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Real Time Crossbow Measurement and Control

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The transverse curvature of a strip referred to as ‘crossbow’ has always been a factor present in the coated steel production process. Its existence at the galvanizing pot and consequence on coating control need to be managed. Many attempts have been made to reduce its effect. Using an array of sensors across a strip, strip position (passline) and strip shape can be measured just above the air knives. While the passline shift and crossbow are considered separate effects caused by properties of the substrate and pot roll configuration, they are not independent of each other. In the same way, the control of crossbow by adjusting the correcting roll affects both the passline and crossbow. The resulting strip position and curvature measurement can be fed into the coating control air knife and correcting roll positioning systems. This paper presents results from a laser strip profile and passline measurement system employed at the air knives. The use of measurements of strip shape and subsequent development of a crossbow model and control system that can be used to reduce or minimise the crossbow in the steel strip at air knives are also discussed in this paper.

Keywords: *Crossbow, Strip shape, Passline, Correcting roll, Curvature*

1. Introduction

The transverse curvature in the strip, or a strip shape effect referred to as ‘crossbow’, has always been a factor present in the coated steel production process.

The presence of some form of curvature in the steel strip is a familiar sight at all points along the traditional metallic coating line. The coating process line has evolved to cope with the strip shape effects. However, the need to guide the steel substrate around the pot rolls, coupled with the elevated temperature and tension does induce internal stresses in the strip which results in crossbow at the gas wiping region directly above the pot. Crossbow at the pot presents a serious process problem and adversely affects the coating distribution across the strip width. Further downstream of the pot, excessive crossbow can be problematic to the inline painting and induction heating sections. The term “excessive” crossbow is used to describe a curvature limit that when exceeded is great enough to cause a problem to the process line and it is a different value of curvature for each line.

The ideal coating line would be one that is equipped to actively measure and control the amount of crossbow generated in the pot area. This will improve coating distribution and reduce other disturbances downstream of the pot to an acceptable level.

Hatch has developed and supplied two generations of coating weight control systems over the past 30 years. These systems adjust the air knife position, pressure and height using a comprehensive mathematics-based model to provide both feedforward and feedback functions. These systems rely on the measurements of a coating weight gauge, which are typically over one hundred metres downstream of the pot, to provide the correction for the effects that passline and crossbow changes create. The logical progression is to measure the passline and crossbow changes directly at the pot and adjust the knife position as they occur. The next step is to go further than reacting and actively adjust the pot roll position(s) to minimise the crossbow at the pot. This paper presents the steps that Hatch has taken along this path.

2. Current Situation Without Strip Shape Measurement

The typical metallic coating line processes a steel

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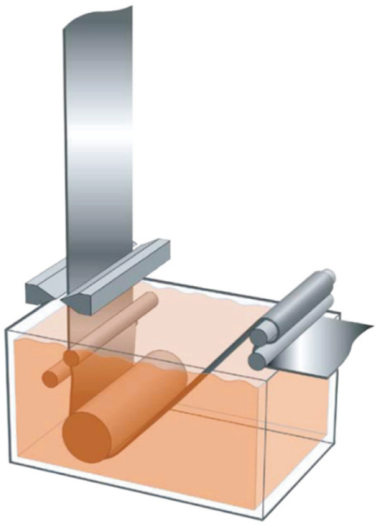

Fig. 1. Typical Three Roll Pot Configuration

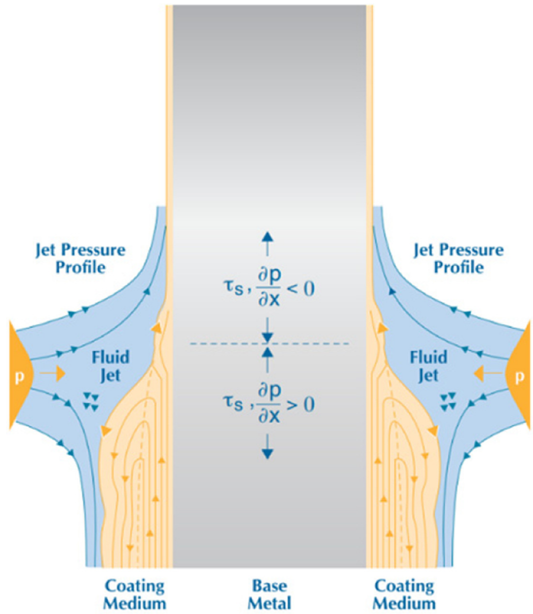

Fig. 2. Classic fluid flow model [1]

substrate that is heated and conditioned in a continuous processing furnace, then passed through a bath containing the molten metal coating. After passing around a series of submerged rolls, the strip emerges from the bath vertically passing through a pair of air knives which are used to remove excess coating. The gas wiping process utilises a high-pressure gas, typically air or nitrogen, flowing through a carefully controlled slot, which is used to create a high pressure at a point on the strip surface. This restricts the amount of liquid metal that can 'squeeze' past the air knives and returns the excess metal back into the bath.

Strip curvature creates undesirable coating affects. The concave surface will have lighter coatings on the edges compared to the centre, and the convex surface on the opposite side of the strip will have heavier coating on the edges compared to the centre. The standard Triple Spot method for classifying and selling the product is biased towards the edge coating measurements, with two edge and one centre value being used in the average coating calculation. Because of this bias, the crossbow disproportionately affects the calculated coating when comparing the two sides. Besides creating the possibility of undercoating, this is particularly important for coated product used for automotive applications, where coating variation is strictly specified and controlled.

The strip deviation from the nominal passline (i.e. the theoretical position of the strip if it were to lie flat/straight between the submerged roll and the top turn roll) at the air knife wiping zone is typically due to three main causes:

- Average offset (passline):
  Average strip displacement caused by gauge, tension and pot geometry changes.
- Curvature (crossbow):
  Transverse curvature apparent after the strip has passed through the pot rolls.
- Continuous movement (flutter):
  Fluctuating strip disturbances caused by the submerged rolls/bearings and after pot cooling.

Various methods are currently used in the industry to produce flatter and stable strip at the air knives, in an attempt to produce a more even coating distribution:

- Electromagnetic stabilizing systems:
  Electromagnetic stabilizing systems are used to mitigate both the curvature and higher frequency strip position variations. These systems can offer temporary correction of the curvature and a reduction on the higher frequency movements at the air knives, but they do not provide a permanent correction to the strip shape.
- Pneumatic stabilizing systems:
  Pneumatic floater pad systems can be mounted very close to the air wiping zone. These simple systems, such as the Air Flotation Stabilizer system, can offer

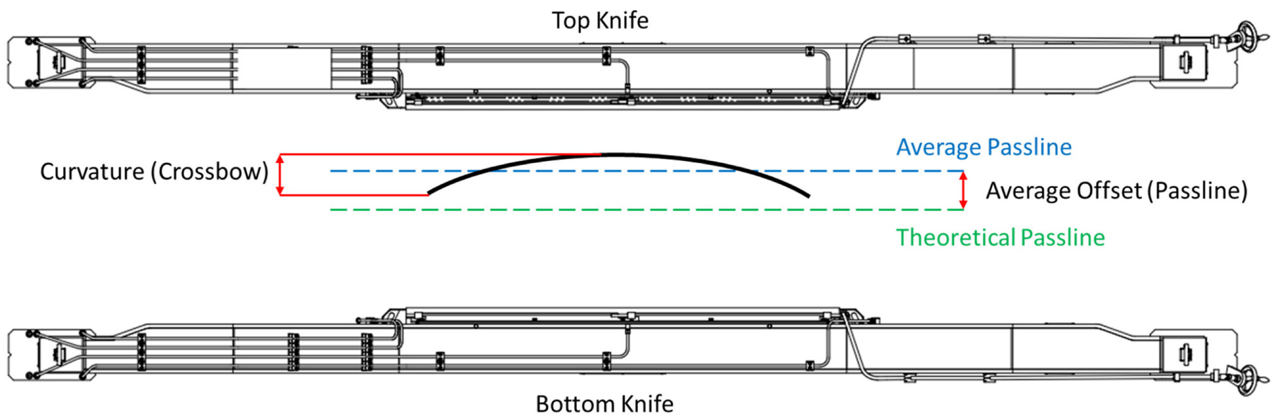

Fig. 3. Plan View of Wiping Area Showing Strip Offset and Curvature

significant benefits at a lower cost, but they do not offer as much correction control as the electromagnetic systems.

- Touch Rolls:
  Touch Rolls are used on some coating lines but are only suitable for Galvanneal products. Touch rolls can be an effective solution but are not popular with the line operation crews due to maintenance issues and other strip defects they can cause.

The use of these systems can improve the strip flatness near the air knives but does not offer permanent correction. A better solution will be to adjust the correcting roll position to yield the strip and permanently reduce the curvature of the strip before the air knives.

3. Strip Position and Shape Measurement at the Pot

In order to accurately measure the strip deviation from the nominal passline, Hatch has developed and utilized a patented laser-based sensor arrangement called the Air Knife to Strip Sensor (AKSS) [2]. It consists of an array of position sensors located across the width of the strip that can be mounted directly above the air knife. The AKSS uses these position sensors to determine the average strip position (passline), strip shape (including curvature/crossbow), and flutter in real time. The number of lasers can be customized based on the range of coil widths that are run. An increased number of lasers will provide a better resolution of the true strip shape. For wider coils, the full array of lasers will be able detect the strip, while for narrower coils only the lasers active near the centre of the air knife will be able to detect the strip. Ideally, a minimum of three lasers should be able to detect the strip at all times in order to provide some indication of strip shape and position.

The AKSS uses specialised signal processing and filtering to provide continuous strip position measurements relative to the air knife across the position sensor array with sub-millimetre accuracy. A semi-automated calibration procedure ensures that the knife to strip distances remain accurate after the initial setup and commissioning, even if adjustments are made to the air knives or the AKSS. It has been proven to work reliably on both Galvanized and Galvannealed material.

4. Passline Definition, Measurement and Control, and Its Effect on Average Coating

The effective passline and induced crossbow [3] are functions of many process parameters. The effective strip passline has proved historically difficult to predict by pure calculation. Minor corrections for changes in strip thickness can be made based on an empirical analysis of the production data. However, even this simple correction scheme will be dependent on the many variations in pot roll configurations, yield strength, strip thickness and width, and the correcting roll intermesh. While an empirical model based on strip thickness can help, it is incomplete without further tuning from a large set of data points.

If the strip is relatively flat, changes in the effective passline can be easily seen and the air knives adjusted accordingly. However, once a significant and consistent amount of crossbow is present in the product, then there is no obvious definition for the effective passline because the strip does not remain flat. In general, the effective passline has been described as the midpoint between the two air knives when producing the same target coating weight on both the top and bottom surfaces of the strip. The coating weight controller moves the top and bottom air knives to provide the requisite coating on each side of the strip.

Prior to producing a passline control, the actual passline didn't need a specific definition. It is normally found somewhere between the air knives, hopefully at the midpoint between the air knives.

The Triple Spot average and scan average are the industry standard methods for classifying the coating thickness on products. Compared to the Triple Spot average, the more representative Four Spot calculation goes one step further in providing a value closer to the true average coating on the product due to the biasing mentioned previously. In this paper we will use the Four Spot average as a proxy for the true scan average. Fig. 4 explains the difference in calculating the Triple Spot and Four Spot averages.

Taking the above example of a coated product with crossbow effects (Fig. 6), the Triple Spot average is 100 g/m2 on both top and bottom surfaces, however the more representative Four Spot evaluation method shows a 10% difference between the top surface compared to the bottom. It is noted that the Triple Spot and Four Spot results are the same for the flat strip case (Fig. 5). The presence of the coating distribution caused by crossbow creates the divergence between the Triple Spot and Four Spot data. Using these two methods of calculating coating weight, the calculated passline (the position that would provide a balanced coating on both surfaces) is different.

We can define the actual passline as the position of the strip that would provide the same calculated coating on both the top and bottom surfaces. When calculating the passline as a control variable, the method of classifying the coating for the sale of the product needs to be considered. When crossbow is detected, the individual

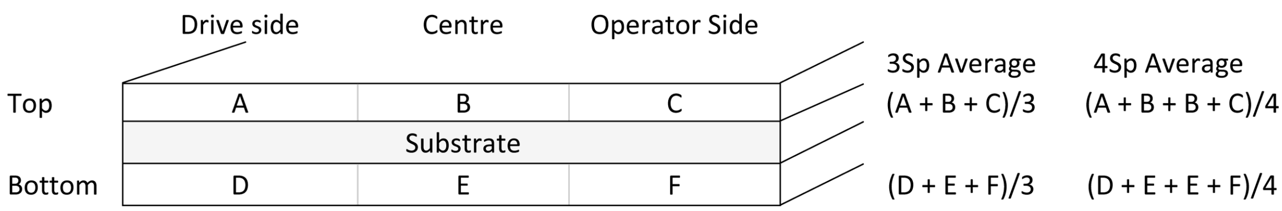

Fig. 4. Method for calculating the Triple Spot and Four Spot coating averages

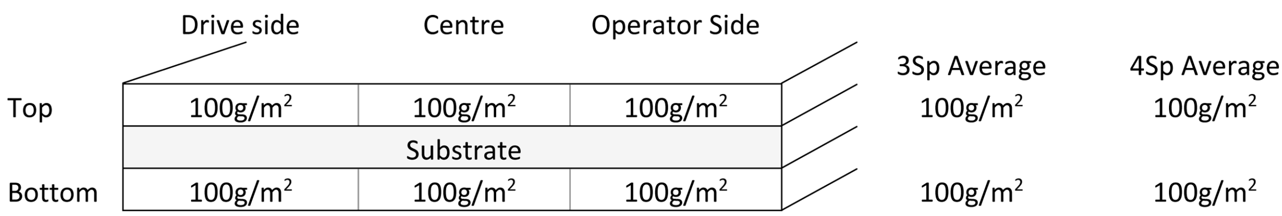

Fig. 5. Ideal coating distribution for flat strip

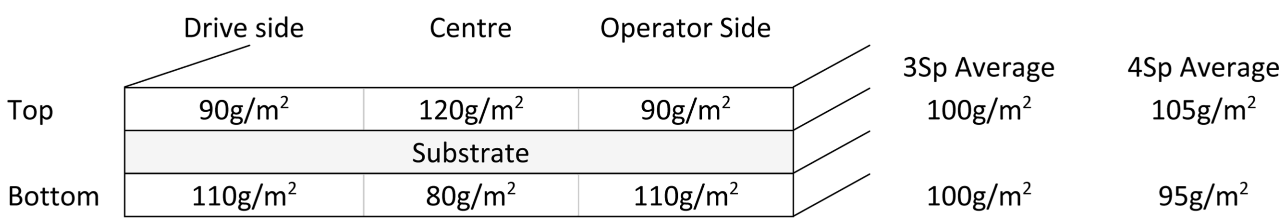

Fig. 6. Example of uneven coating distribution caused by crossbow and the relative Triple and Four Spot average coating thickness

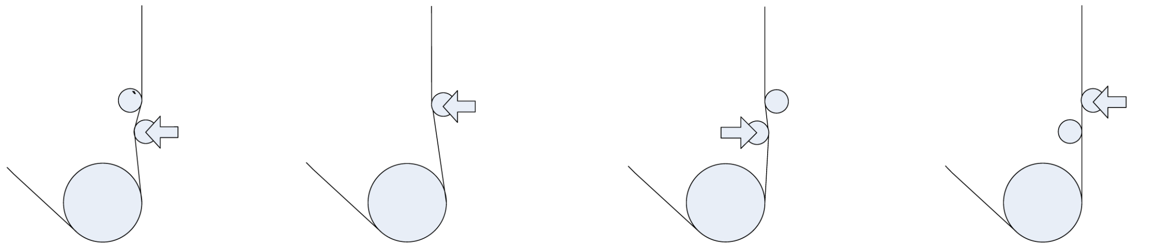

Fig. 7. Pot Roll Configurations included in the Crossbow Model

strip position measurements and the calculated passline need to consider the type of coating evaluation method being used.

In summary, if the coating line is selling products based on the Triple Spot measurement, then the strip passline calculated using the average of three points three spot is acceptable. If the line is selling from scan average, then the Four Spot calculation for the distance measurement needs to be used.

5. Crossbow Modelling and Control

While the passline shift and crossbow are considered separate effects caused by properties of the substrate, process characteristics and pot roll configuration, they are not independent of each other. The same is true for the control of the crossbow. Most pots have a movable correcting roll, usually the second roll in both a three-roll pot and a two-roll pot configuration. Changing the position of this roll will cause a minor change in the passline in the case of the three-roll pot and a major change in the case of the two-roll pot. In creating a crossbow control system that will change the strip curvature by changing the correcting roll position, measuring the change in passline in real-time is desirable.

Accepting that requirement, the crossbow controller is free to use the full range of correcting roll movement (intermesh). In practice, the range of intermesh is limited by the need to keep the roll turning and also not to overload the mounting arms, beam and bases.

Hatch has developed a mathematical model that is used to calculate the accumulated internal stresses in the steel substrate and the resulting crossbow. It can be used for any pot roll configuration, with the option to include the final rolls in the furnace prior to the pot rolls. There are four main configurations currently programmed into the model, illustrated in Fig. 7.

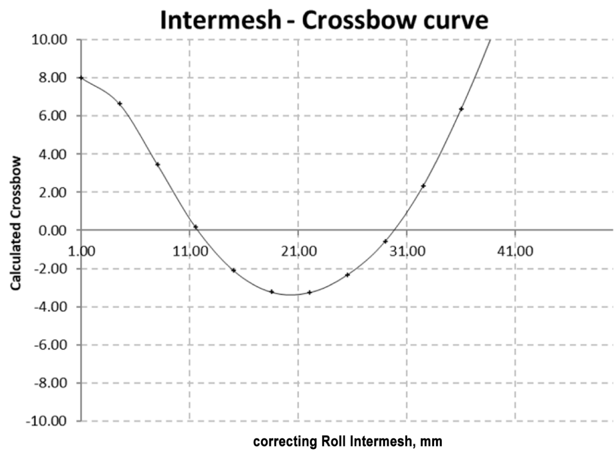

Fig. 8. Crossbow result for a Correcting Roll Intermesh

The crossbow calculation uses the roll diameters and distances between the rolls to determine the resulting wrap angles and the maximum curvature (minimum bend radius) around each roll.

Using the 'Common 3 roll' pot equipment configuration and the roll parameters described below, the strip stress model can be used to determine the resultant stress and deflection profiles for various values of roll intermesh. Consider the following geometry:

Sink Roll Diameter: 600 mm
Correcting Roll 1 Diameter: 200 mm
Correcting Roll 2 Diameter: 200 mm
Sink Roll to Correcting Roll 1 height: 400 mm
Correcting Roll 1 to Correcting Roll 2 height: 200 mm
Strip Width: 1000 mm
Strip Thickness: 2 mm
Strip Strength: 300 MPa (cold value)
Pot temperature: 460 ºC

The basic information above gives the crossbow verses intermesh curve shown in Fig. 8.

The point where the results intercept the zero crossbow axis is usually referred to as a ‘neutral point’ – the point where the strip does not exhibit either a convex or a concave curvature.

Based on the roll configuration, the crossbow curve for a range of correcting roll intermeshes has two neutral points. Looking at the progression of the strip stresses, the strip exiting from Correcting Roll 2 has a net zero moment weighted stress result. From the results, the first neutral point occurs at 11.70 mm and the second at 29.85 mm of intermesh. Although there are internal stresses present within the strip at these neutral points, they should produce a nominally flat strip at these intermesh values. The following stress curves are obtained for the stresses in the x (lengthwise) and y (transverse) directions.

The first neutral point at 11.7 mm of intermesh produces minimal crossbow in the strip (Fig. 8), but with less stress in the length wise direction (Fig. 9) than the second neutral

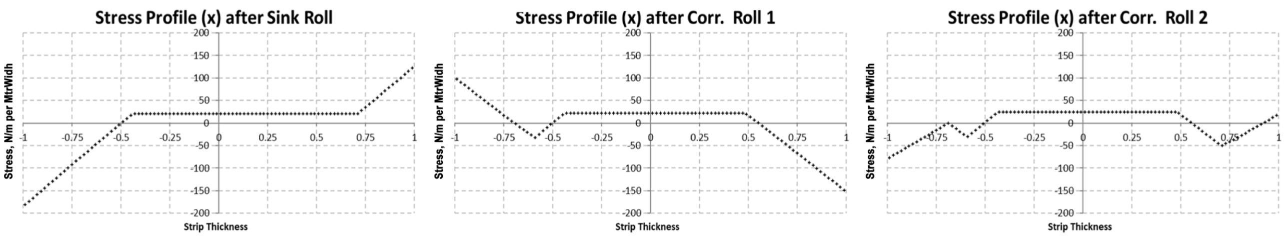

Fig. 9. Stress Profile in the length based direction (x) Intermesh = 11.70 mm

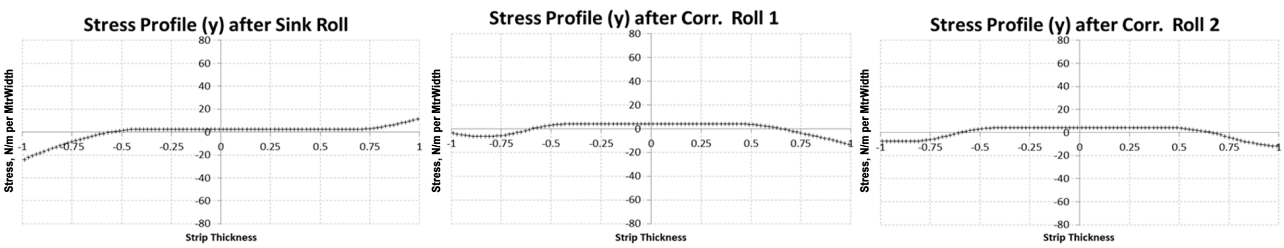

Fig. 10. Stress Profile in the transverse direction (y) Intermesh = 11.70 mm

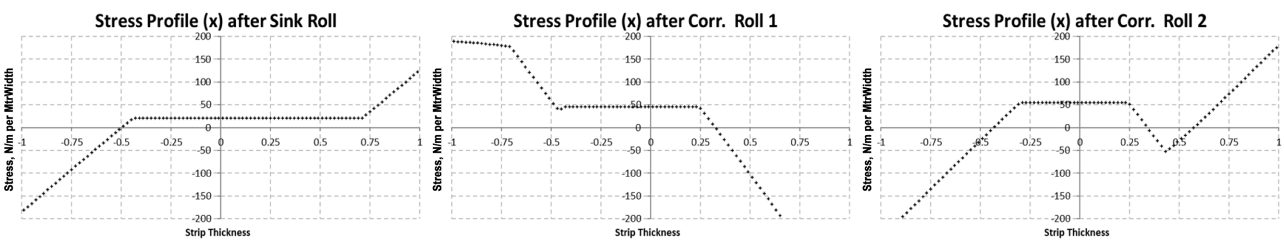

Fig. 11. Stress Profile in the length based direction (x) Intermesh = 29.85 mm

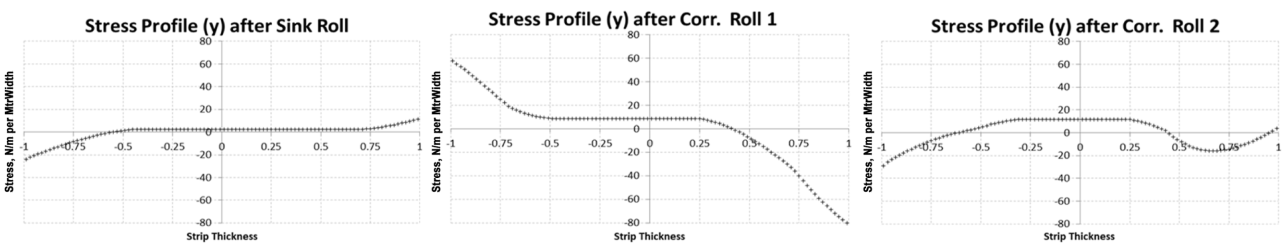

Fig. 12. Stress Profile in the transverse direction (y) Intermesh = 29.85 mm

point, so this may be a preferential intermesh value.

The second neutral point at 29.85 mm of intermesh produces minimal (Fig. 8) crossbow in the strip, but with greater stress in the length wise direction (Fig. 11) so may not be the best result. Importantly, flat strip will not be stress-free but the sum of the transverse stresses will be close to zero.

While the second neutral point with the greater intermesh will give strip with little crossbow, which is desirable from a coating distribution perspective, the length wise stress profile is much greater and may display coil set when the tension is released.

6. Crossbow and Passline Measurement

As described in Section 2, the Hatch AKSS [4] uses an array of sensors that can be used to measure crossbow and passline. The AKSS is mounted on the air knife beam, which supports the air knife body below. The position of the air knife carrying the AKSS is altered by the coating control system, however the position of the air knife beam is known. Therefore, the air knife to strip measurement can be corrected for the air knife movement. Using this technique, the absolute position of the strip passline can be determined.

The operator display for Hatch's AKSS system (Fig. 13) provides a clear display of the strip shape and the position of the strip relative to the two air knives and provides the basis for the Crossbow control system feedback. The display also provides condition monitoring for the laser temperatures and alarms.

Much of the strip shape is consistent through the body of the coil. However, as the welds pass the pot, some of the product shows a significant flattening at the weld with the crossbow returning immediately afterwards. Fig. 14 provides strip shape measurements taken from a project site that is in steady state operation over a period of approximately two hours and demonstrates the change in strip shape as the weld passes the pot. This example clearly shows the change in crossbow at the welds and the subsequent effects of correcting roll adjustments.

The change in crossbow at strip locations A and B can be attributed to the change in the correcting roll position, as illustrated in Fig.s 15 and 16. A relatively small change in correcting roll position, of 1.9 mm and 2 mm respectively, produced an immediate change in the measured crossbow.

The changes in strip shape presented in Fig. 14, Fig 15 and Fig. 16 indicate changes in the strip properties at the beginning and end of the coils. In reviewing the strip

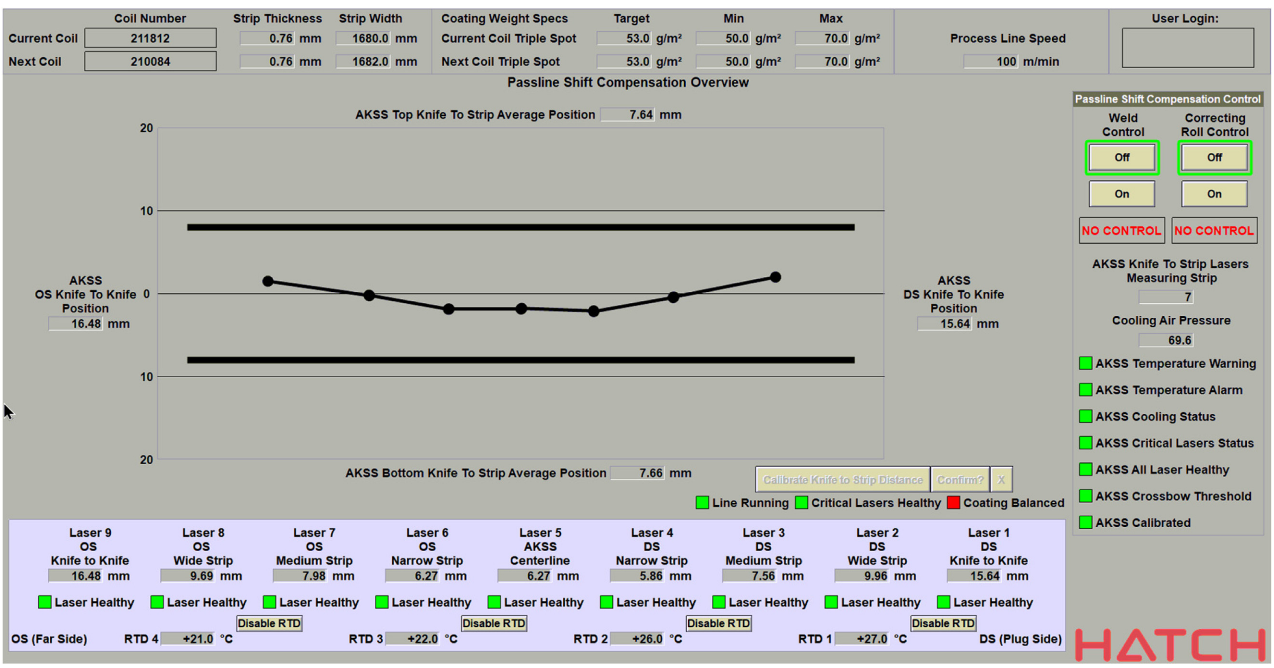

Fig. 13. Strip Shape Measurement Screen

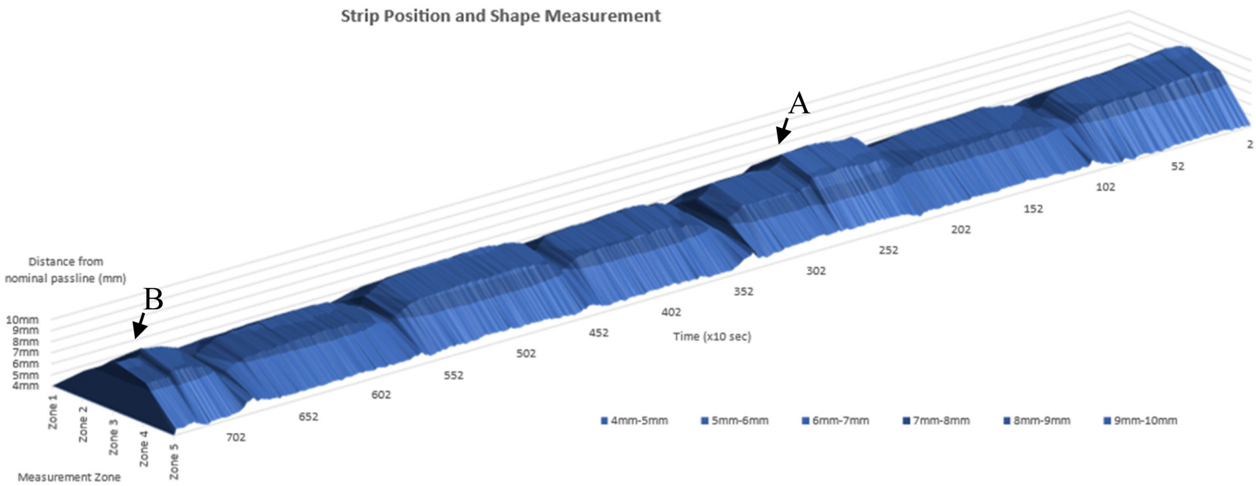

Fig. 14. Plot of the crossbow measurements over two hours of production

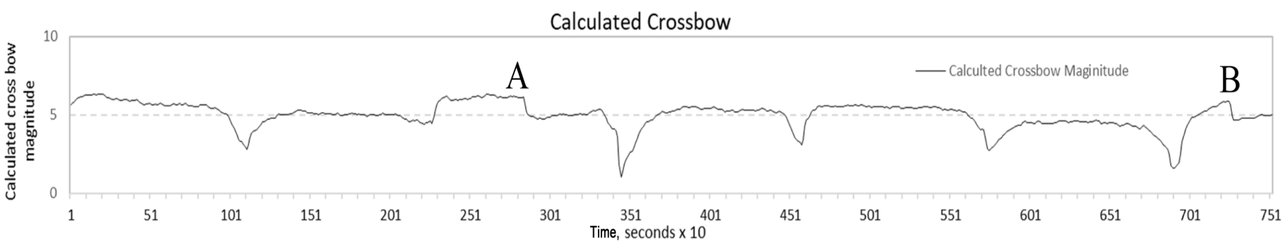

Fig. 15. Measured Crossbow (AKSS Data)

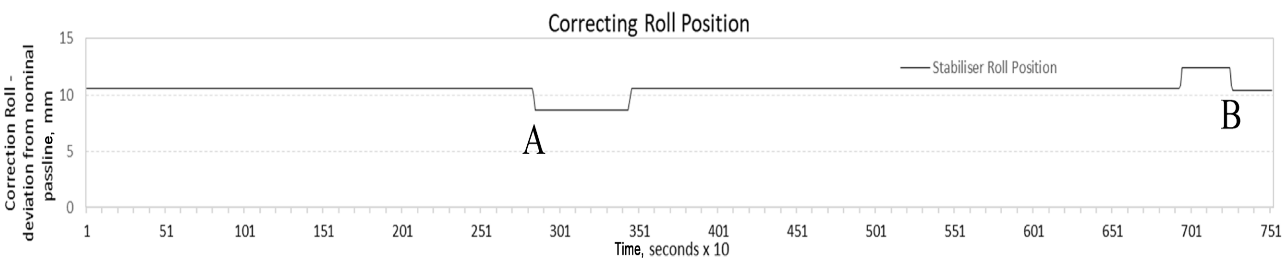

Fig. 16. Correcting Roll Position

shape recorded in Fig. 14, since the process parameters, strip thickness, grade and tension are constant for the coils, then a difference in yield strength of the material is one possible source of the change in strip shape at the welds.

On critical products with a yield strength specification, the measured strip shape could be indicative of product that may need further testing before releasing for sale. Measured strip shape information can be used to improve the upstream processes to identify and eliminate the production of steels with variable yield strength values at the extreme ends of the coil.

7. Conclusion

The change in the strip stress as it passes through the pot rolls has been a factor in the metal coating progress since the continuous galvanizing process started. The many factors that affect the magnitude and direction of the crossbow complicates the operator gaining an empirical understanding of the cause and effect. This complex problem surrounding strip shape presents an ideal application for mathematical models to assist with the estimate and control of this effect.

The development and implementation of a strip position and shape measurement system such as the AKSS opens the possibility of implementing an online real time control of the pot rolls to minimize the occurrence of crossbow at the air knives. There are other potential benefits from real time strip shape measurement at the air knives.

With the development of highspeed PLC platforms now available, crossbow or strip shape control will become an important new tool to provide an ongoing path to the continuous improvement in the quality of metal coated product.

Acknowledgement

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