Managing the Effects of Passline and Strip Shape on Metal Coatings



The use of automated coating control systems is commonplace in modern galvanizing lines. However, the increased need for higher-strength steels has required steel coil producers to adapt their processes and equipment to produce wider ranges of material properties and gauges. This shift has resulted in difficulties in the coating control process that producers have had to overcome — strip passline changes and shape effects. This article presents the direction of technology developments that Hatch has undertaken to address these difficulties: a laser-based strip position measurement system, and a control system to actively mitigate transverse curvature in the strip (crossbow).

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Introduction

The presence of curvature in the steel strip is a familiar sight along traditional metallic coating process lines, which have had to evolve to cope with these strip shape effects. Excessive crossbow at the pot presents a serious process problem that adversely affects the coating distribution across the strip width and can also be problematic to the in-line 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 in the process line. The limit for "excessive curvature" will be a different value for each coating line.

The ideal coating line would be one that is equipped to actively calculate, 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.

The limitation for current coating control systems in the industry is a reliance on the measurements of a coating weight gauge, which are typically over 100 m downstream of the pot, to provide any air knife corrections for the effects that passline and crossbow changes can create. The logical progression for such control systems is to measure the passline and crossbow changes directly at the pot and adjust the knife positions as they occur. The next step is to go beyond the current reactive approach and actively adjust the pot roll position(s) to minimize the crossbow at the pot. This article presents the steps that Hatch has taken in the evolution of their coating weight control system.

Discussion

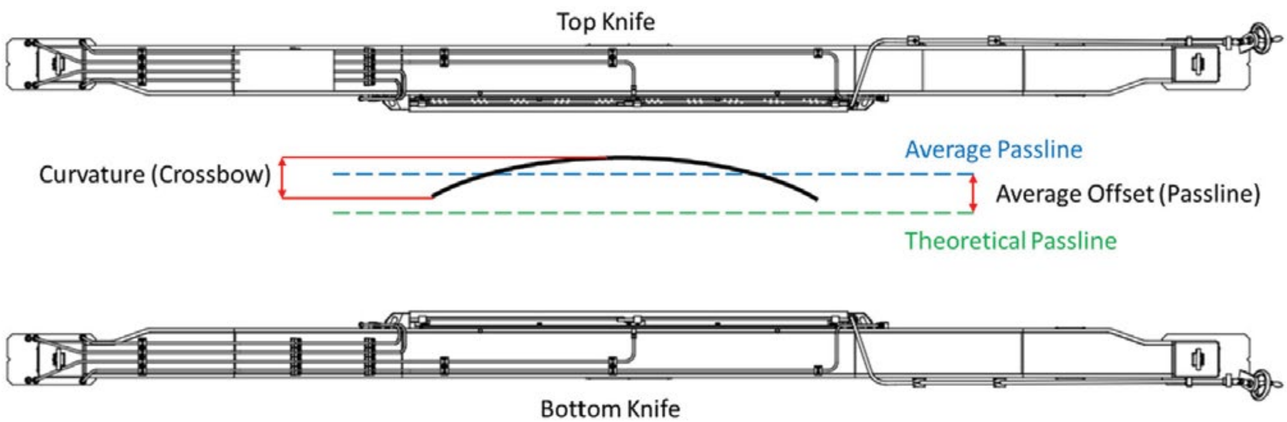
Current Situation Without Strip Shape Measurement

Strip curvature creates undesirable coating effects. The standard Triple Spot method for classifying and selling coated product is biased toward the edge coating measurements, with the two edge and one center value being used in the average coating calculation. Because of this bias, any crossbow disproportionately affects the calculated coating when comparing the two sides. This is particularly important for coated product used for automotive applications, where coating variation is strictly specified and controlled.

The strip deviation from the theoretical passline (i.e., the intended

Figure 1

Plan view of wiping area showing strip offset and curvature.



position of the strip if it were to lie flat/straight between the last 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 from theoretical passline, which can be 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/vibration):
  - Fluctuating strip position, typically caused by disturbances from the submerged rolls/bearings and after pot cooling.

The continuous metal coating industry employs various systems to produce flatter and stable strips at the air knives, which is financially justifiable if they can produce a more even coating distribution:

- Electromagnetic stabilizing systems:
  - Utilized to mitigate both the curvature and higher frequency strip position variations. Although these systems can offer temporary correction of the strip curvature and a reduction on the higher frequency movements at the air knives, they do not provide a permanent correction to the strip shape.
- Pneumatic stabilizing systems:
  - Simple pneumatic floater pad systems, such as the air flotation stabilizer system, can be mounted very close to the air wiping zone to offer benefits at a lower cost.[1] However, they do not offer as much correction control as the electromagnetic systems and are only effective for thinner-gauge lines.
- Touch rolls:
  - Water-cooled touch rolls are used on some coating lines to reduce strip shape effects and movement but are only suitable for galvanneal products. Touch rolls can be an effective solution but are not popular with the line operators due to maintenance issues, zinc dust generation and other strip defects they can cause.

Although these systems can improve the strip flatness near the air knives, none offer permanent correction of the strip shape.

Strip Position and Shape Measurement at the Pot

Hatch has commercialized a patented laser-based sensor arrangement called the Air Knife to Strip Sensor (AKSS). Typically mounted directly above the air knife, the AKSS consists of an array of position sensors located across the width of the strip. The AKSS can 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 on the line. Increasing the number of lasers will provide a better resolution of the true strip shape. For wider coils, the full array of lasers will be able to detect the strip, while for narrower coils only the lasers active within the strip width will be able to detect the strip.

Using specialized signal processing and filtering, the AKSS can provide continuous strip position measurements relative to the air knife across the position sensor array with submillimeter accuracy. A semiautomated calibration procedure is utilized to ensure that the knife to strip distance measurements remain accurate, even if adjustments are made to the air knives or the AKSS after initial setup and commissioning. The AKSS has been proven to provide reliable measurements on a wide range of galvanized and galvannealed material.

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

Prior to producing a dedicated passline control, the actual passline needs to be defined.

The Triple Spot average and scan average are the most common methods for classifying the coating thickness on products. Compared to the Triple Spot average, a 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 of the Triple Spot average mentioned previously.

This article will use the Four Spot average as a proxy for the true scan average. Fig. 2 explains the difference in calculating the Triple Spot and Four Spot average coating thickness.

Using the example of a coated strip produced with crossbow effects shown in Fig. 4, the average coating based on the Triple Spot method is 0.3 oz/ft^2 on both top and bottom surfaces. Alternatively, the Four Spot evaluation method shows ~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. 3). The presence of the uneven coating distribution caused by crossbow creates the divergence between the Triple Spot and Four Spot data. Note that when using these two methods of evaluating coating

Figure 2

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

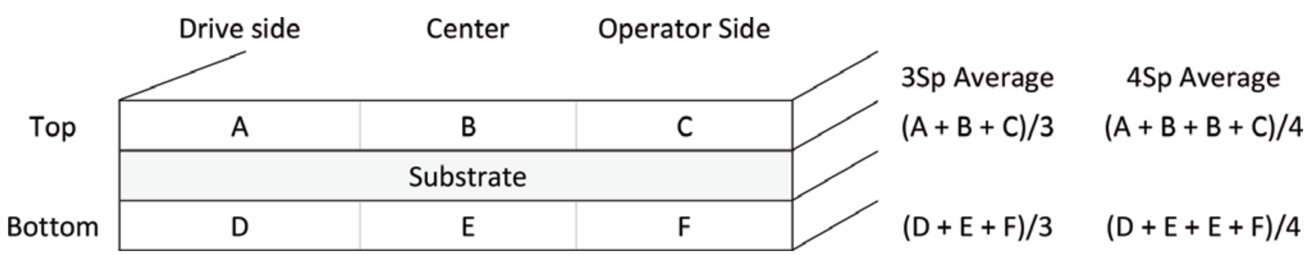


Figure 3

Ideal coating distribution for flat strip.

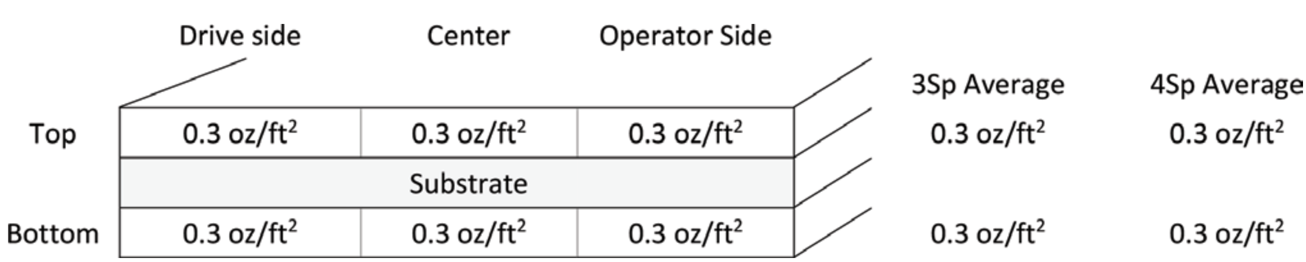


Figure 4

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

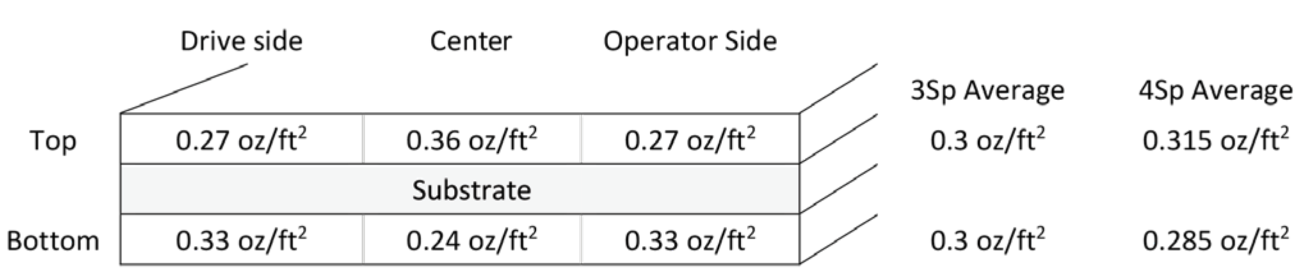
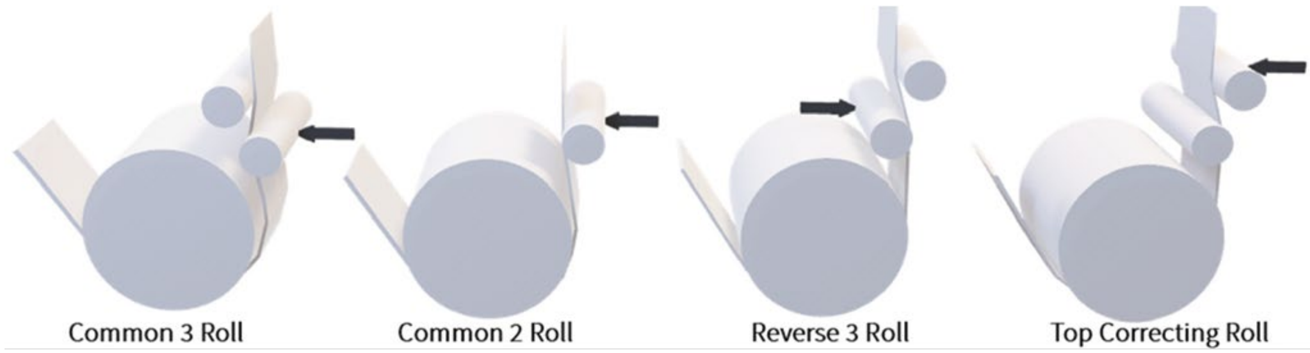


Figure 5

Pot roll configurations and correcting roll adjustments included in the Crossbow Model.



weight, the calculated passline (the position that would provide a balanced coating on both surfaces) is different.

Proposed Definition for the "Passline"

The actual passline is defined 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, if crossbow is detected, the individual strip position measurements and the calculated passline need to consider the type of coating evaluation method being used.

If the coating line is selling products based on the Triple Spot measurement, then the strip passline calculated using the average of the Triple Spot is acceptable. If the line is selling from scan average, then the Four Spot calculation for the passline calculate needs to be used.

Crossbow Modelling and Control

In creating an active 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 this requirement, a crossbow controller is free to use the full range of correcting roll movement (intermesh). However, in practice, the range of intermesh is limited by the need to keep the correcting roll turning and prevent overloading the mounting arms, beam and bases.

Hatch has developed a mathematical model to calculate the accumulated internal stresses in the steel substrate and the resulting crossbow as it progresses through the various stages of the submerged rolls. It can be used for any pot roll configuration. The four main pot configurations currently considered in the model are shown in Fig. 5.

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

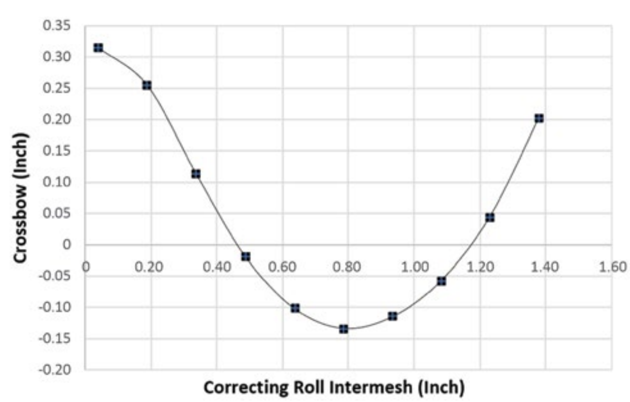
Using the "Common 3 Roll" pot equipment configuration shown in Fig. 5 and the roll parameters and geometry below, the strip stress model can be used to determine the resultant stress and deflection profiles for various values of roll intermesh:

Sink roll diameter	23.62 inches (600 mm)
Correcting roll 1 diameter	7.87 inches (200 mm)
Correcting roll 2 diameter	7.87 inches (200 mm)
Sink roll to correcting roll 1 height	15.75 inches (400 mm)
Correcting roll 1 to correcting roll 2 height	7.87 inches (200 mm)
Strip width	39.37 inches (1,000 mm)
Strip thickness	0.079 inch (2 mm)
Strip yield strength	43.5 ksi (300 MPa) [cold value]
Pot temperature	860°F (460°C)

The resulting crossbow versus intermesh curve is shown in Fig. 6.

Figure 6

Crossbow result for a Correcting Roll Intermesh.



The points where the results intercept the zero-crossbow axis are often referred to as "neutral points." Based on the proposed roll configuration described previously, the crossbow curve for a range of correcting roll intermeshes has two neutral points — intermesh values where the strip does not exhibit either a convex or a concave curvature. The first neutral point occurs at 0.46 inch and the second at 1.18 inches of intermesh. Although there are significant internal stresses present within the strip at these neutral points, these intermesh values should produce a nominally flat strip.

To calculate the resulting crossbow, the model determines the internal strip stresses after passing each submerged roll and provides the final stress state after passing through the pot for the range of intermesh values. Refer to Fig. 7 for the definitions of the stresses that are calculated. Fig. 8–11 present the stress curves that are obtained for the stresses in the Y (lengthwise) and X (transverse) directions at both neutral points.* Note that the stresses are the bulk stress through the strip width, and do not include edge effects.

Looking closer at the internal strip stresses for the two neutral points shown in Fig. 6, the first neutral point of intermesh produces minimal crossbow in the strip, but with less stress in the lengthwise direction (Fig. 8) than the second neutral point, so this may be a preferential intermesh value. Importantly, flat strip will not be stress-free, but the sum of the transverse stresses will be close to zero.

Although the second neutral point with the greater intermesh will still result in strip with little crossbow,

*The horizontal axes of the graphs in Fig. 8–11 denote the position through the thickness of the strip; the vertical axes display the stress at each calculated position. For the horizontal axes, 0% is the side of the strip that is in contact with the sink roll and 100% is opposite side of the strip.

Figure 7

Axes definition for stress profile graphs.

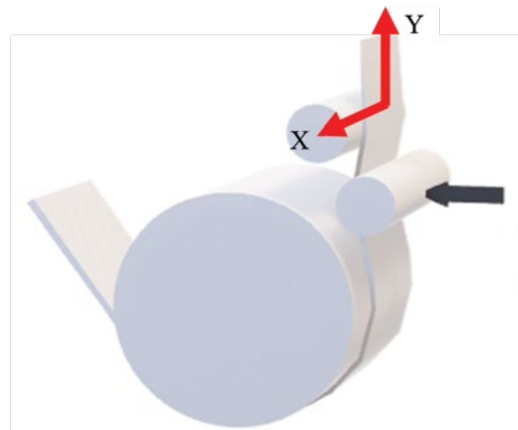


Figure 8

Stress profile in the lengthwise direction (Y) at correcting roll intermesh = 0.46 inch.

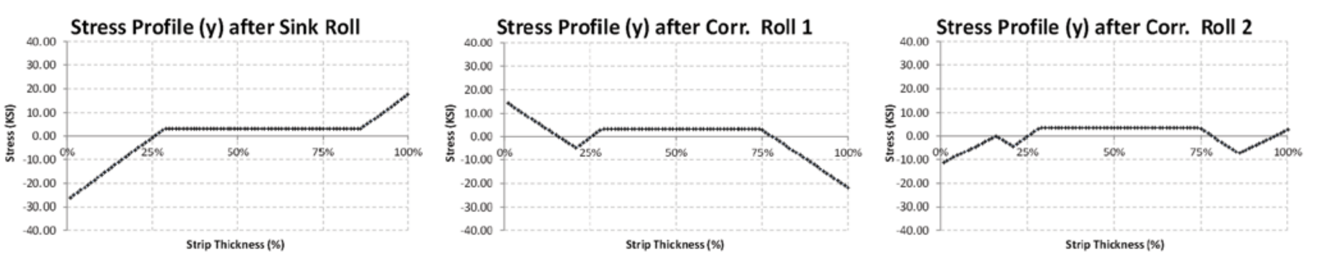


Figure 9

Stress profile in the transverse direction (X) at correcting roll intermesh = 0.46 inch.

Figure 10

Stress profile in the lengthwise direction (Y) at correcting roll intermesh = 1.18 inches.

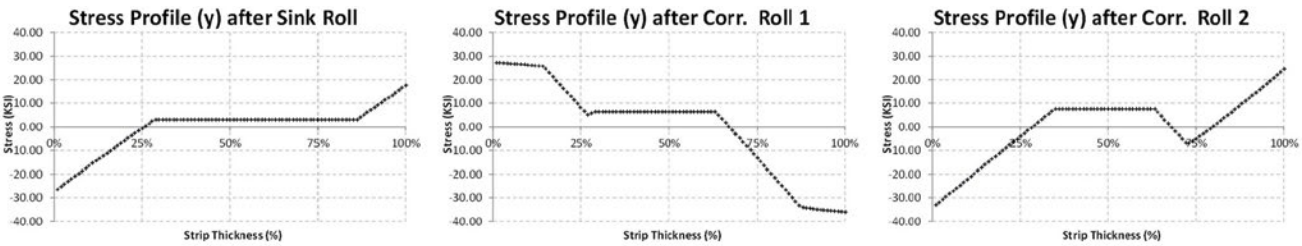
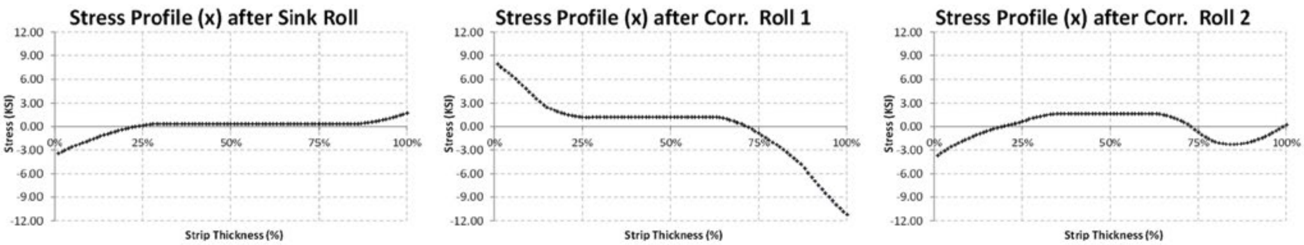


Figure 11

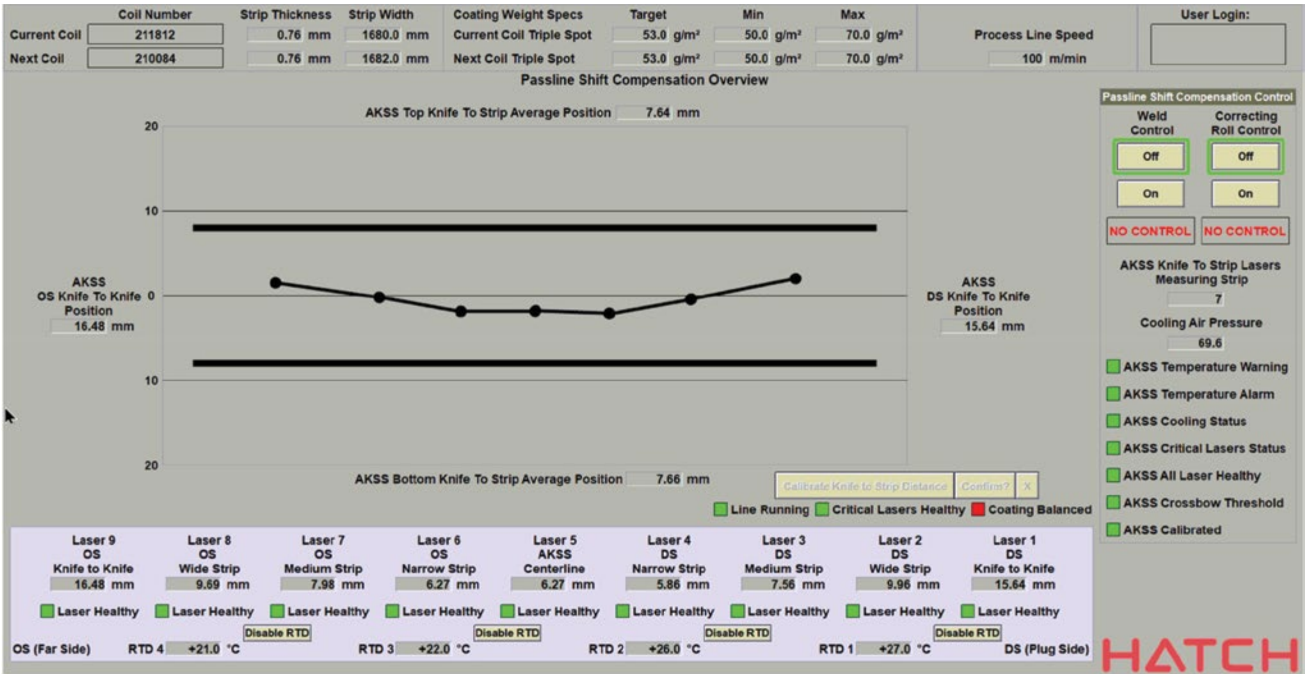
Stress profile in the transverse direction (X) at correcting roll intermesh = 1.18 inches.



which is desirable from a coating distribution perspective, the lengthwise stress profile (Fig. 10) after passing the submerged rolls is much greater and may display coilset when line tension is released.

Figure 12

Strip shape measurement screen.



Crossbow and Passline Measurement

The Hatch AKSS is used to measure the strip crossbow and average 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 controlled by the coating control system, and the position of the air knife beam is known. Using this technique, the absolute position of the strip passline can be determined. Therefore, any resulting air knife position can be corrected to account for the actual air knife to strip measurement.

The typical operator display for Hatch's AKSS system (Fig. 12) provides a clear presentation of the strip shape and the position of the strip relative to the two air knives, and provides a basis for the crossbow control system feedback. The display also provides equipment condition monitoring for the laser temperatures and related alarms.

On-Line AKSS Crossbow Measurement Results

Fig. 13 provides typical AKSS strip shape and position measurements taken from a project site that is in steady-state operation over a period of approximately 2 hours. In general, much of the strip shape is consistent through the length of the coil. However, as the welds pass through the pot, some of the product indicates a significant flattening at the welds with the crossbow returning immediately afterwards.

This example clearly shows the change in crossbow at the welds but also demonstrates the subsequent effects of correcting roll adjustments. The change in crossbow at strip locations A and B in Fig. 13 can be attributed to adjustments of the correcting roll position, which are illustrated in detail in Fig. 14 and Fig. 15. The data demonstrates that a relatively small change in correcting roll position, of 0.075 inch (1.9 mm) and 0.079 inch (2.0 mm), respectively, produced an immediate change in the measured crossbow.

Figure 13

Plot of the crossbow measurements over two hours of production.

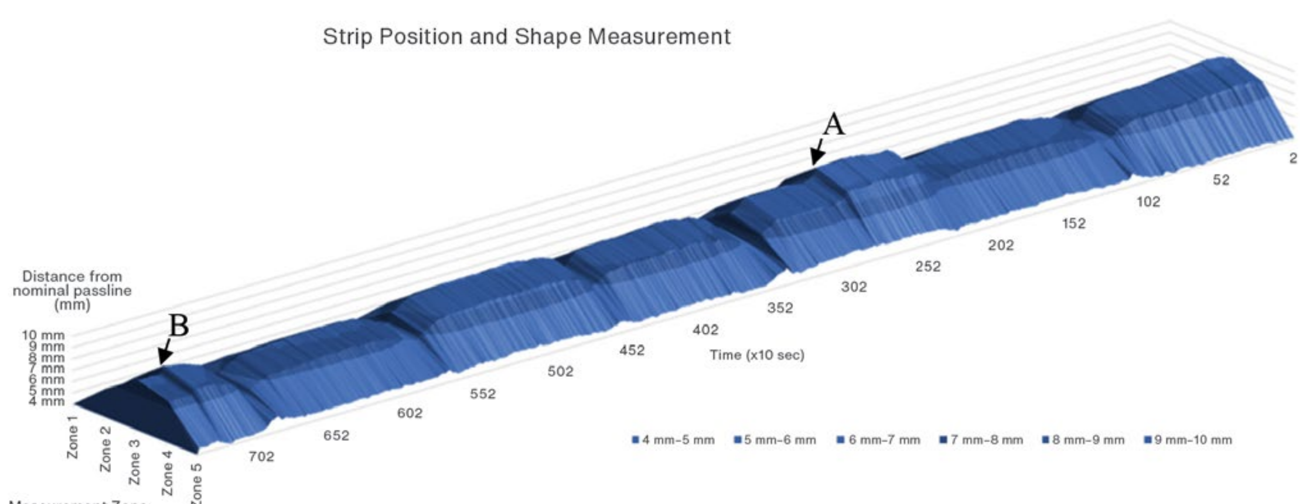


Figure 14

Measured crossbow (Air Knife to Strip Sensor data).

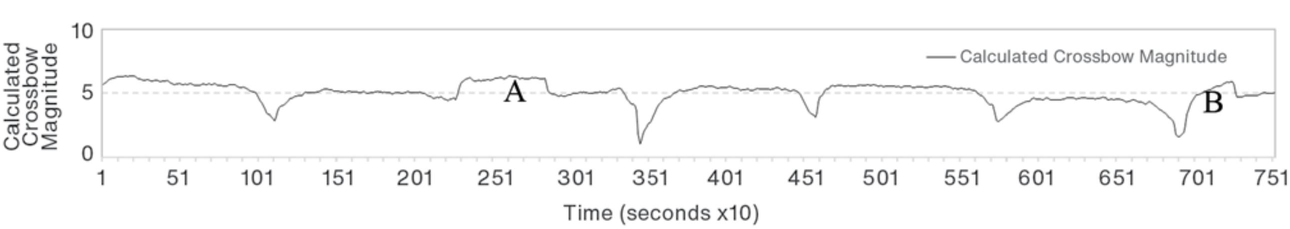
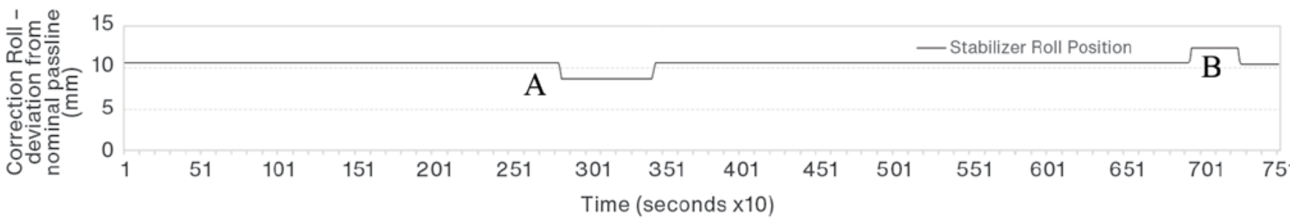


Figure 15

Correcting roll position.



The changes in strip shape presented in Fig. 13–15 indicate changes in the strip properties at the beginning and end of the coils. In reviewing the strip shape in Fig. 13, since the process parameters such as line speed, 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.

Conclusions

The change in the strip stress as it passes through the pot rolls has a considerable impact in metallic coating control. The many factors that affect the magnitude and direction of the resulting crossbow complicates the operator gaining an empirical understanding of the cause and effect. This complex problem surrounding strip shape and passline position 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 on-line realtime 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 high-speed programmable logic controller platforms now available, crossbow control will become an important new tool to provide an ongoing path to the continuous improvement in the quality control of metal coated product.

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Reference

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