NEW HOT ROLLING TECHNOLOGIES FOR THE PRODUCTION OF THIN HOT BAND

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Abstract
The demand for hot rolled strip is growing in multiple ways. To remain competitive, new and existing mills must meet arisen challenges in the best possible way. The production of hot strip is a key element of steel production. Since close to half of all steel produced is hot-rolled to strip, mills require maximum throughput and availability combined with geometrical precision and the ability to create optimum material properties.
Today there is a clear trend in developing new steel grades with high-strength and improved formability, like 3rd generation AHSS (Advanced High Strength Steels), as well as a trend to produce thinner and wider gauges. This trend challenges hot strip mills because it requires new technologies which provide more flexibility in metallurgical treatment during the rolling process.
In order to meet and promote these trends Primetals Technologies is currently working on different concepts and solutions. One example is the development of a new mill stand technology Flex-HI HOT which allows to adapt the last finishing mill stands by efficiently switching from 4-high to a 6-high mode with small work roll diameter based on production needs. Another solution is to apply a permanent 6-high rolling stand at the end of the finishing train. A smaller work roll diameter allows to achieve higher specific thickness reductions and deformation rates resulting in significant thinner hot-strip gauges with valuable metallurgical benefits. The developed solution concepts with technological and metallurgical benefits will be presented in this paper.
Keywords: Hot rolling, Hot Strip Mill, Flex-HI HOT, 6-high, small work roll diameter, AHSS, high-strength steels, thin hot band.

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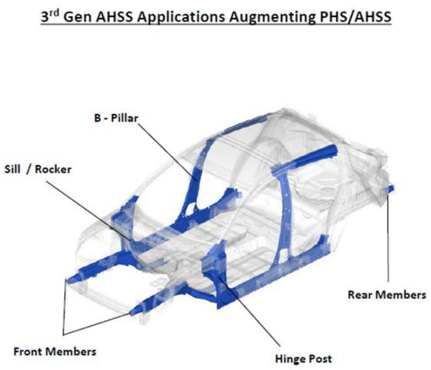
1. INTRODUCTION

Growing demands for Advanced High Strength Steels (AHSS/UHSS), which is mainly driven by the automotive industry, requires new concepts and modernization solutions for steel manufacturing plants.
Harder and thinner flat steel products contribute significantly to weight reduction of vehicles and consequently to improved fuel consumption and reduction of pollution.
From 2019 to 2025, a net increase of AHSS/UHSS grades of steel of approximately 80 kg per vehicle is expected. This translates to an annual average growth of about 13 kg per year. Main driver is a higher demand for 3rd generation AHSS grades and UHSS grades (ultra-high strength steel). These grades have proven mass saving capabilities as compared to mild steel or HSS/HSLA grades. (cf. Figure 1 and [1]).



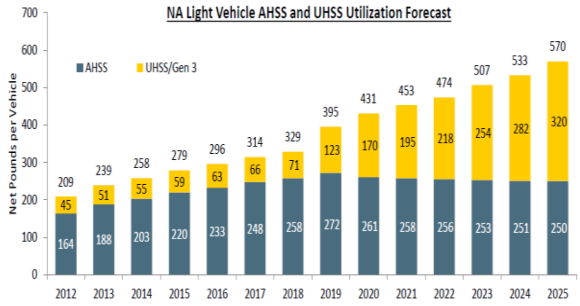


Figure 1. Automotive demand of AHSS/UHSS grades. (Source: Ducker Worldwide [1])

As a consequence, steel producers are faced with the challenge of producing AHSS/UHSS steel grades that exceed the capability of existing production facilities in many cases.

2. IDEAS AND MOTIVATIONS

The basic idea of Flex-HI HOT is a product-mix extension for an existing hot strip mill (HSM) due to the adaptation of the last finishing mill stand by switching efficiently from an existing 4-high mode to a newly introduced 6-high mode with small work roll diameters an back again based on the actual production needs.

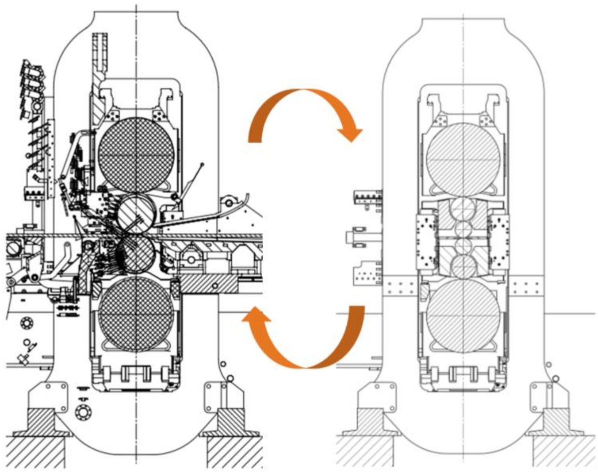


Figure 2. Flexible switch between 4-high and 6-high.

With this 6-high configuration a higher reduction capability in the last finishing stand - up to approximately 30% - can be achieved. This leads to thinner hot-strip gauges and metallurgical benefits.

This demand calls for a reliable system, which makes a quick change between 4-high and 6-high rolling mode possible, thus fulfilling the high process demands of steel producers.
In case of a Flex-HI HOT revamp only limited modifications in the mill stand are required.
The main reason and benefit for the possibility of switching back to a 4-high mode is to ensure that there are no limitations for any existing product mix and the production conditions in 4-high operation. In comparison to an additional new finishing mill stand the installation of Flex-HI HOT requires lower investment costs (OPEX) at similar performance results. A detailed modernization study of a hot strip mill has clearly shown that Flex-HI HOT installed at stand F6 is a serious and viable alternative to an additional 7th finishing mill stand. This makes Flex-HI HOT also an attractive solution for revamping mills with limited space for additional rolling equipment.

3. CONCEPT FOR FLEX-HI HOT

To be able to replace the existing large work roll (4-high mode) by an intermediate roll and a smaller work roll in 6-high mode, the work roll diameter of the 4-high mill should be larger or equal to approximately 650 mm (for a strip width of about 1,700 mm). Smaller 4-high work rolls do not leave enough space for replacement with a 6-high configuration, because of the additional rolls with diameter ratios for work roll and intermediate roll in the range of dWR/dIR= 0.9 to 1.0. To emphasize the advantages of the Flex-HI HOT technology, only minimal restrictions on backup-roll diameter should exist; the goal is to keep it the same as in the remaining stands and obtain benefits of improved spare part management and maintenance efforts.

From a technological point of view a smaller 6-high work roll diameter results in increased benefits compared to the 4-high mode, but finally the design and operational restrictions must be obeyed.
Pass schedule calculations have shown (cf. Figure 3) that for a constant high reduction (approx. 30%) in the last finishing stand the rolling force can be reduced by up to 28% in a work roll diameter range from 250 mm to 350 mm; the rolling torque can be reduced by up to 36% at the same time.

F6	WR min=WR max= 250mm			WR min=WR max= 300mm			WR min=WR max= 350mm		
	Mmax [kNm]	F roll max [kN]	Red. [%]	Mmax [kNm]	F roll max [kN]	Red. [%]	Mmax [kNm]	F roll max [kN]	Red. [%]
S355MC 1,2 x 1300mm	82	11837	31,04	104	14112	31,04	127	16495	31,04
S355MC 1,5 x 1500mm	103	12975	31,04	130	15266	31,04	158	17631	31,04
S420MC 1,2 x 1300mm	87	12552	31,04	110	15004	31,04	135	17609	31,04
S420MC 1,5 x 1500mm	109	13725	31,04	137	16187	31,04	167	18736	31,04
S500MC 2 x 1500mm	131	14026	31,04	164	16319	31,04	186	17794	29,92
DP600 2,0 x 1250mm	90	9550	31,04	113	11092	31,04	136	12647	31,04
DP1000 2,0 x 1250mm	111	11888	31,04	140	13879	31,04	170	15903	31,04

Figure 3. Results of pass schedule calculations for different work roll diameters.

Additional pass schedule calculations were made for specific steel grades like MnB steels and HSLA grades, which demonstrate the opportunities of a small work roll diameter of 300 mm with regard to reducing rolling force and torque.

Material	Width [mm]	Last stand work roll dia.	Reduction [mm]	Roll-force last stand [kN]	Torque last stand [kNm]	Rolling speed [m/s]
MnB	1300	700 mm	2,42 - 2,00	14.676	154	10,36
MnB	1300	300 mm	2,42 - 1,75	8.529	79	10,30
HSLA	1850	700 mm	4,97 - 4,4	14.769	234	5,56
HSLA	1850	300 mm	4,97 - 3,60	17.279	236	5,48

Figure 4. Results of pass schedule calculations for specific steel grades.

Figure 4 illustrates the comparison between typical work roll diameters and small work roll diameters. For the MnB–grade there is a reduction in the rolling force of approximately 40% in spite of a higher draft and therefore a thinner exit strip thickness.
For the HSLA-grade there is an increase of the rolling force (which is still **much** below the stand force limit) with a similar level of rolling torque, but of course at significantly increased reduction and deformation rate.

The limiting factor for thickness reduction in the last stand is typically not the stand force limit, but the specific rolling force, Hertzian pressures between the rolls and torque limits corresponding to the smaller roll trunnions.
Driven work rolls are essential because of the direct torque transfer. This prevents slippage between intermediate and work roll. The horizontal deformation due to the tangential force is negligible compared to the case of driven intermediate rolls.

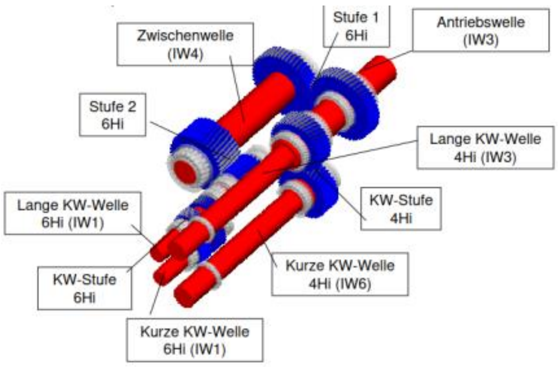


Figure 5. Switchable gear.

Flex-HI HOT requires flexible switching between 4-high and 6-high mode and therefore expanded requirements on the gear box design. After an intensive study the preferred configuration was found in a switchable pinion-reducer gear with four output shafts - one pairs for 4-high mode and another pair for 6-high mode. The design of this gearbox will consider the higher rotational speed of the smaller work rolls in 6-high mode, but will not impair the standard 4-high operation at lower rotational speeds.
Gear type spindles with a high load capacity in the 6-high mode require the spindle angle to be restricted to about 2° during operation. This leads into a certain minimum distance from the mill stand for positioning of the switchable gear box.
Due to the small work roll diameters in 6-high mode the size of the trunnions and thus also the maximal transmittable torque is limited. Since the torque requirements are significantly lower compared to the first finishing mill stands, this is still acceptable for most products.
As described above, two pairs of spindles are in use. The spindle change between the 4-high and the 6-high mode will be done fully automatically within a typical roll change duration of a hot strip mill. There are two independent spindle support mechanisms for both spindle types attached to the housing with minimal changes to the housing to avoid machining as far as possible.
Locking of rotation for the unused spindle set is required because of small torques remaining from the detached drive train.

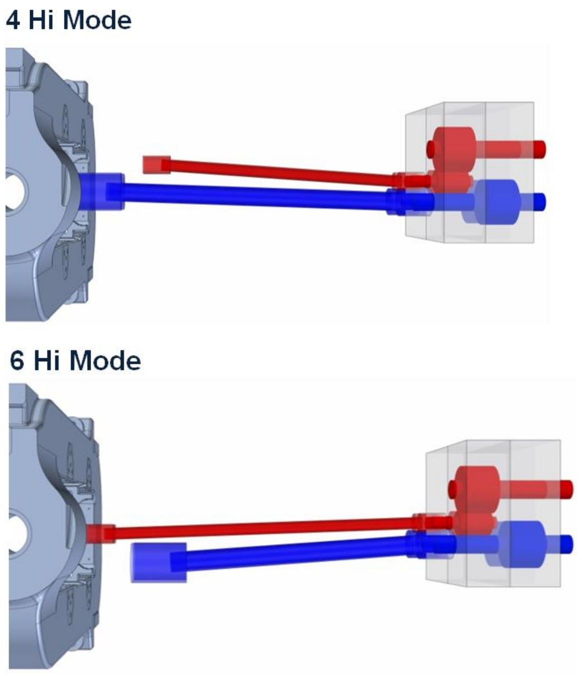


Figure 6. Spindle positions in 4-high and 6-high mode.

The spindle change requires axial travel for both types. The reason for this unloaded travel position is the ability to park both spindles in the retracted position to avoid collisions during backup roll change. This possibility of travelling without spring load of the spindle has been confirmed by a spindle supplier.
The main advantage of Flex-HI HOT is its high flexibility. The roll change remains basically unchanged in terms of time duration and handling compared to a typical

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work roll change procedure. This is made possible by a 6-high cassette design with similar chock design as for the 4-high mode, which makes it interchangeable with the 4-high work roll stack.
In combination with the absence of hydraulic connections on the cassette this technology fulfills the requirement for manipulations similar to the 4-high mode.

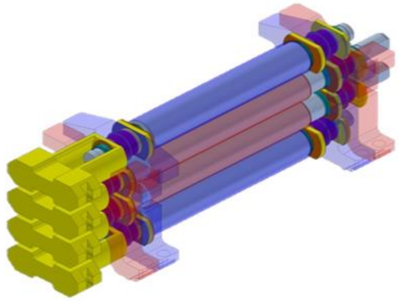

Figure 7. Example of 6-high cassette design with Work and intermediate gear. (combined roll stack)

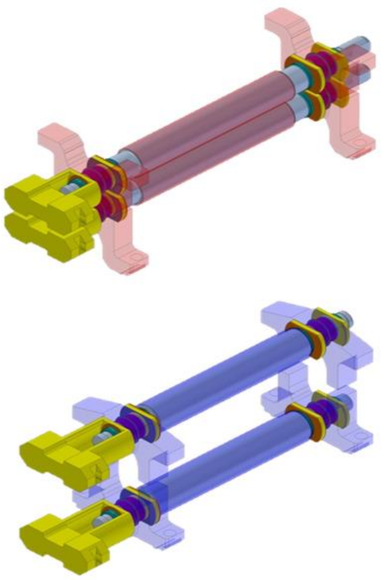

Figure 8. Example of 6-high cassette design with work and intermediate gear. (separated roll stack)

As depicted in Figure 7 and 8, an individual stacking of unused work rolls and intermediate rolls without any special rack is possible, so a change of these rolls can also be done separately, if required. These stacking possibilities have additional advantages regarding roll shop handling.
To maintain the strip flatness requirements, individual positive bending of work roll and intermediate roll is possible. The bending block includes four cylinders per roll neck with two bending cylinders acting on each chock side (entry and exit). In 4-high mode, both cylinders apply the bending force on one chock side, in 6-high mode these two cylinders are acting separately (hence with half of the bending force compared to 4-high mode) to the chocks of work and intermediate roll.
In order to ensure a sufficiently large flatness adjustment range in the last stand, roll shifting with SmartCrown® technology is applied in addition to work roll bending, which enlarges the window of operation significantly further.
Latching of the rolls can be done with the same shifting unit as in 4-high mode. In 6-high mode the work and intermediate rolls are shifted together pairwise. To prevent bending of the bearings out of the centerline, individual axial latching units for all rolls will be installed.

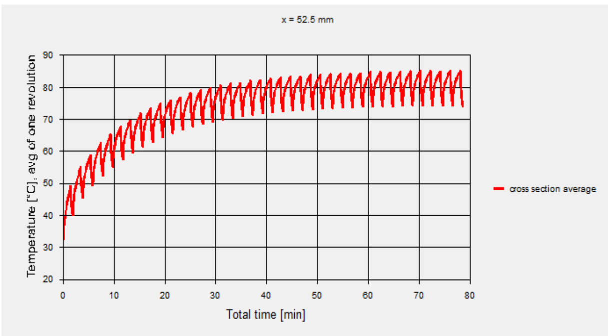

Figure 9. Work roll temperature.

Due to operation with small work roll diameters intensive work roll cooling is required. Therefore, an optimized design and position of the cooling headers has to be considered to ensure a sufficient cooling effect. To enable the adjustment in vertical direction between 4-high and 6-high mode, a sophisticated wiper and cooling header design is needed.
Thus, a detailed analysis of thermal crown build-up and necessary changes in shifting position and bending forces required to ensure the flatness quality is essential.
Figure 9 shows an example of the results of thermal calculations of the work roll

temperature evolution based on a work roll diameter of 300 mm and optimized header design and position. This leads to typical steady-state temperatures of up to approximately 80 °C.

An additional point to consider is the optimum roll stack arrangement of backup, work and intermediate roll. The deflections of the rolls are strongly dependent on the arrangement and have an influence on flatness quality.

Basically, two kinds of roll stack arrangements are possible, which are shown in Figure 9, right hand side: The V-arrangement (work and backup roll are on the centerline, intermediate roll with offset) and the I-arrangement (all rolls are on the same line but have offsets with respect to the centerline).

By means of a Finite Element Analysis the deflections in vertical and horizontal directions were investigated. The rolling force was increased from 2 to 12 MN for a constant offset of 12 mm.

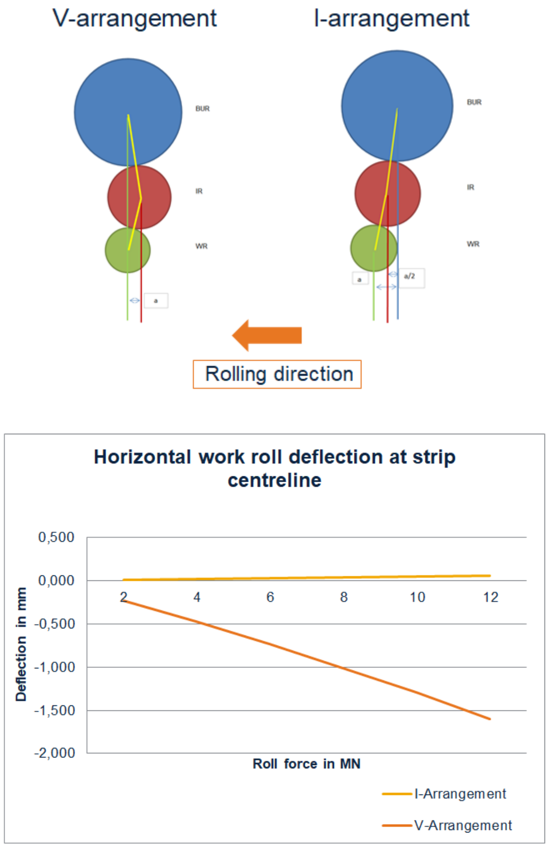

Figure 10. Roll Stack arrangement and results for horizontal deformation.

The graph in Figure 10 depicts the results of the horizontal work roll deflection at the strip center, which may influence the flatness of the strip. It shows that the stack in V-arrangement is much more stable and so it is much more favorable to arrange the roll stack in that way.

4. METALLURGICAL ASPECTS

Flex-HI HOT introduces new conditions for the thermo-mechanical behavior of the strip, which affect the microstructure evolution during rolling and cooling as well as final properties of the steel.

The typical reduction in final finishing mill rolling stands is less than 20 %. For high strength steels this reduction is typically even significantly smaller. The application of standard rolls results in a high shear stress in the subsurface area of the strip due to roll flattening. This defines the specific behavior of the microstructure of the strip.

The microstructure behavior changes significantly by applying Flex-HI HOT due to the reduction of the roll diameter and increase of the strain and strain rate.

The increase in strain and strain rate in the last or the last two rolling stands leads to an increase in the pancaking ratio and dislocation density. If the temperature of the strip is above TNR (non-recrystallization temperature), the microstructure gets more driving force for recrystallization and, as a result, grain refinement. If the temperature of the strip is below TNR, the material accumulates this strain. Both cases lead to an increase in the number of nucleation sites for ferrite and diffusion. This accelerates the phase transformation and results in refinement of the final microstructure. Reducing the roll diameter leads to a significant decrease in the shear stress in the strip and contributes to the development of texture with γ-fiber.

Changes in the behavior of the microstructure, caused by Flex-HI HOT, can be applied to different grades of steel.

- Refinement of the final microstructure allows saving alloying elements for LC and micro-alloyed steels. Grain refinement reduces the need for alloying elements used for solid solution strengthening and increase hardenability.
- Development of texture with γ-fibre is favorable for improving deep-drawing properties.
- Acceleration of phase transformation is useful for high-alloyed steel grades with a slow phase transformation such as high-carbon steel etc. This helps to ensure complete phase transformation before coiling.

5. CONCLUSION

The Flex-HI HOT technology is a novel technology with the following benefits:

- Achieve **higher reductions** in last finishing mill stand in 6-high mode for **thinner-gauge hot-strip products**
- **Extension of product mix** range at high operational flexibility
- Enables the production of **new products with high profit margin** (special grades and thinner strip-gauges can be rolled)
- **Metallurgical benefits** in terms of accelerated recrystallization for low-alloy steels and refinement of microstructure for AHSS and HSLA grades
- **Thinner gauge cold-rolled strip** can be achieved by reduced hot-rolled strip gauge without any additional upgrade to the cold rolling mill

Primetals Technologies is in discussion with world's leading roll manufacturers to combine their competences and expertise to master the challenge of manufacturing of smallest work rolls for the introduction of Flex-HI HOT.
Based on cooperation with a roll manufacturer and a hot strip producer, further developments and tests of Flex-HI HOT shall be performed in an industrial hot strip mill, to prove that this novel technology can be applied successfully for the development of new steel grades and products of tomorrow.

REFERENCES

1 NA Automotive Steel Content MarketStudy, Final Report Executive Summary, 6. June 2018, Ducker Worldwide