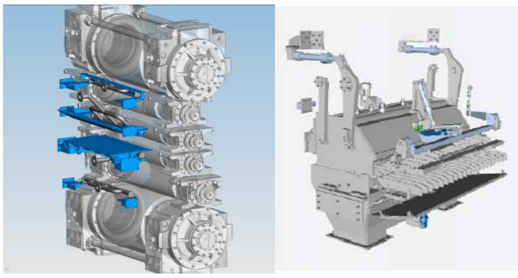

Figure 8: Roll gap lubrication and strip blow-off system.

The SIROLL design ensures efficient blow-off at all mill speeds, therefore contributing to highest strip surface quality after rolling and a minimum of emissions to the environment.

Mill drive system with minimized losses

The mill drive system plays an essential role in the quality of the final strip. High dynamic response and accuracy of the strip-speed control system are the main challenges to achieving the best results in thickness control.
In addition to these technological challenges, several governments require from plant suppliers and operators the introduction of energy-saving motors that adhere to the EU efficiency classes EEF 1 and 2 or the American EPAct norm. By using these kinds of motors, the loss is reduced by more than 40 percent compared to standard motors.
With SINAMICS drive technology, Siemens offers a wide range of solutions for nearly all market requirements. The medium-voltage source-converter system SINAMICS SM150 covers all the requirements of mill drives, while the low-voltage converter system SINAMICS SM120 is mainly used for auxiliary drives like hydraulics, bridles, loopers, and tension reels.

SIROLL Off-Gauge Optimizer for increased overall yield in PLTCMs

After cold rolling, it is necessary to cut off strip sections with unacceptable gauge performance. This scrap needs to be processed again, and therefore consumes avoidable energy, manpower, and plant utilization time and reduces the overall yield of the cold rolling plant.
Leveraging the mill's hidden potentials, the SIROLL Off-Gauge optimizer significantly cuts this reprocessing cost. The system combines technology, process control, and instrumentation and features in implementation of the tandem cold-mill control algorithm based on the mass-flow principle.
The SIROLL off-gauge optimizer is based on the three following modules:

AMF_{new}: New advanced mass flow control algorithm

Advanced Mass Flow new (AMF_{new}) is a consequent implementation of the control algorithm of a tandem cold mill based on the mass flow principle. In the well known Advanced Mass Flow (AMF), the mass flow reference point is given by the thickness gauge behind stand No. 1. At this location the thickness is well known but the exact strip speed is not. Inside the automation system, the estimated strip speed is calculated from circumferential speed of work rolls and modeled slip of the strip.

ISSN 1983-4764

AMF_{new} transfers the entry side mass flow reference point to the entry of stand No. 1, where the strip thickness and the strip speed are well known. Basis of the modified mass flow control algorithm is the impression of the incoming actual mass flow on the reference mass flow.
AMF_{new} assures a very stable rolling condition so that the corrections of the target thickness by the mill exit feedback control can be kept to a minimum. The targeted thickness is achieved directly after the end of the flying-gauge-change function which controls the transition of two welded strips.

Soft-sensor for strip thickness: SST

The soft sensor for strip thickness estimates the strip thickness in all stands based on a known entry thickness and the measured strip speeds. The reliability of the system was proven on several fully equipped cold mills. With help of the soft sensor it is possible to reduce the non-essential measurement equipment. Apart from lowered installation costs, customers will benefit from a reduced number of spare parts, lower maintenance costs, and higher overall availability of the plant.

Feed-forward control for the next-to-last stand: FFC_{n-1}

With help of the FFCn-1 system, a reduction of thickness errors, including those induced during weld-seam rolling is achieved. The thickness errors are detected by the SST described above, or by an existing thickness gauge in front of the next-to-last stand.
In a reference installation at the voestalpine Stahl continuous tandem cold mill (CTCM) in Linz, Austria, the off-gauge optimization proved its efficiency by shortening off-gauge lengths by an average of approximately eight meters (the total mean off-gauge length has been decreased from 13.72 meters to 5.79 meters). This corresponds to a yield increase of 0.25 percent for a typical product mix, or to an output gain of approximately 4,000 tons per year in an annual production of 1.6 million tons.

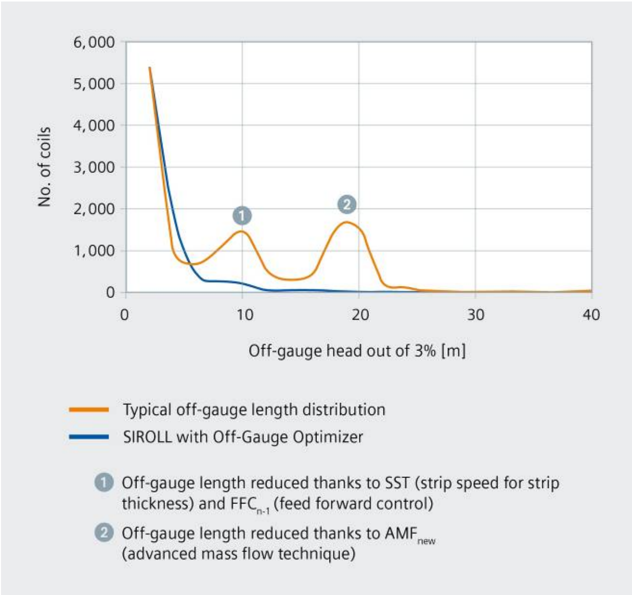

Figure 9: Typical off gauge length distribution with and without the application of the SIROLL Off-gauge optimizer.

ISSN 1983-4764

CONCLUSION

Even if the pickling cold rolling operation is mostly seen as low potential field with regard to energy saving and environmental protection, there are a number of examples, how a PLTCM can contribute to energy saving and also minimum to zero emission output. Some of these solutions provided by Siemens VAI are presented in this paper.

Abbreviations

PLTCM: Pickling line and tandem cold mill
AMF: Advanced Mass Flow technique

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