

Hot Skin Pass Mill & Tension Leveler Line for Ultra High-Strength Steel

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Summary

In order to reduce CO₂ generated from internal combustion engines, various efforts have been made to reduce the weight of vehicles over the last few decades. High-strength steel materials are indispensable for the reduction of vehicles weight. It is for this reason, the materials used for the frames and chassis are being made of Advanced High-Strength Steel (AHSS) and/or Ultra High-Strength Steel (UHSS) possessing properties of high yield strength, and also better mechanical characteristics. There exist strong requirements for materials to be fed to the automobile production lines with precise dimensional accuracy, favorable physical shape and improved surface quality. On the other hand, in the production line of UHSS material, higher rate rapid cooling with water on the run-out table is inevitable, which becomes one of the elements of lower flatness performance than conventional strips. To produce UHSS material to the required quality, JP Steel Plantech Co. designed, manufactured and delivered a Hot Skin Pass Mill Line with Tension Leveler adopting various techniques and innovations suitable for UHSS materials. This paper introduces details of such techniques and innovations.

Key Words

Hot Skin Pass Mill Line, Ultra high-strength hot rolled strip, Advanced high-strength hot rolled strip, Crop Removal, Elongation and Flatness Control, Lateral Strip Walk, Real Time Control, Tension Leveler for Hot Skin Pass Mill Line

1. Introduction

Hot Skin Pass Mill Line (HSPML), having very important role as a finishing facility before selling hot rolled coils produced by a hot strip mill to customers, or as a pre-treatment facility before downstream processes, has often been installed after a hot strip mill line in the past.

In the recent years, constructions of new HSPML has been continuing to reflect new requirements on performance which are difficult to cope with conventional facilities.

Since 2015, six (6) lines of HSPML have been delivered by JP Steel Plantech Co. (SPCO) to customers in Japan and overseas to meet the new requirements. This paper will introduce new technologies on HSPML.

2. FUNCTIONS OF HSPML

In addition to the basic functions adopted for conventional lines, the higher functions required for HSPML built in recent years are described as follows:

Basic functions of conventional HSPML

- Elimination of yield point elongation (stretcher strain)

- Improvement of strip flatness and warpage
- Improvement of surface roughness
- Removal of leading end and tail end crops

Additional higher functions required in recent years

- Improvement of flatness of ultra high-strength hot rolled strip for automobile use
- Further improvements on productivity and product yield
- Products of further stable quality (elongation and flatness)
- Automatic collection and recording of various quality data
- Solutions for extreme thick products (Max. 12.7 mm)

3. IMPROVEMENT OF FLATNESS OF ULTRA HIGH-STRENGTH HOT ROLLED STRIP FOR AUTOMOBILE USE

3.1 Configuration of conventional HSPML supplied by SPCO

Type A: Conventional HSPML

Figure 1 shows a conventional HSPML (Type A). This is a simple configuration having entry and exit reels and Hot Skin Pass Mill in between. Flatness achieved generally in this line is 0.6 to 1.0%^[1].

In this line, there were following problems to overcome the flatness control of the UHSS material:

- (1) Although strip tension is given between the reels, it is impossible to provide sufficient tension values to level the high-tension strips having high yield point strength.
- (2) Due to deformation of drums of the reels and shape of coil not being perfectly cylindrical, it is difficult to obtain uniform tension in full width of the strip.
- (3) Controlling of strip elongation, which is the most important factor for strip flatness correction, cannot be carried out accurately.

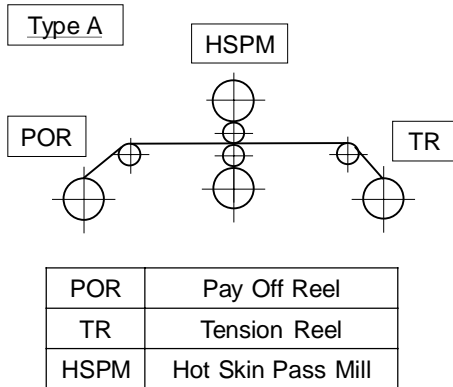


Figure 1: Conventional HSPML (Type A)

Type B: High-Tension type HSPML with Bridle Rolls
 Figure 2 shows a high-tension type of HSPML with bridle rolls (BR) retrofitted on a conventional HSPML (Type A) to apply higher tension on strip. Strip flatness achieved generally in this line is 0.4 to 0.6%^[1].

By installing BR at entry and delivery side of Hot Skin Pass Mill, higher and more stable tension can be applied on the strip than tension generated by reels only. Further, since it becomes possible to apply stably controlled strip tension, more accurate elongation ratio can be obtained. Therefore, the three (3) problems in Type A as stated above are all solved, and the flatness controlling capability for UHSS strips becomes remarkably better than that of Type A.

Figure 3^[2] shows the actual test results obtained by performing strip leveling test. The horizontal axis shows the ratio of unit tension and yield point stress, and the vertical axis shows the relative steepness which is defined by taking the flatness correction effect by strip tension into consideration. Here, center buckle is shown above the zero point on the vertical axis, and the edge wave is shown on the lower side.

In case of applying tension about 20 to 30% of yield stress of the strip having about 1.5% steepness before leveling, the result shows that the relative

steepness of the strip becomes improved to as better as 0.5% after leveling.

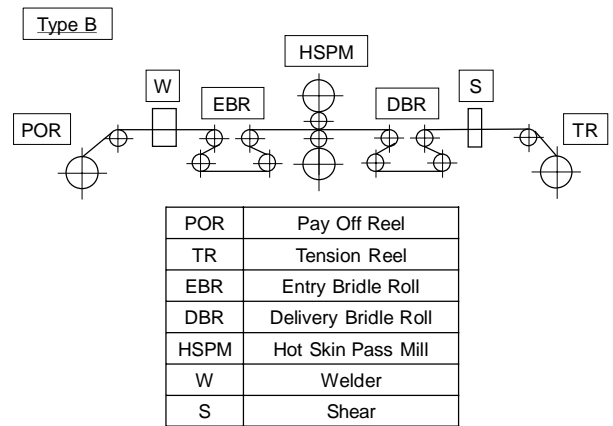
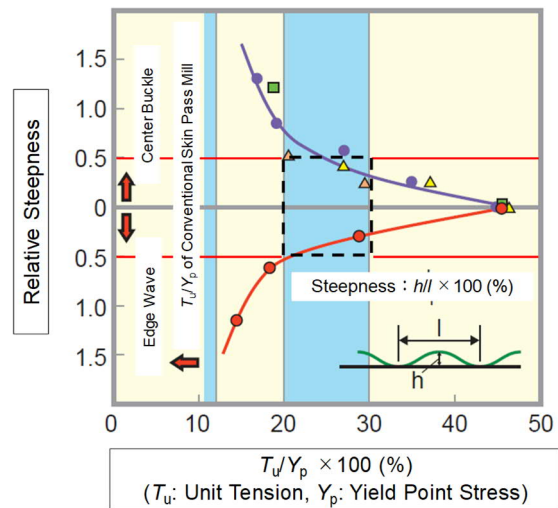


Figure 2: High-Tension Type HSPML with BR (Type B)



Condition	Symbol	●	●	▲	▲	■
Rolling Force kN		2156	1862	3332	2842	1911
Bending Force kN		Dec 803.6	Inc 411.6	Dec 1029	Dec 274.4	Dec 245.0
VCROLL™ (*) MPa		6.9	6.9	21	9.8	49
Line Speed m/min		20	20	20	20	20
Elongation %		0.3~1.7	0.5~1.0	1.0~2.2	0.4~1.7	0.7~1.5
Strip Size mm		1.6' × 1524 ^w	3.3' × 1090 ^w	1.6' × 914 ^w	1.6' × 1524 ^w	1.6' × 1524 ^w
Yield Point Strength Y _p MPa		294	255	294	294	294

(*) VCROLL™: Variable Crown Roll

Figure 3^[2]: The test results of leveling materials with High-Tension Type HSPML with BR (Type B)

Type C: High-tension Type HSPML with BR and additional Tension Leveler

Figure 4 shows Type C, a high-tension type HSPML with BR and Tension Leveler (TL) in which TL is additionally installed in Type B. Strip flatness achieved generally in this line is 0.2 to 0.3%^[1].

Type C, configured by adding tension leveler to Type B, levels such strips which are difficult to be leveled in Type B.

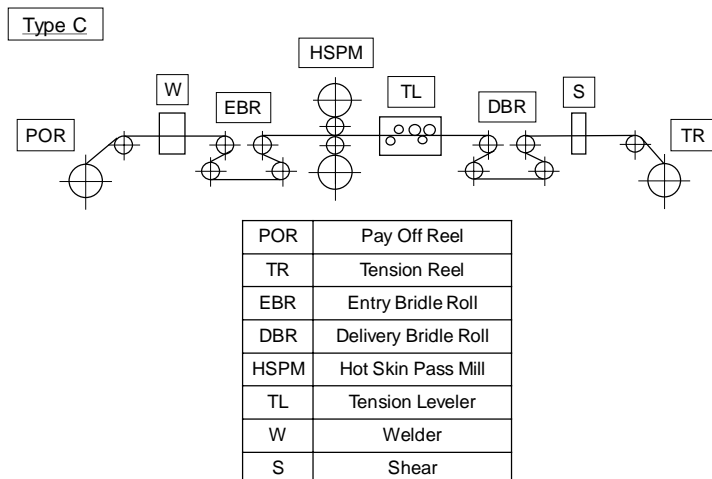


Figure 4: High Tension Type HSPML with BR and additional TL (Type C)

Figure 5^[3] shows the test results of actual strip leveling test. The horizontal axis shows the flatness of the strip at entry side and vertical axis shows the flatness after leveled by Hot Skin Pass Mill and TL.

Before leveling, the flatness of the strip was 2% or more for both edge wave and center buckle, however, strip flatness became 0.2 to 0.3% for both edge wave and center buckle after leveled.

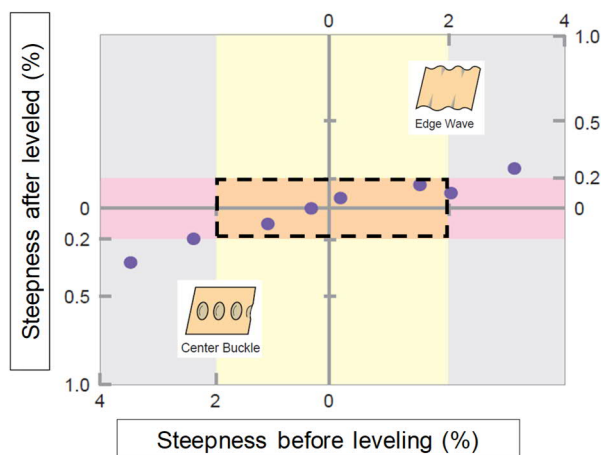


Figure 5^[3]: The test results of leveling materials with high-tension HSPML with BR and additional TL (Type C)

3.2 The most modern HSPML

Figure 6 shows the HSPML delivered recently to process hot rolled UHSS for automobile use. In this paper, this line is named “Type C Advanced” for consistency with this section.

Compared with the conventional configuration, it becomes possible to widen the range of strip thickness and yield stress combination by increasing strip tension at exit side of tension leveler. Specifically, in the conventional HSPML with TL, the

designed maximum strip tension at exit side of tension leveler was 416.5 kN (42.5 tonf), however, the latest delivered HSPML realized 637 kN (65 tonf) maximum which is 1.5 times higher than that of the conventional line. Furthermore, the maximum rolling force was also increased from 11,760 kN (1,200 tonf) to 16,660 kN (1,700 tonf). As the result, the yield stress of strip to be leveled was increased from 784 MPa to 1,350 MPa.

Although strip flatness becomes improved in Type B and C lines, still problems described below may occur:

- (1) Due to structure of bridle rolls, threading work of strip leading end is inevitable. Therefore, a welding machine for strip leading and tail ends is required.
- (2) Because of the structure of bridle rolls and the space for welding machine, required distance for strip threading becomes longer, which results in longer off-gauge length and lower product yield.

In order to solve the above problems, the roll arrangement of BR was redesigned in the latest line. Specifically, an upward and downward roll design was adopted. That is, rolls are lifted at threading, and after the leading end of strip passes through, rolls are lowered to apply tension on the strip.

By adopting new arrangement of bridle rolls, the following advantages were realized:

- The distance for strip threading becomes shorter.
- Welding machine becomes unnecessary.
- The line becomes simple and compact.
- Cost (both OpEx and CapEx) saving is also achieved.

As to be described later, in Type C Advanced, although the materials with higher yield stress are processed compared to type C strip, the flatness (steepness) reaches 0.2 to 0.3%^[1].

3.3 Leveling of strip in HSPML (Type C Advanced) for ultra high-strength hot rolled strip for automobiles

Figure 7 shows the photographs taken during ultra high-strength hot rolled steel sheet is actually leveled in Type C Advanced HSPML. The photo on the left hand shows the strip before leveling, and right hand shows the strip after leveled on the delivery side of bridle rolls where strip tension is low.

In the photograph before leveling, edge waves and large warpage are recognized, however, in the photograph after leveled, no apparent flatness defects are observed by Type C Advanced HSPML.

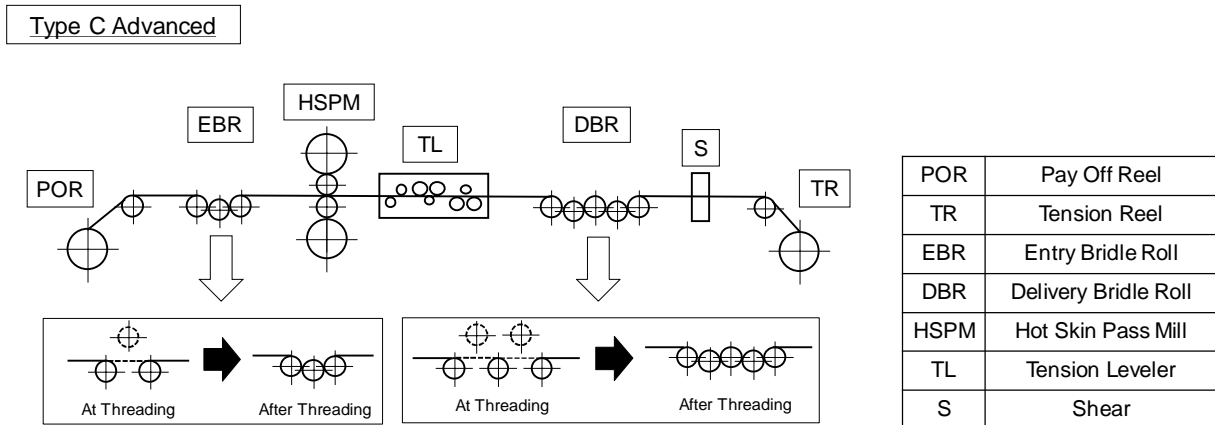


Figure 6: HSPML for hot rolled UHSS for automobiles use (Type C Advanced)

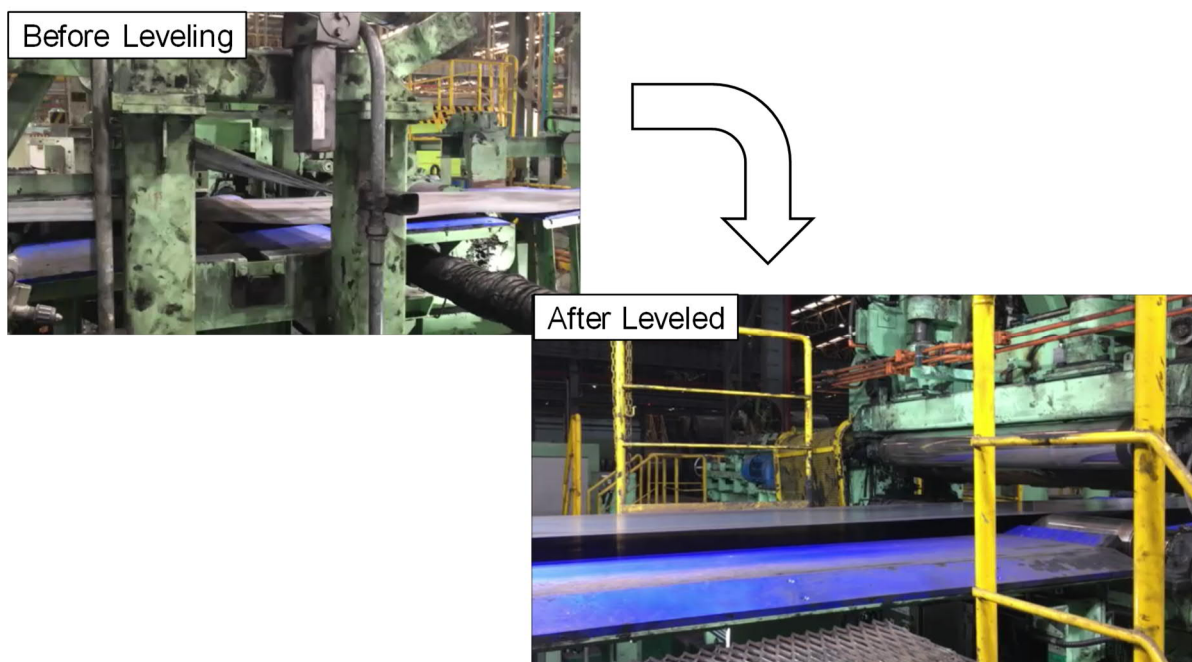


Fig 7: Photographs highlighting before and after leveling of ultra high-strength hot rolled strip

4. SOLUTIONS FOR FURTHER IMPROVEMENTS ON PRODUCTIVITY AND PRODUCT YIELD

For the captioned improvements, the following functions were introduced:

- Line speed increased up to 800 m/min
- Rolling the leading end of strip and implementing shape control at threading
- Installation of off-line crop shear for automatically cutting the leading end of coil
- Automatic winding-up and taking-out of scrap coil

Construction of new HSPML continues in response to the recent increase in demand of skin pass material. To realize higher throughput, the line speed tends to

be increasing. SPCO has delivered two lines of HSPML with maximum rolling speed of 800 m/min.

Regarding the rolling force and shape control at the leading end of strip during threading, the shape meter cannot be used because of non-existence of tension on the strip, and as increasing of the rolling force, the strip shape becomes worse (tends to be edge wave). In order to avoid such demerits, the most optimum rolling force control and shape control (automatic bender function) are applied for the strip leading end, which are very effective to improve the flatness and products yield together with threading ability of the leading end.

The off-line crop shear for coil leading end automatically cuts the crop in accordance with length information from the hot strip mill. Owing to

shortening the crop cutting and handling time, the line productivity is improved by reduced total threading time of the strip.

The scrap coil winding control is a function having cut the leading end and tail end of a coil to the scrap length automatically based on the information from the hot strip mill, then wind up and take out as scrap coils. Practically, scrap coil winding work is performed by an operator manually in many cases. However, by adopting this automatic function, it is effective to shorten the cycle time and reducing manpower as well.

5. SOLUTIONS FOR PRODUCTS OF FURTHER STABLE QUALITY (ELONGATION, FLATNESS), AUTOMATIC DATA COLLECTION AND RECORDING OF PRODUCT QUALITY

5.1 Arrangement of sensors and detectors for quality control

Figure 8 shows various sensors and detectors for quality control installed in HSPML. A shape meter (see Figure. 9) is a sensor composed of split discs arranged in the width direction having load detector in each disc to detect strip tension distribution in widthwise due to elongation difference. The data are converted into the flatness of the strip for the purpose of indication, recording and control.

The thickness gauge measures the strip thickness by means of X-ray. The width meter measures the strip width and off-center amount by using optical emitter and receiver.

ASIS (Automatic Surface Inspection System) is a flaw detecting device for top and bottom surfaces of the strip, which takes photographs with a CCD camera, and automatically judges the type and degree of defects on the strip, and displays and records.

The elongation rate is calculated by the speed difference between entry roll and delivery roll of Hot Skin Pass Mill.

There are two types of speed measuring system, one is to use deflector rolls for pay off reel (POR) and tension reel (TR), the other is to use additional measuring rolls equipped at horizontal position of strip on entry and delivery side of Hot Skin Pass Mill.

Real time measured quality data such as strip thickness, width, shape (flatness), elongation and surface defect are recorded and transferred to the upper computer system (Level 2) with tracking information of strip leading end.

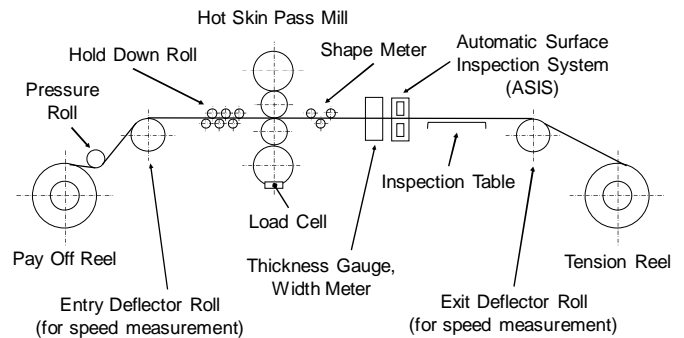
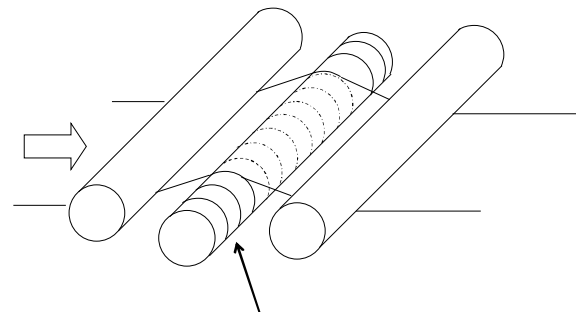


Figure 8: Example of arrangement of detectors and sensors for strip quality control on HSPML



A shape meter composed of split discs arranged in the width direction having load detector in each disc to detect strip tension distribution in widthwise due to elongation difference.

Fig 9: Shape Meter

5.2 Elongation Control

One of the important purposes of Hot Skin Pass Mill is to improve mechanical properties of the rolled strip. By applying 0.5 to 2% plastic elongation to the strip by Hot Skin Pass Mill, elimination of yield point elongation is achieved, and prevention of occurrence of stretcher strain by presses in the subsequent process is realized. Comparing to the other processes which give plastic elongation to the strip, skin pass rolling has been mainly used because of remarkable effect to delay the recovery phenomena (elongation at yield) of yield point elongation after processing.

From the upper control system (Level 3), required target value of elongation are given to HSPML in accordance with strip material and thickness. The rolling force is controlled by measured elongation to reach the target value.

The deformation resistance of the strip varies in accordance with the rolling speed (strain rate). Therefore, the elongation value changes from time to time at acceleration and deceleration of the line. In order to compensate the delay time of feedback control by elongation measurement, real time roll force control is applied when accelerating and decelerating of the line. This control logic is effective

to improve the response speed of elongation control (see Figure 10).

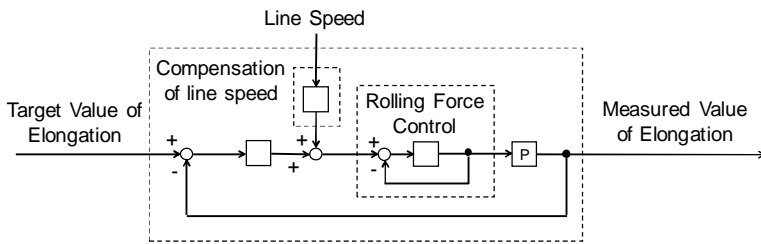


Figure 10: Elongation Control

5.3 Flatness Control

To improve strip flatness, which is one of the major purposes of Hot Skin Pass Mill, work roll bending and roll tilting functions are adopted to eliminate flatness defects such as edge wave and center buckle, thus the mill flattens the strip. A shape meter detects the strip flatness.

Particularly for high-tensile-strength materials, the appearance and flatness of the coil become worse because they are cooled rapidly on the run-out table of hot strip mill, improvement of the flatness and correction of the coil appearance are performed by Hot Skin Pass Mill.

Fluctuation of rolling force by the elongation control affects strip flatness as well. In order to compensate time delay of feedback control of shape meter, "auto bender" function performs real time control to increase or decrease roll bending force in accordance with the rolling force. This is effective to improve response speed of strip shape control (see Figure 11).

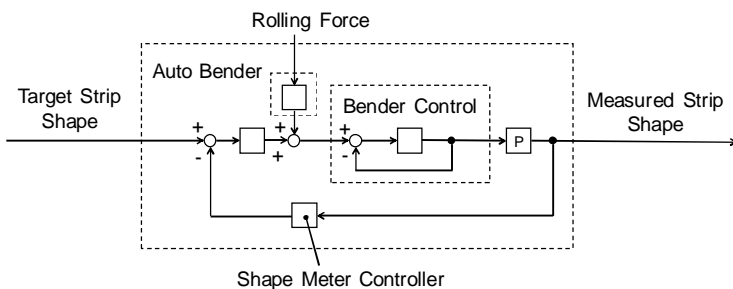


Figure 11: Strip Shape Control

As an example, when measured elongation is lower than target value, rolling force is increased automatically by the elongation control, however, as the rolling force increases, the deflection of the work rolls also increases. Therefore, reduction and elongation of strip edge portion become larger than those of center portion. This results in edge wave of the strip. On the other hand, "auto bender" which increases bending force in accordance with the increase of rolling force, enables highly accurate strip shape control (bending, tilting) with feedback data

from shape meter while keeping fast response speed. Thereby, flatness can be maintained.

5.4 Reduction of lateral strip walk

Strip tends to walk laterally on the mill line due to various factors as described below and becomes obstacle while threading, rolling and coiling:

- Camber and wedge of strip
- Appearance of rolled coil at hot strip mill
- Variation of strip deformation resistance in strip width direction
- Pinch roll pressure against strip
- Difference of rolling force between work side and drive side of the mill

In order to reduce strip lateral walk, the following countermeasures were implemented:

- Installation of hold down roll to prevent strip from lateral walking
- Implementing total rolling force control & minor position control
- Adopting rolling force and shape control while threading the leading edge of strip
- Constant Position Control of roll gap (CPC)
- Optimization of pinch roll open and close timing at threading and tail end coiling, and optimization of strip tension

Hold down roll assembly is effective to reduce lateral strip walk and to prevent strip from wrinkles caused by rolling. Hold down roll assembly consists of 5 to 6 rolls arranged right closed to Hot Skin Pass Mill at entry side.

Independent control of rolling force for mill work side and drive side respectively is known as good and stable for skin pass rolling of strip having uneven hardness, thickness and shape. However, as shown in Figure 12, when the strip walks laterally in the rolling mill, cambering of strip occurs due to increasing rolling gap on the meandering side, which leads a decrease in the rolling reduction ratio, and an increase in the backward slip, and strip lateral walk is likely to progress^[4].

"Total rolling force control & minor position control" is an effective solution of controlling the rolling force on the work side and the drive side respectively while maintaining the roll gap difference between the work side and the drive side. With this control method, the occurring of strip lateral walk described above hardly occurs.

SPCO have installed strip lateral walk control system, with optical strip side walk detector on the entry side of rolling mill, which corrects work roll gap on work side and drive side respectively in accordance with the detected amount of strip lateral walk.

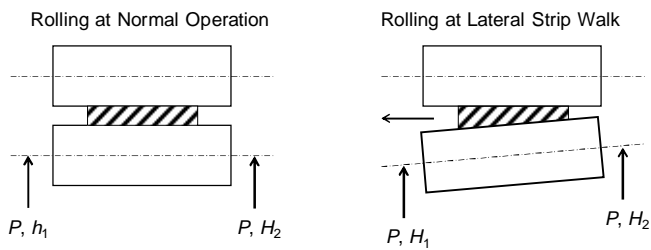


Figure 12: Example of lateral strip walk on rolling mill

5.5 Statistical Process Control (SPC)

Various data of operation and quality information from hot strip mill and HSPML are stored in SPC server as big data and those data are used for statistical control including multivariate analysis, machine set-up learning, in order to improve strip quality, line productivity, product yield, and also used for analysis of parameters which caused troubles. Thus, operational parameters are optimized.

SPCO delivered HSPML considered logging system of data such as strip thickness, width, flatness, surface defect, strip elongation, tension, rolling force etc., sampled at constant pitch on the strip, which are stored on the level 2 server that works with SPC.

6. SOLUTIONS FOR EXTREME THICK PRODUCTS

In order to meet the market demands of high-strength materials having maximum tensile strength of 1,200 MPa and maximum strip thickness of 12.7 mm, SPCO installed two lines of HSPML having maximum rolling force of 14,700 kN (1,500 tonf), maximum POR tension of 164.6 kN (16.8 tonf) and TR tension of 323 kN (33 tonf) which greatly exceeded conventional specifications.

7. CONCLUSION

In this paper, some of remarkable new technologies and functions of the latest installed HSPML were introduced. In order to meet the recent demands to process hot rolled materials of higher tensile strength with higher strip quality, the latest HSPML, as the finishing facility of hot rolled products of higher performance than conventional ones, is put into operation. This is SPCO's answer to fulfil such various demands in the market. SPCO is committed to continue to provide HSPML that responds to newer and higher demands of customers including solutions of AI and IoT.

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