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PLATE MILL TECHNOLOGY SOLUTIONS FOR THE PRODUCTION OF MODERN STEEL GRADES[1]

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Abstract
The Plate Mill has become a versatile tool in the steelmaker's armoury over the recent past. Its capabilities have been developed to allow it to produce a full range of flat products to compete in some of the fastest growing and technological challenging areas that face steelmakers. Pipe plate is a good example of this and demonstrates how the flexibility of the unit can be used to service a number of markets with the use of a Plate Steckel Mill to service the thinner gauge end of the market whilst retaining the thicker market with standard plate mill processes, both utilising enhanced technologies to provide maximum benefit to both supplier and customer of plate.
Keywords: Steckel; Technology; Plate.

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1 INTRODUCTION

A full package of equipment for a new installation is supplied for the client with the important and key contributions from the solution provider in determining the engineering, procuring the equipment and supervising the installation and commissioning. The most fundamental part of designing the plate mill and the solution and associated equipment is to understand the market that is intended to be served and produce a product mix that can be delineated at an early stage. The key parameters will therefore translate into width and thickness of the finished material and the desired properties. In a number of cases there will be constraints that drive the solution such as pre existing supply chain and downstream facilities to supply. However a fundamental revisit of the market dynamics and the expected capabilities that will be developed will provide the basis for plant design that will provide many years of activity. There may well be a phasing of the project to allow both production to commence and an accredited process route to be developed as well as amortising the considerable capital investment over a longer period which may be necessary particularly in the wake of the financial crisis of 2008.
Once the desired product mix is determined the appropriate technological solutions can be developed in conjunction with client and supplier working closely to understand the full benefits that an alternative path may provide. For example the determination of a steel chemistry may impact on the choice of microstructural formation which can be achieved through cooling practices.
The dependency of steel slab supply is also of critical note in the final determination of equipment. The existing casters may not capable of producing the quality required dependent on product mix and this may need to be factored in the overall site calculations. Once the product mix has been formulated then the mill concept can be determined. As with most design considerations there is necessary compromise on the range of products to be produced, the investment parameters and flexibility of the plant for current and future / perceived needs. Dependent on this design will also be the considerations for ancillary equipment. This will be a factor on the customer and how much supply they will want to mange and how much will be done by a solution provider. For a Plate Mill, the slab yard equipment and reheat furnace are examples where Siemens VAI does not usually supply the actual and will work with the client on providing the integration to the project.

2 METODOLOGY

2.1 Plate Mill Technologies

The choice of mill configuration will depend upon a number of factors of which the forecast product mix is the key. The following mill technologies show the mill choice is influenced by the product mix and plate requirements.

2.1.1 Conventional Plate Mill

The conventional plate mill will deliver a range of products and is the workhorse of the steel works particularly where there is an integrated site and the control of feedstock is very much within the producer servicing a known and mature market base. Figure 1 shows a typical set up which will be based on known inputs and outputs and can produce plate of varying thicknesses (6 to 300mm) and a standard mill width range (3800, 4300, and 5000mm). The throughput is a function of the

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amount of equipment but will deliver 1.0mtpa as a minimum and up to 2.5mtpa if two mill and two shear lines are employed.

Plate Mill – Typical Layout

Product = Plates

- Standard mill nominal widths = 3800mm, 4300mm, 5000mm
- Thickness range = 6 – 300 mm

One Mill Stand – One Shear Line

➔ Throughput = 1.0 – 1.5 mtpa (depending on width & product mix)

Two Mill Stands – Two Shear Lines

➔ Throughput = 1.6 – 2.5 mtpa (depending on width & product mix)

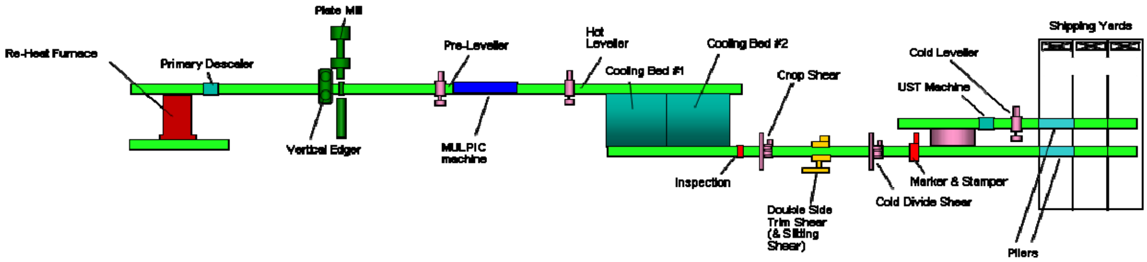

Figure 1. Typical Plate Mill layout.

The layout is fairly straightforward and allows the product to be handled is an efficient manner. The plate will start as a pre-determined slab almost certainly from the continuous casing supply route. The efficiencies and consistencies of supply and the minimisation of inspection and handling between the caster and plate mill have been significant achievements in recent years. The elimination of the gap between casting and milling has been achieved in the production of strip through the endless strip process (ESP) at Arvedi but there a number of difficulties replicating this type of process route for conventional plate. The slab yard will act as a stockyard and there may be some preparatory cutting of pieces. The slab is fed into the reheat furnace. A number of furnace types are equipped to deal primarily with varying lengths of slab with typically a walking beam furnace being used for flexibility and efficient control of energy, one of the major costs in running the overall mill. The key objective is preheat the slab to required temperature with sufficient soak to ensure the body of the slab is at thermal equilibrium but without excessive time and energy spent doing and to avoid the accumulation of excessive scale, which is lost yield and detrimental to surface quality unless adequately dealt with. After reheating, the slab is discharged from the reheat furnace and is moved directly to the primary descaler to remove scale prior to rolling. Following descaling, the slab is transported to the mill where two alternative rolling strategies are employed: -

- If the slab is approximately the same width as the final product then the slab is rolled by simple forward and reverse passes without turning.
- If the slab is narrower than the final product then the slab is turned on a turntable and broadside rolled to the required width as shown in Figure 2.

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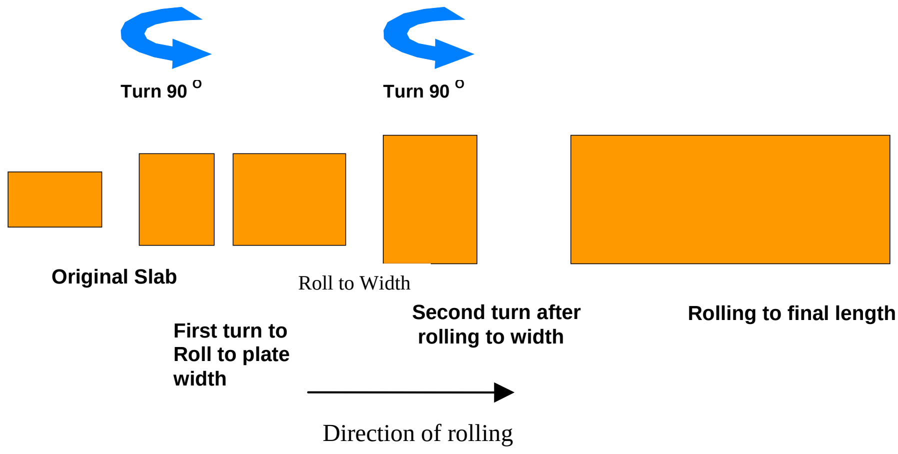

Figure 2. – Typical Plate Mill layout Schematic representation of slab turning.

The implication of turning is the provision of turntables and the design and positioning of side guides is carefully done to avoid interaction and the control of slab piece length feedstock is therefore critical. The conventionally cast slabs can be rolled without broadside rolling if the slab width is approximately equal to the final product width. If the final product width is greater than the slab width then the slab is turned – typically after 1 or 2 sizing passes – then rolled to width and then turned again as in conventional plate rolling. If medium thickness full width slabs are used then the slabs are always rolled in-line without turning. Normally an edger is used on the appropriate rolling passes to improve the width tolerances and rectangularity of the as-rolled products. Edging is carried out down to approximately 30 mm thickness; below this thickness edging is no longer effective. This can eliminate the requirement for side trimming and be very cost effective in reducing yield loss.
The core process is rolling the presented slab in the mill stand to the requisite dimensions of the finished product. Detailed calculations and modelling work will have been undertaken to ensure that the correct metallurgical properties are achieved through the mill and that the dimensional accuracy is met. The mill load and torque computations are a significant part of ensuring that the productivity of the mill is commensurate with mechanical and electrical design.
The exit temperature of the mill is critical to ensuing thermomechanical controlled rolling (TMCR) processes and in the sophisticated development of hold patterns for semi rolled products allows for interleaving rolling to maximise productivity, before finishing passes and accelerated cooling in the Mulpic equipment. The use of pyrometers, both fixed and scanning at key points along the process allow for real time data to be into the process models to ensure accurate tracking and metallurgical processing is undertaken.
The finished mother plates will require trimming to remove head and tail crops, side trimming to ensure that the plate is dimensional accurate. The balance between achieving through properties that are not lost across the plate and minimising yield loss is vital importance to the steelmaker. There will be a requirement for levelling to ensure to good finished product. This can be done hot and / or cold. Sufficient care has to be taken to ensure that the physical properties are not compromised by the use levelling but that residual stress is relieved and the desired flatness achieved.
At the point that the plate is considered cropped to its final dimension it must be labelled and a sample made available for testing. This traceability is critical to

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ensuring that the plate reaches its final destination with the correct accreditation for the final application. The quick feedback of testing information will ensure that mill performance can be monitored online in real time and potential problems avoided.

2.1.2 Steckel mill

The Steckel Mill has proven to be a very effective way of producing coils particularly for long plate applications such as line pipe. The thickness of the coils is between 2 and 25mm but will depend on the width and steel grade as to the minimum possible. The Steckel process is shown in figure 3 and progressively involves rolling the slab through a rougher mill to achieve a basic feedstock for Steckel mill and to speed up the actual Steckel process. This uses intermediate furnaces on the entry and exit sides of the finishing mill as the final length of the product becomes too long for metallurgical transformations to take place without them due to the loss of temperature.
These successively pass the ever increasing length of coil through the mill between the entry and exit furnaces until the requisite thickness is achieved. This coil can then be fed through to a Downcoiler or the can then be used with a flying shear to produce mother plates for further cutting.

Steckel Mill – Typical Layout

Product = Coils	One Mill Stand	Two Mill Stands
▪ Strip width = 900 – 2000mm	Capacity = 0.6 – 0.8 mtpa	Capacity = 0.8 – 1.2 mtpa
	Min. thickness = 2.0 mm	Min. thickness = 1.5 mm

Min. thickness depends on width and steel grade – Capacity depends on product mix

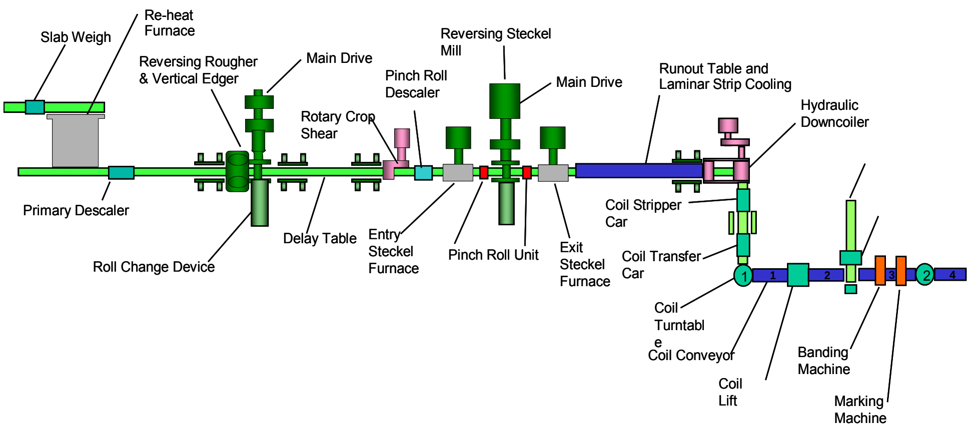

Figure 3. Typical Steckel Mill layout.

In order to derive the maximum flexibility from a combination of equipment then the Plate-Steckel Mill has the potential to deliver a wider range of products. In Figure 4 the range of plate capabilities produced from different mill configurations are illustrated with respect to product dimensions and physical properties.

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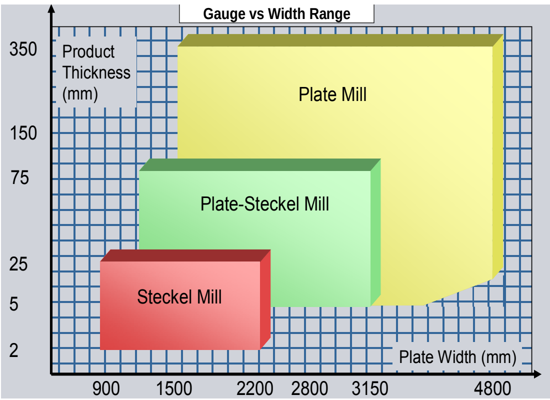

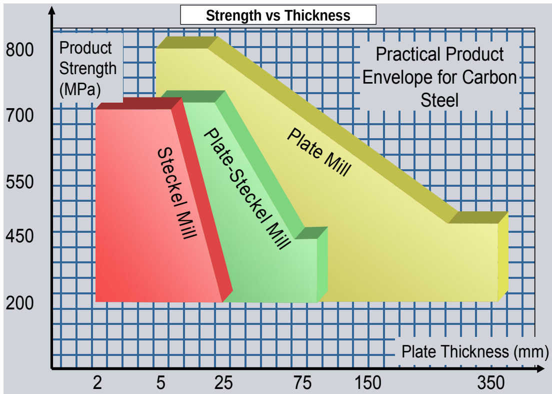

Figure 4. Thickness vs. width and strength to determine mill configuration.

The main decision driver is the final thickness of the plate and the application. For grades >25mm thick and where high strength and toughness are important then a conventional plate mill is the solution. Conversely if only coils in the range 2- 25 mm are required then the Steckel Mill is the solution (up to 2000mm wide). If the product mix includes coils, coil-plates (plates that are coiled in the Steckel coiler furnaces and cut to length at the exit from the mill stand).and plates with a minimum thickness of the products of 4mm, a coil width up to 2500mm and a plate or coil-plate width up to 3200mmm, the Plate-Steckel Mill is the appropriate solution. If it includes thin coils (< 4mm), with width ≤ 2000mm, and thick and wide plates, then an hybrid solution – Combination Plate Mill + Steckel Mill – has to be considered

A plate mill can be converted into a Plate-Steckel Mill. Phase 1 is the construction of a conventional mill. The second phase would see the addition of the coiler furnaces, a crop shear, downcoiler and coil handling facilities. A Plate-Steckel Mill can also operate as a "conventional" Plate Mill when rolling some thick and/or wide products (the "Steckelling" function with the Coiler Furnaces is not used). Typically a Plate-Steckel Mill rolls long, full-width (3200mm), medium thick slabs (e.g. 165mm) but with a two-stand configuration can also roll long, full-width (3250mm), thick slabs (200mm and above) – the technology for wide thick casters is available and machines up to 400mm thick are being built and proposed. Siemens VAI have many references for Steckel Coiler Furnaces.

3 RESULTS

3.1 Benefits of the Plate-Steckel Mill versus Plate Mill

A higher throughput can be achieved because long full width slabs can be rolled (there is no need broad siding / cross rolling required to develop the width).The long slabs can be used also for thin gauge products, because these products are coiled during rolling and then either sheared before going onto the cooling beds, or down-coiled. There is less Reheat Furnace flexibility required. The Reheat Furnace doesn't need to be designed to handle a wide range of slab lengths, e.g. with multiple row charging and an increase in yield will be achieved (fewer head/tail crops).

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3.2 Limitations of the Plate-Steckel Mill versus Plate Mill

There are limitations in the process due to mechanical strains on the equipment and the ability to coil steel grades with certain properties. It is unsuitable for wide plates as the maximum slab width is 3250mm and short slabs have to be used for broad siding so Steckelling is not possible due to minimum length (~30m) requirements for Coiler Furnaces operation. The Coiler Furnaces can be used only for products < 25mm and is therefore unsuitable for thick plates and it is unsuitable for API grades with very demanding low temperature or sour service requirements. For example, API X80-X100 grades with Charpy - 60°C / DWTT -10/-20°C need reduction ratios of slab to plate equal to 10, therefore a very thick slab is required to produce plates. There are problems of accreditation of these products if the PSM route is used as long inter-pass times allow recrystallisation, preventing the correct temp-strain path .The Mulpic[1] cooling system cannot be used (unsuitable for coils) and therefore more alloying may be required to achieve the same mechanical properties (high strength, high toughness). Not as suitable for thin narrow coils. The PSM is too wide to produce narrow thin strip with a good flatness but the problem is partially mitigated if SmartCrown is installed.

3.3 Combination of Plate–Steckel Mill and Plate Mill

This hybrid solution may be applicable for where both plates and coils are required but different widths are needed with high productivity. Figure 5 gives an example layout. A roughing mill is installed which rolls plates and transfer bars for the finishing mill. The Finishing Stand is a Steckel Mill and rolls only strip.

Combination Plate Mill + Steckel

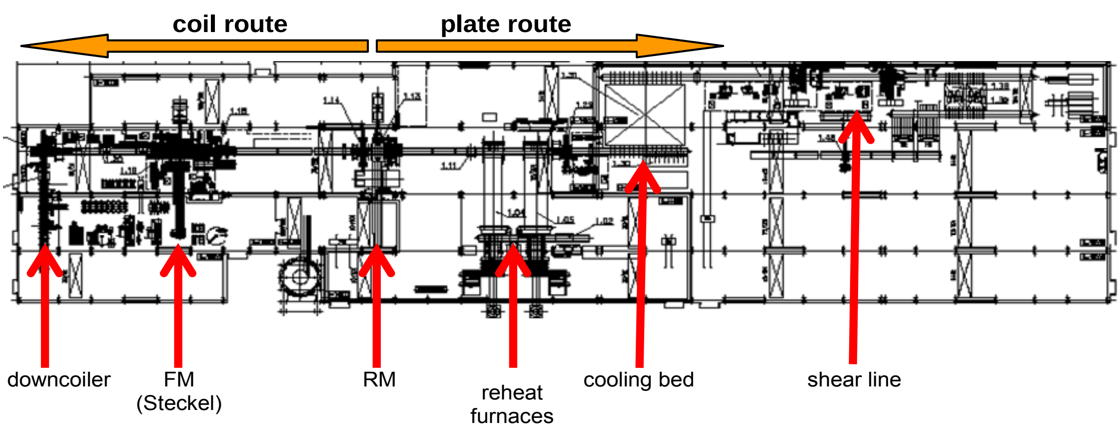

Figure 5. Combination Plate Mill and Steckel Mill configuration.

4 DISCUSSIONS

4.1 Modular Technologies

These key modular technologies can benefit not just new plant installations but improve the performance of existing ones. Table 1 illustrates how trends in the properties of plate steel grades require similar but different solutions.

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Table 1. Product trends and solutions

Trend	Solutions
Higher **Strength** Products	Steel Making + TMCR + MULPIC® SmartCrown® High Strength Shears Model Based Control
Higher **Toughness** Products	Steel Making + TMCR + MULPIC® Model Based Control
Better **Weldability**	Steel Making + TMCR + MULPIC®
Higher **Throughput**	SmartCrown® + MULPIC ® Model Based Control
Higher **Quality** – thickness, flatness, mechanical properties	AGC, SmartCrown®, MULPIC® Advanced Automation Systems including Model Based Control

At the outset the contribution of high quality steelmaking and casting will present to the mill a consistent and reliable feedstock from which a suitable high value product can be derived. The properties of the product can be determined by the installation of a combination of solutions.

4.1.1 Thermomechanical Rolling and Automation Modelling

These include the full scope of thermo mechanical rolling in combination with advanced process control, of model-based control of the plate mill, to the micro-structure monitor for on-line property prediction. In order to correctly control the mill configurations and have real time knowledge of mill passes, temperature and controlling the outputs, this requires a complex and intricate know how of the set up and capabilities of the mill. Also there is a need to ensure that the productivity is met but does not compromise the quality and to cope with a range of varying inputs. For thick plates which are Thermo-Mechanically Rolled, (TMCR), the hold time at the hold thickness can be longer than the rolling time. For these products the mill production can be increased by rolling several slabs in the mill at the same time – rolling the 2nd slab whilst holding the 1st slab, etc. This is called ‘interleaving’ or ‘batch rolling’. After the first slab is rolled to the hold thickness (Phase 1 rolling) it is held down stream of the mill while the second slab is rolled. If the hold time is long enough this process continues for further slabs. The batch is then transferred back to the entry side of the mill. After the batch has been moved back to the entry side then Phase 2 rolling of the first slab in the batch can start. This is followed by Phase 2 rolling of plate 2, then plate 3 etc. For a single stand mill the number of plates that can be interleaved is the hold time divided by the maximum of the Phase 1 rolling time and the Phase 2 rolling time plus the gap times – in Figure 7 there are a total of 5 plates in the batch.

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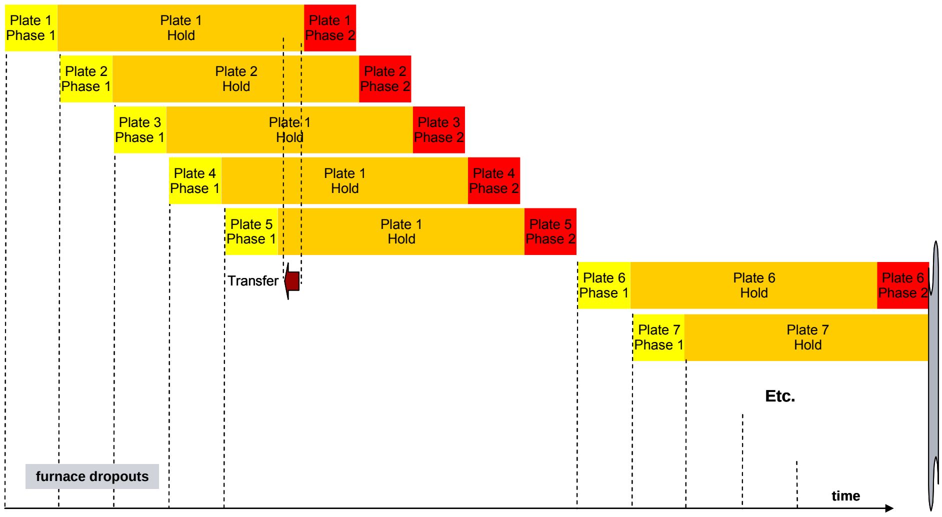

Figure 6. Interleaving of thick plates for increased productivity.

4.1.2 MULPIC® (Multi Purpose Interrupted Cooling) plate cooling technology

This is the Siemens VAI patented technology to achieve accelerated cooling and hence the requisite metallurgical properties with lean alloy chemistry. The Mulpic[1] plate cooling technology has a number of advantages to offer the steelmaker. There are 4 cooling banks with the first having the capability of a direct quench. Height adjustable headers are installed with high velocity jets to achieve the desired cooling effect in accelerated cooling and direct quench modes and a large flow control range of 20:1 is available. Feed forward allows the possible variation in plate temperature to effectively control the water sprays in each zone as the plate approaches by using a scanning pyrometer in advance of the Mulpic[1]. Figure 7 shows a new installation.


Figure 7. Mulpic line installed.

Speed control adjusts the plate speed through so that the cooler tail can be processed more quickly taking account of the total plate length. Edge masking and head tail masking are used to avoid over cooling of these areas and is dynamically controlled compensating for position of the plate on the roller table. Oscillation control is used to ensure thick plates are cooled correctly.

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Water crown control ensures that the plate will have the same properties across the width and the cooling is adjusted to suit the known runoff. A pre leveller can be installed to ensure that the cooling is carried out on the flattest surface possible. Zone separation allows for zero water carryover from one zone to another and to prevent further overcooling. Automation control will use the real time data and existing model information to ensure that the water cooling is controlled and directed with accuracy. Low maintenance is assured with high filtration standards and stainless steel parts.

4.1.3 SmartCrown® Technology

The system of using bottle-shaped rolls with a '3rd order roll contour' is a well-known and proven technology, which is in operation in numerous hot and cold rolling mills throughout the world. Siemens VAI have been building and upgrading mills equipped with this system for more than a decade. Siemens VAI's latest development in the field of flatness control is a new work roll contour called SmartCrown®, which offers significant advantages in terms of higher order profile and flatness control compared to the '3rd order roll contour' technology. The basic principle of SmartCrown® and the '3rd order roll contour' technology is very similar. Both systems utilise lateral shifting of the work rolls to adjust the loaded roll gap contour to match the relative crown of the ingoing strip as shown in figure 8. The SmartCrown® roll contour can be described as a sum of a sinusoidal and a linear function (SMART = Sine Contour, Mathematically Adjusted and Reshaped by Tilting).

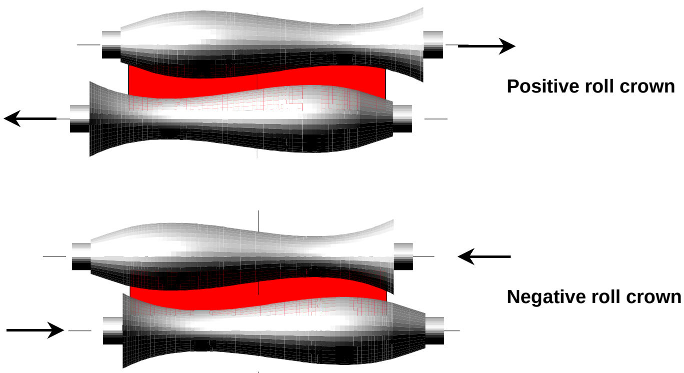

Figure 8 – Axial Shifting of the SmartCrown rolls changes the roll gap profile.

The advantage of the SmartCrown profile is there is an additional variable - the 'contour angle' – which can be adjusted to optimise the higher order profile (e.g. to minimise quarter buckle). The advantages of SmartCrown® compared to a conventional mill stand with heavy bending are: -

- Fewer rolling passes and increased production. Particularly on thin and hard products, SmartCrown® allows higher rolling loads to be used whilst still achieving good flatness as shown in Figure 9.
- Much larger profile and flatness control range. This makes it much easier to achieve good flatness and the correct target profile.
- The ability to control higher order flatness problems such as quarter-buckle. The SmartCrown® 'contour angle' can be adjusted to optimise the plate flatness.

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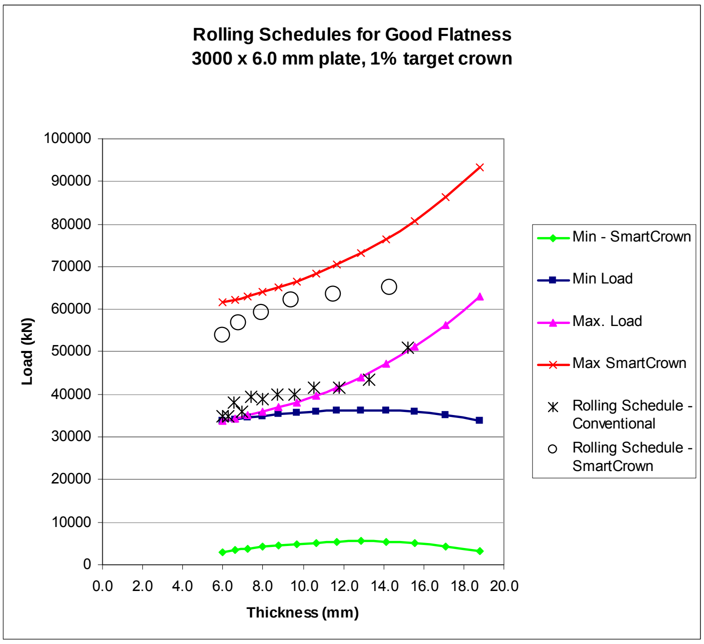

Figure 9. example rolling schedules for a plate with good flatness.

4.1.4 Additional Technologies

The development of Plate Mill technologies is a part if continuous process. From the use of neural networks to refine automation processes to the implementation of long stroke cylinders for automatic gauge control and the construction of some of widest mills with multi piece large back up rolls, Siemens VAI has been promoting innovation. Equipment needs to be able to handle and shape far higher strength and dimensional larger pieces whilst reducing operating and maintenance costs.

5 CONCLUSIONS

The choice of the plate mill configuration will depend upon a number of factors. Location, slab supply, end customers, projected volumes, market development are all key drivers to ensure a successful project can be implemented to meet the requirements of financial and other stakeholders. The paper has outlined the key considerations for driving that choice and the product mix is fundamental to that. The development of the project may be phased and allowances can be made for plant changes at an early stage of the design. Energy costs and productivity are important to ensure that a quality product is successfully produced.

The choice of mill configuration is driven by a number of factors including product mix, operational requirements as well as financial considerations. The plate produced can be enhanced by the use of existing and proven technologies. These are being continually developed to attain an increasing demanding range of properties and applications.