

# Overview of Heat Treat Leveler for ArcelorMittal Burns Harbor

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## INTRODUCTION

JP Steel Plantech Co. (SPCO) supplied the heat treat leveler in the re-engineered heat treat line at ArcelorMittal Burns Harbor (AMBH) which was one of the most important pieces of equipment and has the widest leveling range in the world. This leveler has been in operation since April 2012. It has a wide leveling range compared to a conventional leveler, and is used on all heat treated plates produced by AMBH. To begin with, a conventional leveler cannot satisfy the leveling range required by AMBH. Next, some of the technology which has been developed in order to fulfill the required leveling range is introduced. Finally, this paper shows that the supplied leveler by SPCO has an expanded leveling range as compared to a conventional one, and has satisfied the leveling range required by AMBH.

## COMPONENTS OF THE PLATE ROLLER LEVELER

Figure 1 shows the components of plate roller leveler. It is mainly composed of 4 parts.

- 1) Upper and lower roll frame, roll unit. These are comprised of upper and lower rolls which are used for plate cyclic bending. Upper and lower roll assemblies are composed of leveling rolls (LR) and back up rolls (BUR). The former is used for working the leveling plate, the latter is support for the LR.
- 2) Upper and lower frame
- 3) Main cylinder (hydraulic drive type). Main cylinder is used to exert force on the leveling plate.
- 4) Drive unit. LR are driven by a drive unit. Generally, the drive unit is composed of motors, reducers, universal spindles.

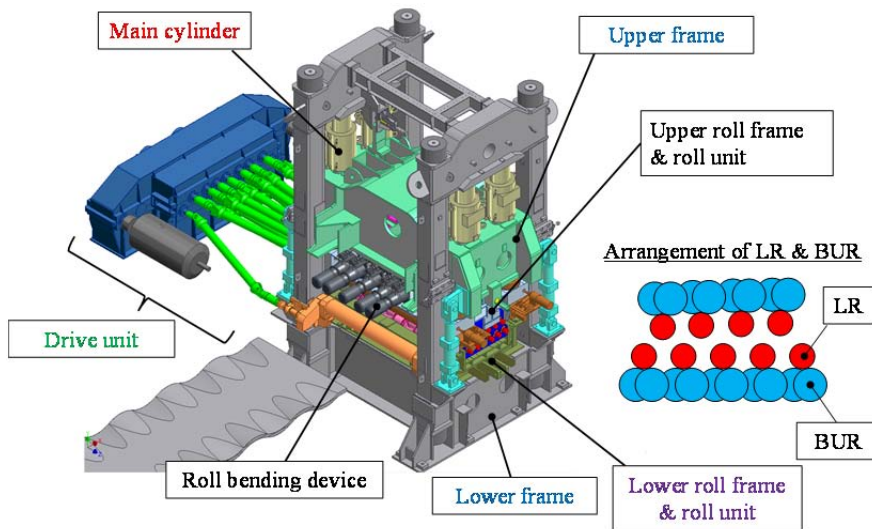


Figure 1. Components of the Plate Roller Leveler

### LEVELING RANGE OF A CONVENTIONAL LEVELER

Figure 2 shows the leveling range of required by AMBH (highlighted yellow color). Here, the vertical and horizontal axis designates leveling plate yield stress and thickness, respectively. The following items are indicated in Figure 2:

- 1) Wide leveling range from thin plate to thick plate.
- 2) Leveling requirement for Ultra high strength plate.

Figure 3 shows the leveling range of a conventional leveler which is fabricated by SPCO. This figure is called the leveling capacity diagram of plate roller leveler. Leveling capacity is determined by the following three factors:

- 1) Leveling force capacity
- 2) Universal spindle capacity (considering the drive unit, the universal spindle is limiting factor of transmitted torque).
- 3) Bending radius/intermesh limitation.

The area of the three curve intersection indicates leveling capacity. The highlighted yellow color, whose plate thickness is about 10-35mm and plate yield stress is about 200-800MPa in Figure 3, shows the leveling capacity of the conventional leveler. Here, the boundary of the thick black line shows the leveling range required by AMBH. It became obvious that conventional leveler would not meet the requirements.

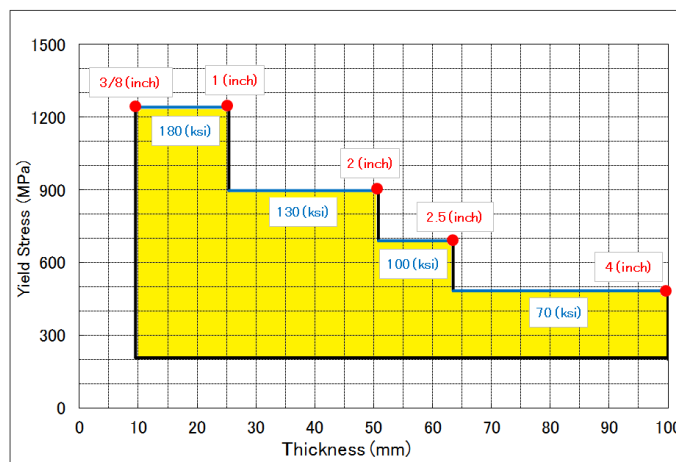


Figure 2. Leveling range required by AMBH

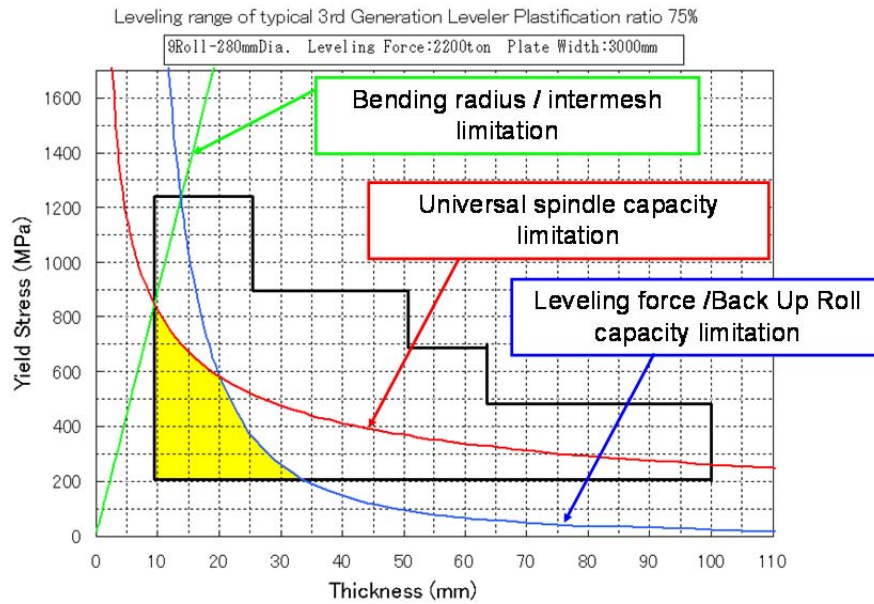


Figure 3. Leveling range of the conventional leveler

## CHALLENGE TO THE LEVELING FORCE LIMITATION

### Development of the dynamic compensation for deformation [1, 2]

SPCO has supplied plate roller levelers since 1965 in all the countries of the world. Early plate roller levelers with leveling capacities of about 2000tonf experienced deformation of the leveler itself caused by the high leveling force. As a consequence, the following two (2) problems existed:

- 1) Leveling plate is not able to meet the required bending values
- 2) Non-uniform bending strength in the direction of plate width

Therefore, the original capacity of the leveler was not able to be utilized. There are two types of deformation, vertical and lateral. Lateral deformation consists of both normal and compression deformation. Figure 4 shows the deformation of the leveler caused by the leveling force. As shown in Figure 4, the vertical deformation is transferred to the leveler housing in the vertical direction. Also, the horizontal deformation is transferred to the upper and lower frames, roll frames, and rolls in the horizontal direction. Therefore, the leveler design needed to make improvements in terms of compensation for deformation in the vertical, lateral and compression deformation areas, respectively. Table I shows the historical transition for the various forms of deformation compensation. Here, the conventional leveler written in this paper refers to a 3<sup>rd</sup> generation leveler and the AMBH leveler refers to a 4<sup>th</sup> generation leveler. Figure 5 shows the 3<sup>rd</sup> and 4<sup>th</sup> generation levelers. The most significant point between the 3<sup>rd</sup> and 4<sup>th</sup> generation leveler is the method employed for the lateral and compression deformation compensation. The former is a preset method, and the latter is a dynamic method. First, this paper describes what the preset method is, and the related issues. Next, the dynamic compensation for deformation is explained. Finally, this paper demonstrates that the 4<sup>th</sup> generation leveler has solved the above two problems and improved the leveling effectiveness.

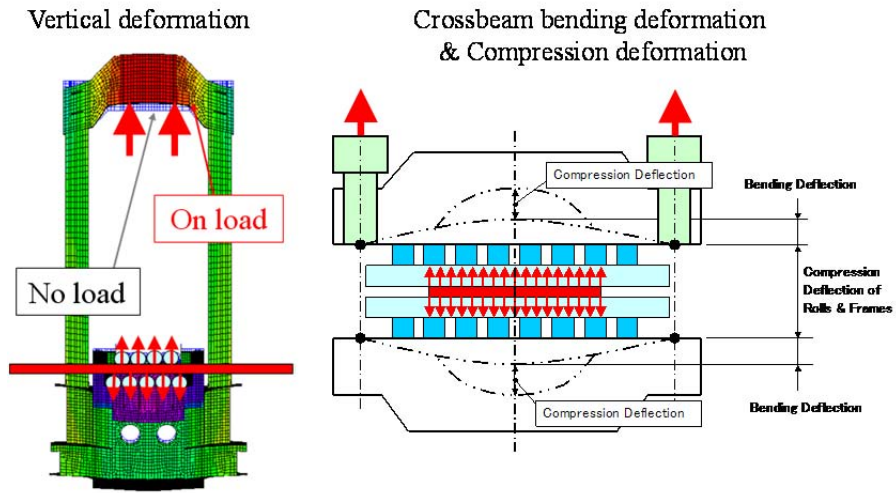


Figure 4. Deformation of the leveler caused by leveling force (conceptual diagram)

Table I. Historical transition of the deformation compensation function

Generation	Screw down	Bending system	Vertical Deformation Compensation	Lateral Deformation Compensation	Compression Deformation Compensation	Guarantee of roll gap	Year
1st	Worm&screw by motor	None	None	None	None	None	1960-1975
2nd	Worm&screw by motor	Preset bending	None	Preset Compensation	None	None	1975-1985
3rd	ARGC by Hydraulic screw down	Preset bending	Dynamic Compensation	Preset Compensation	None	None	1985-1997
4th Intelligent type	ARGC by Hydraulic screw down	Dynamic bending	Dynamic Compensation	Dynamic Compensation	Dynamic Compensation	Yes	1998-

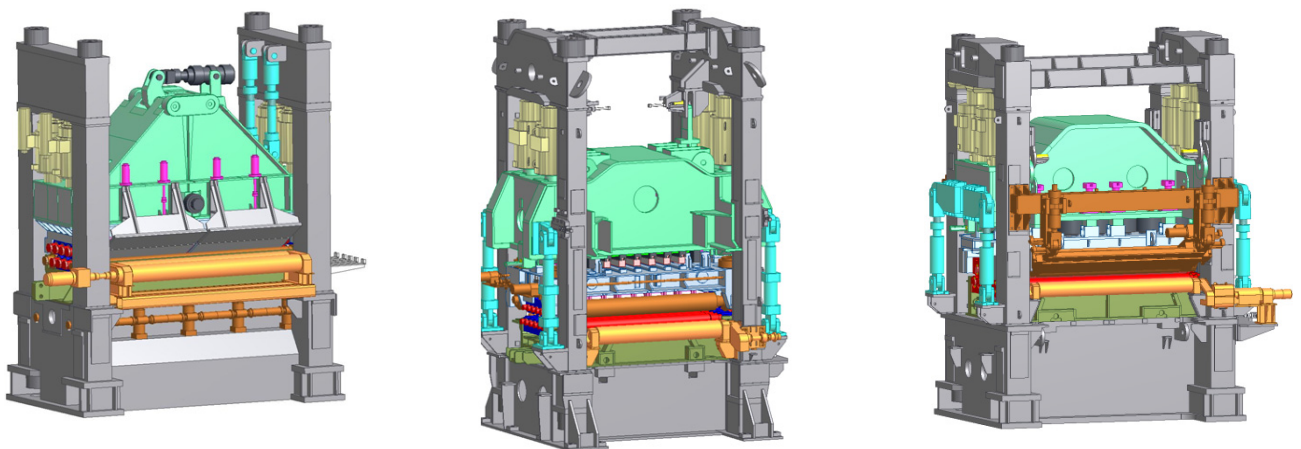


Figure 5. 3<sup>rd</sup> generation leveler (left: split frame type; middle: wedge type) and 4<sup>th</sup> generation leveler (right)

### Lateral deformation compensation of 3<sup>rd</sup> generation leveler

The 3<sup>rd</sup> generation leveler has applied the preset method for lateral deformation compensation. Figure 6 shows the procedure of this preset method. Applying this method has highlighted the following points:

Problem 1) In the case of high strength plate, the leveler is not able to accurately produce the yield stress value. In this respect, compensation of roll gap deviation cannot be complete.

Problem 2) In the case of fluctuating yield stress values (longitudinal direction), the leveling force fluctuates. However, compensation of roll bending cannot follow the fluctuating load during leveling.

Problem 3) When the plate enters and exits, the leveling force of the plate tip and tail edge changes from 0 to normal leveling forces. However, roll bending cannot follow with the leveling force change and its value is constant, on this point, it makes poor flatness at the tip and tail edge of the plate.

Problem 4) In the case of improper roll gap (width direction), some BUR will be experience an excess concentrated load. Hence, they will be damaged.

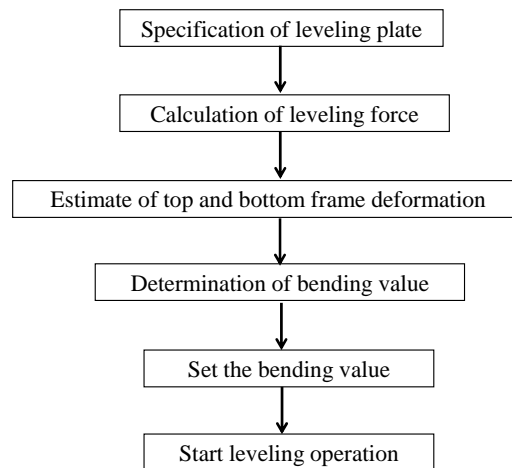


Figure 6. Procedure of preset method for lateral deformation compensation

### Lateral deformation compensation of the 4<sup>th</sup> generation leveler

The 4<sup>th</sup> generation leveler has the innovation of incorporating dynamic compensation for the deformation in order to solve the problems of the 3<sup>rd</sup> generation leveler's preset method. It is realized as follows:

- 1) Lateral deformation is compensated by the crowning cylinders which are arranged between the upper frame and the upper roll frame.
- 2) Crowning cylinders are also arranged in the direction of plate movement. They can be independently set using a crowning value on the entry and delivery sides (Figure 7).

As a result of applying dynamic compensation for the deformation, the 4<sup>th</sup> generation leveler attained the ability to keep a constant roll gap value though the leveling force changes. This ability is the greatest feature of the 4<sup>th</sup> generation leveler and solved the above four problems. Each solution is shown as follows:

Solution 1) There is no need to predict leveling forces in advance. (Problem 1)

Solution 2) If the leveling force momentarily fluctuates, the 4<sup>th</sup> generation leveler has the ability to keep the roll gap constant, therefore, it can essentially follow the fluctuation. (Problems 2, 3 and 4)

Also, the 4<sup>th</sup> generation leveler was improved over the 3<sup>rd</sup> generation leveler in terms of flatness improvement.

- 1) Flatness Improvement.

- Plate flatness was improved by applying dynamic compensation for deformation for the plate overall length and width if the leveling force was changed during operation.

- The leveler can produce flat plates up to the limitation of its capacity with improved cross bow with the necessary plastification ratio.
- Leveling force changes due to the distribution of yield stress which caused by accelerated cooling or non uniform temperature. However, roll gap value is not changed thanks to the dynamic compensation for deformation; therefore the 4<sup>th</sup> generation leveler can produce improved plate flatness over previous generation levelers.

2) Reduction of Residual Stress.

If the processed plate from accelerated cooling or quenching is cut into smaller parts, it can be deformed due to residual stress. Reduction of residual stress was improved by applying dynamic compensation for deformation for the plate overall length and width.

3) Enlargement of Leveling Force.

- The 4<sup>th</sup> generation leveler can exert larger leveling forces (max. about 10,000tonf) than a conventional one. Because of this, concentrated forces cannot be generated thanks to the dynamic compensation for the deformation.
- In the case of acting concentrated forces on the BUR, the hydraulic pressure of the crowning cylinders can be relieved and act as safety valve.

4) Improvement of Productivity.

- The 4<sup>th</sup> generation leveler has improved performance efficiency. As a result, leveling work requires only 1 pass in most cases. Also, it can be set to full automation and run completely on line.

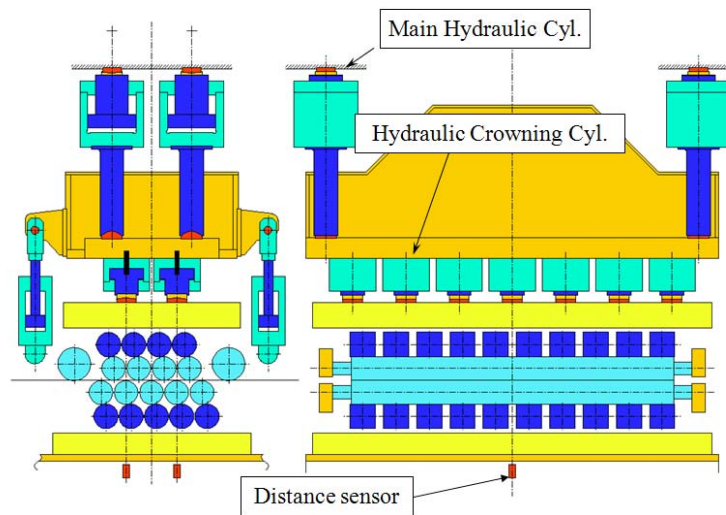


Figure 7. Lateral compensation for deformation of the 4<sup>th</sup> generation leveler

**Enlargement of BUR load capacity**

BUR support the leveling force (see Figure 1). BUR load capacity includes the bearing strength at both ends. The leveling force generated by the main cylinder can spread the load uniformly on the BUR, because dynamic compensation for the deformation was applied with the 4<sup>th</sup> generation leveler. As a result the 4<sup>th</sup> generation leveler's BUR can support a larger leveling force than the 3<sup>rd</sup> generation one, so it was extremely important to increase the capacity of the BUR load capacity. Table II shows the difference in specifications. The diameter of the 4th generation's BUR is 385mm and 3rd generation is 290mm. So, the 4th generation's is about 1.3 times larger than the 3rd generation's. The new generation BUR load capacity is 230Mton/one BUR as compared with the earlier generation design of 76Mton/one BUR. Therefore, the 4th generation leveler can allow about three times more load capacity. The reason for the increase of the BUR load capacity is that the new design BUR was changed to include the special self-aligning roller bearing from the original cylindrical roller bearing design.

### Increase of the leveling force generated by the main cylinder

The Main Cylinder output is determined by the cylinder size and the hydraulic pressure. There is a limitation of cylinder output, because of existing available components and that the maximum hydraulic pressure at 350kgf/cm<sup>2</sup>. Furthermore, it is also considered to be limited by customer specifications. Therefore, a synergistic effect of the applied compensation for deformation and the enlargement of BUR capacity breaks through the limitation of leveling force resulting in a larger than expected cylinder output enlargement effect.

Table II. The difference of the 3<sup>rd</sup> and 4<sup>th</sup> generation leveler's BUR main specification

	3 <sup>rd</sup> generation	4 <sup>th</sup> generation
Leveling Roll Dia.	280 mm	360 mm
Back Up Roll Dia.	290 mm	385 mm
Work Roll Pitch	300 mm	390 mm
BUR Bearing Form	Cylindrical roller bearing	Special self-aligning roller bearing
Parallel Rolling Force	4000 mm width 2200 Mton	4000 mm width 7700 Mton
Allowable Force	76 Mton/one BUR	230 Mton/one BUR

### Enlargement of LR Pitch (5/9 rolls retract)

There are two methods to enlarge of LR pitch: 1) 5/9 rolls cassette switching method; 2) 5/9 rolls retract method. Figure 8 shows type 1) and type 2), respectively. Features of the 5/9 rolls allow for the processing of a variety of plates with different thicknesses and yield stresses in the same machine. Therefore, it needs to take the shortest time to change 5/9 rolls. Considering this, type 1) requires about 4 hours to switch the cassette, so it isn't a practical method. As a result, SPCO has adopted type 2) for the AMBH leveler. It can be accomplished within 3 minutes for switching. Here, type 2) method has flexibility for 5LR. For example, Figure 8 shows the configuration of LR. However, roll pitch is not uniform in the configuration of LR. Therefore, leveling capacity decreases in that case compared with the constant roll pitch. SPCO designed the 5 roll leveler to be a constant roll pitch and have as large a pitch as possible (Figure 9). The AMBH leveler was satisfied with the above conditions because 2 leveling rolls were installed on the entry and delivery sides.

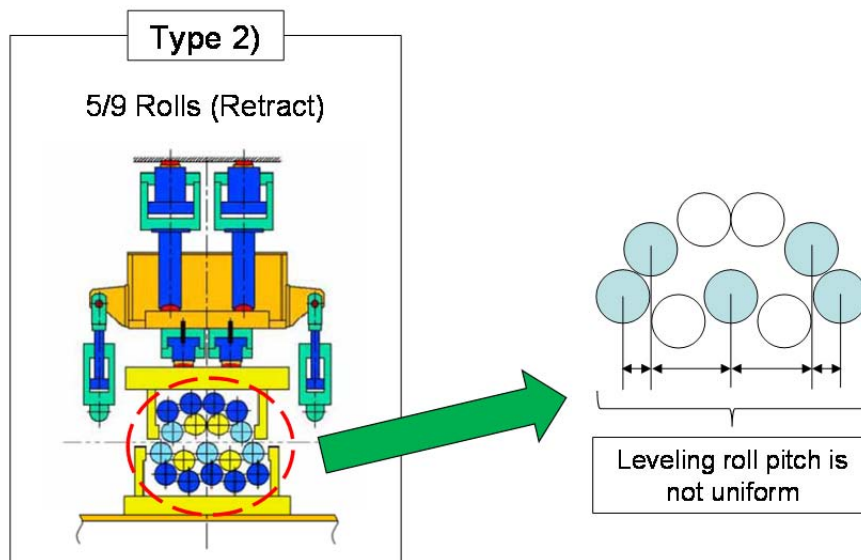
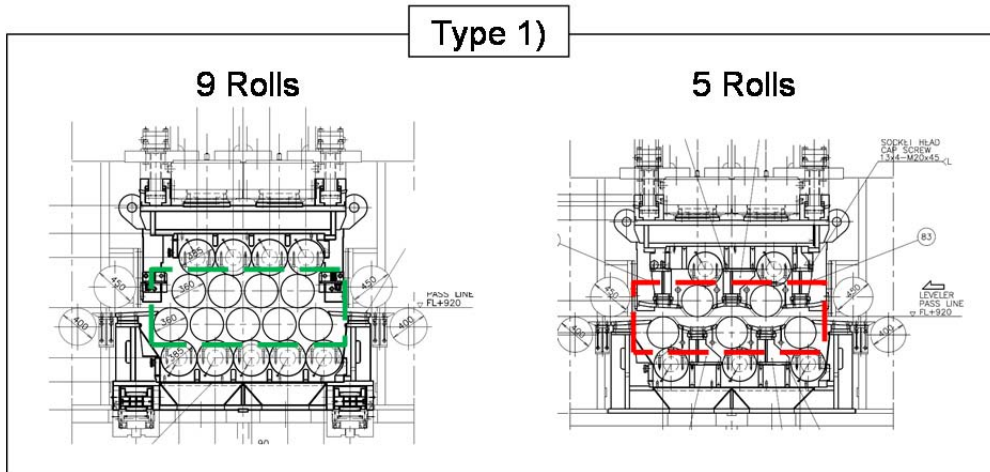


Figure 8. 5/9 rolls cassette switching (type 1) and retract method leveler (type 2)

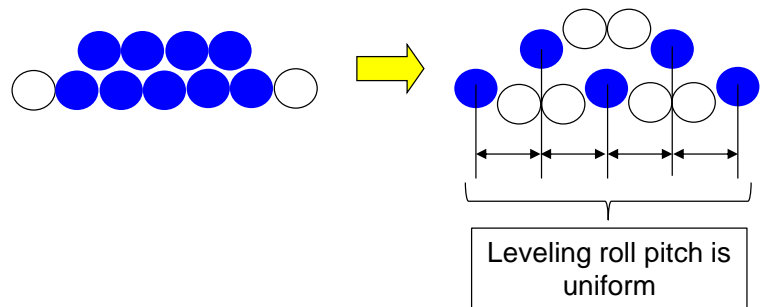
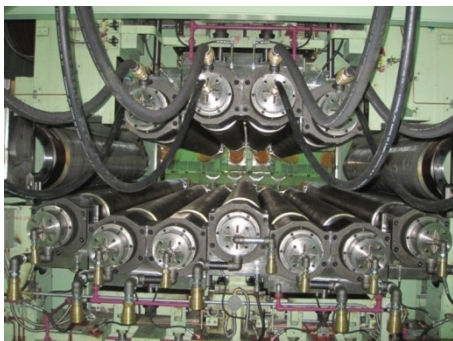


Figure 9. 5/9 rolls retract method (AMBH special specification)



## CHALLENGE TO THE TRANSMITTED TORQUE LIMITATION

In general, the leveling process has adopted the tilting leveling approach which gives strong intermesh value on the entry side and weak on the delivery side (equivalent to plate thickness). Using the above method for plate leveling, plate circumferential speed  $v_A$  (on the contact point of roll and plate at the entry side) is different from  $v_N$  (on the neutral line), however, it is approximately equal on the delivery side (see Figure 10). Therefore, the required power for driving LR on the entry side is larger than that on the delivery side. Supplied power for the driving system is only motor power and its value is constant. Therefore, extra required power needs to be supplied on the entry side from the system. In the meantime, the drive unit has adopted the common drive type or group drive type for a conventional leveler (see Figure 11 left and middle). These drive types use 1, 2 or 3 motors which drive LR and are mechanically tied by a reducer. Therefore, it is natural to consider that extra power required on the entry side will be supplied by the delivery side and power circulation will occur in the drive system. Power  $P$  can be written as  $P = T \cdot \omega = T \cdot 2\pi N$ , where  $T$ : torque for driving,  $\omega$ : angular velocity,  $N$ : LR revolution speed. Power circulation is considered the same as torque circulation because  $N$  is constant. This is called torque circulation phenomenon. Mechanical tying of the LR is the reason the torque circulation phenomenon occurs on the LR driving unit. The AMBH leveler adopted the individual drive type whereby each LR corresponds to each motor (see Figure 11 right). As a result, the torque circulation phenomenon completely disappeared because there is no mechanical tying in the driving unit.

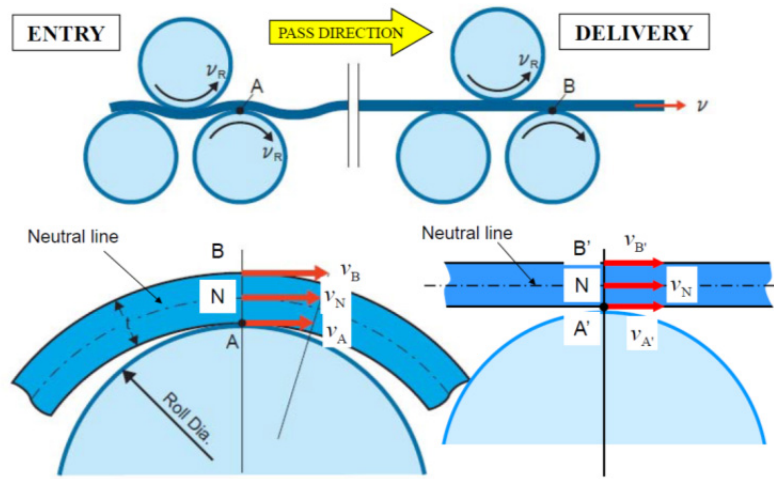


Figure 10. Leveling plate velocity on the entry side and the delivery side

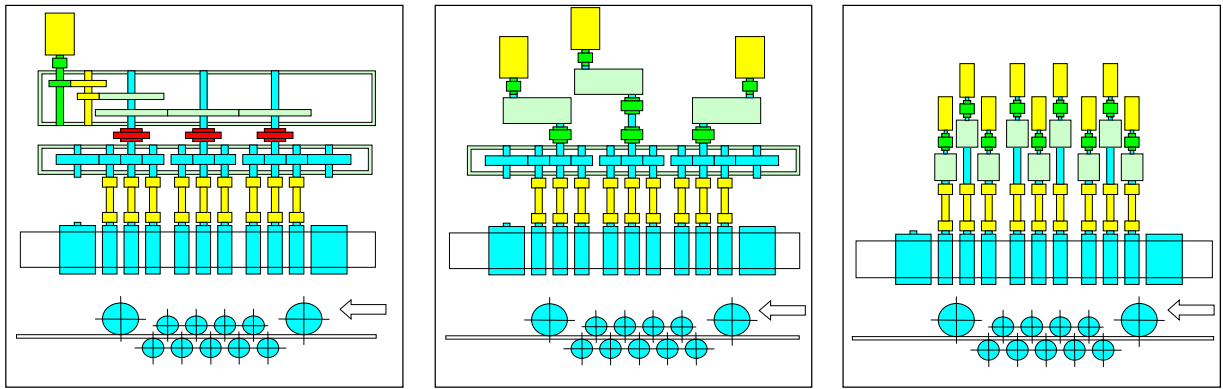


Figure 11. Transition of LR driving type (left: common drive type; middle: group drive type; and, right: individual drive type)

### ALLIGATOR BITING CONTROL

In recent years, demand has been increasing for high strength thin plate leveling, requiring a large intermesh for the LR on the entry side. For that reason, the roll gap is set small. However, the front edge of the leveling plate collides with the LR and the leveling process cannot take place in that area. As a result the plate scratches. Therefore, the AMBH leveler has adopted the alligator biting control (ABC), and it has minimized the limitation of alligator biting. Concepts of ABC are followings:

- 1) If the intermesh setting value has exceeded the limitation of biting value when the leveling plate is biting at its edge tail, the intermesh value is set such that the value doesn't exceed the limitation.
- 2) When the plate edge tail is laid at the position of "L" from No.1 roll, ABC is implemented and the intermesh adjustment velocity  $V$  is set until normal intermesh value is required.

Also, Figure 12 shows the conceptual arrangement of ABC. Adopting this control method, the leveler process can work the plate over the entire area with high strength thin plate except for the tip edge.

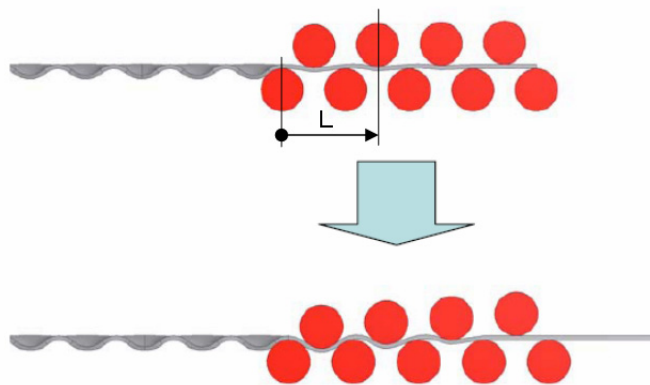


Figure 12. Concept of Alligator Biting Control

## Outline of AMBH Leveler and its Leveling Capacity

### Outline of the AMBH leveler

First, Figure 13 shows the Heat Treat Leveler for AMBH. The leveling force is 7700Mton (8500Ston), and the leveler size is 5.5m in the direction of plate movement, 6.6m in width, and 12m in height.



Figure 13. Heat treat leveler for AMBH (supplied by AMBH)

Secondly, technology challenges adopted in the AMBH leveler can be summarized as follows:

- [1] Challenge to the leveling force limitation
  - 1) Enlargement of BUR load capacity
  - 2) Development of dynamic compensation for deformation
  - 3) Enlargement of the LR pitch (5/9 rolls retract type)
- [2] Challenge to the transmitted torque limitation
  - 1) Adoption of individual drive type
- [3] Alligator Biting Control

Consequently, the AMBH leveler was engineered and manufactured with dramatically increased capacity when compared to a conventional leveler and included three (3) categories of new technologies. Figure 14 shows the leveling capacity diagram for the AMBH leveler. It should be noted that the leveling capacity was expanded by using the 5/9 LR retract technology. Specifically, using 9 rolls when the leveling plate is thin and has high yield stress and 5 rolls for heavy gauge. As a result, these technologies have more than enough capacity to cover the leveling range required by AMBH.

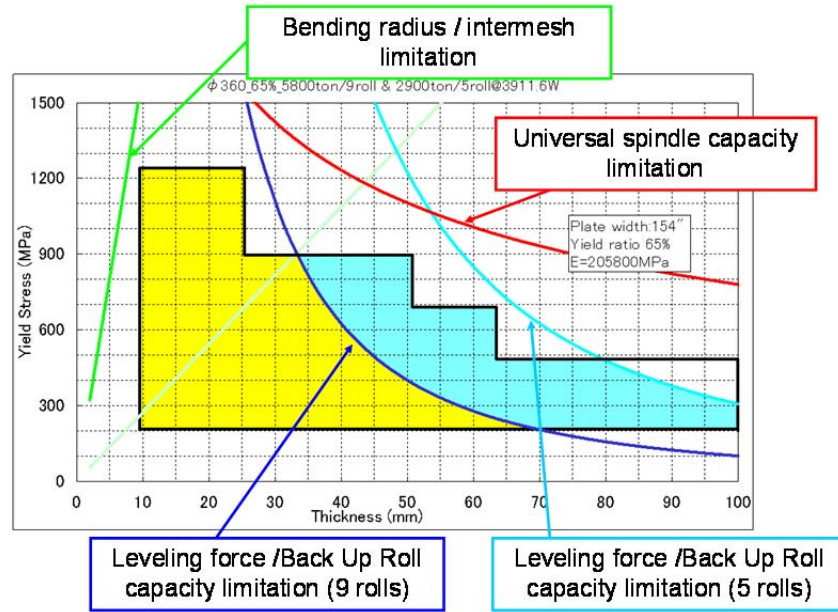


Figure 14. Leveling capacity diagram for AMBH leveler

## Leveling performance

### Effective of compensation for deformation

Figure 15[3] shows the AMBH leveler performance in which lateral compensation for deformation was implemented by the inclusion of the crowning cylinders. Specification of the test material is shown in Figure 15. According to Figure 15, in the case of no implementation of lateral compensation for deformation, the intermesh value is distributed on each measuring point for the target value. In the case of implementation, the intermesh value follows the target value.

### Improvement of flatness

SPCO was required to meet the plate flatness standard of 1/4 or less as described by ASTM Standard for Carbon Steel Plate, HSLA and Alloy Steel Plate, respectively. When SPCO performed this leveling test, the AMBH leveler achieved the plate flatness specification of 1/4 or less as described by the ASTM Standard.

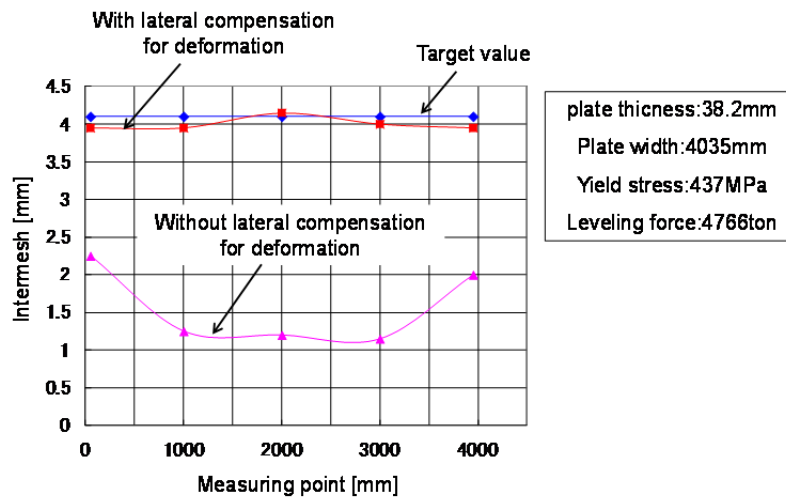


Figure 15. Performance of lateral compensation for deformation with the crowning cylinders [3]

## CONCLUSIONS

SPCO was required to design and provide equipment for leveling a wide variety of heat treated plates, meeting a high level of plate flatness by AMBH. SPCO developed and delivered the new 5/9 rolls retract type plate roller leveler for this challenging requirement. The AMBH leveler incorporated the following technologies:

- 1) Increased load capacity of the BUR
- 2) Deformation compensation technology
- 3) 5/9 rolls retract method (AMBH special specification)
- 4) LR individual drives
- 5) Alligator biting control (ABC)

Therefore, leveling force of AMBH leveler was able to be dramatically increased the leveling force compared with conventional levelers which have been used widely in the world. Furthermore, AMBH leveler can be achieved plate flatness 1/4 or less described ASTM Standard. As a result, AMBH leveler which was developed by SPCO is now essential equipment to AMBH heat treat material business. And, SPCO has contributed and will continue for their business strategy.

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