Maximizing Yield Using Innovation in Automatic Gauge Control for Rolling Mills

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INTRODUCTION

The avant-garde Time-Based AGC is a control algorithm that measures and corrects on a constant time basis, typically as often as 3 milliseconds. The correction rates exceed 350 corrections per meter of material rolled, so it can be up to 3 times more accurate than other AGC systems in use today. The innovative technology has resulted in better overall reduction in thickness deviation, better response on slow speeds resulting in small coil ends, reduced tension disturbance during large incoming thickness variations, reduced high frequency components introduced in to the material and fine grained control of roll force cylinders during rolling.

BACKGROUND

The traditional length based AGC systems available in the market, typically measure and correct every 25 to 50 mm of the strip rolled, which results in 20 to 40 corrections of per meter strip rolled, which means the response is very slow on thread speeds. So, on slow speeds, each roll force cylinder movement creates a small edge after each thickness correction. These steps get compounded on each pass and it gets difficult to achieve a further reduction in thickness deviation after a certain value. Also, it is also not possible to employ frequency limiting in a length domain so a big incoming thickness deviation can be really harsh on the roll force cylinders.

The DIGI-IMPACT™ AGC system is not a traditional AGC system using fixed length intervals as a basis for initiating corrections to material thickness. The DIGI-IMPACT™ system utilizes a timed correction interval and a correction is issued every 3 to 5 milliseconds. This fixed time correction method provides extremely high-resolution corrections at lower speeds while providing step-less transitions to longer correction intervals at higher speeds.
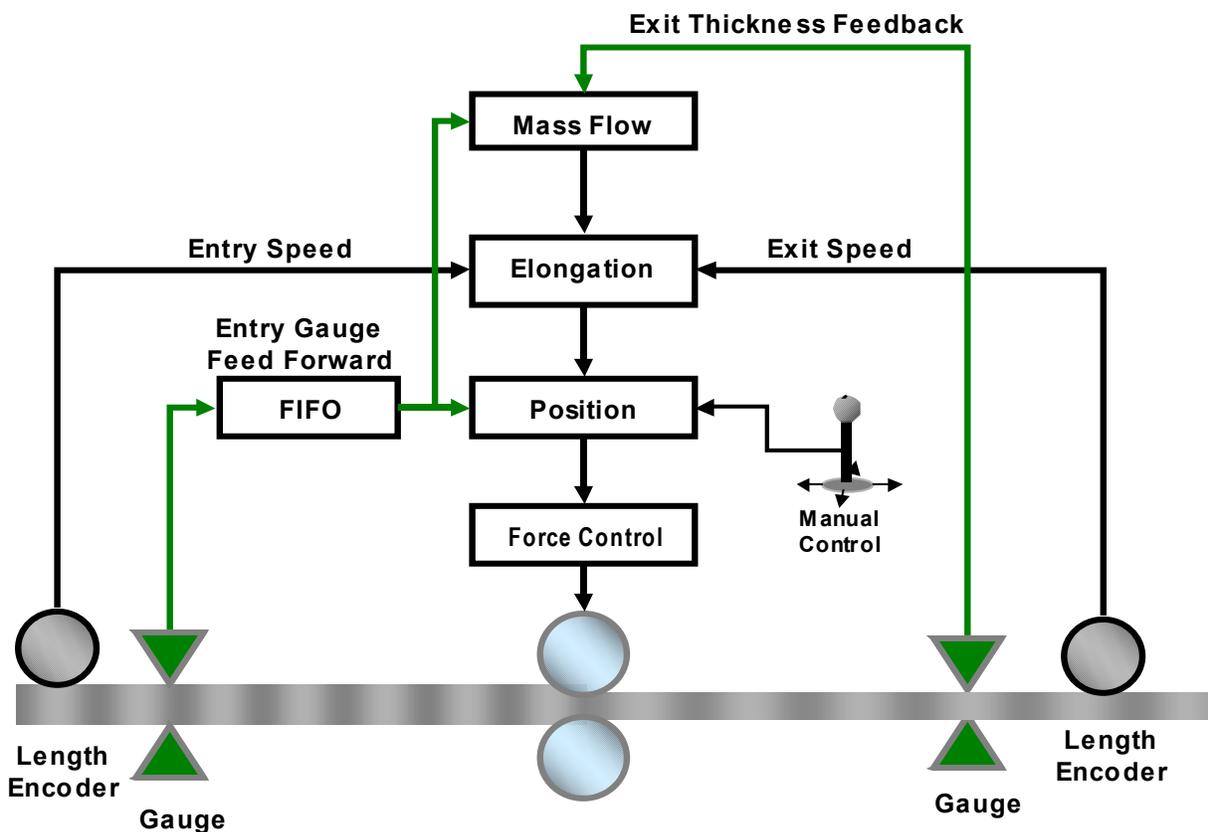
AGC MODES OF OPERATION

Figure 1. Block diagram of the control loops involved in a typical DIGI-IMPACT™ AGC System.

The AGC uses three control loops. Feedback is the primary loop regulating the exit thickness at its set point. Since the exit thickness is measured, some distance after the roll bite this mode is quite slow. The step response is approximate 3-6 times the transportation time between roll bite and exit gauge meter. The feedback regulator is a I-regulator where the in signal is the exit gauge meter and the out signal is a gap correction signal to the roll gap. The PI gains are adapted to strip hardness and roll speed. Feedback is normally used for corrections in:

- Offset in thickness at start or the first pass
- Roll diameter changes due to heat
- Tapered incoming strip
- Slow strip hardness variations

Feedforward is correcting for entry strip thickness variations, measured by the entry thickness meter. The feedforward regulator using the entry gauge meter and the out signal is a gap correction signal to the roll gap. The feedforward regulator delays the correction signal to be precise in timing due to roll speed and response time of the roll gap. The gain of the feedback regulator adapts to strip hardness. Feedforward corrects for:

- Variations due to roll eccentricity
- Speed changes and variations due to offset in the beginning of the strip introduced in previous passes

Massflow is a very fast acting control loop. Instead of using the exit gauge meter it is calculating the exit thickness by measuring the entry speed, exit speed and entry thickness. This means that the thickness is calculated directly in the roll bite.

Exit thickness is then calculated as:

$$\text{Exit thickness} = (\text{entry thickness}) * (\text{entry speed}) / (\text{exit speed}).$$

The Massflow regulator is PI regulator where the in signal is the calculated exit thickness and the out signal is a gap correction signal to the roll gap. The PI gains adapt to strip hardness and roll speed. The calculated thickness should adapt to the measured exit thickness using the I-regulator where the in signal is the difference of the calculated and the actual exit thickness. The out

signal corrects the mass flow calculation. The advantage of Massflow is a faster step response than feedback and feedforward control.

OPERATION PHILOSOPHY

The most basic and important factor of the time based AGC is that material thickness is measured and corrected on a constant time basis. Typical correction rates for a time based AGC system exceed 350 corrections per meter of material rolled. This correction rate is typically ten times more than your average length based AGC system and helps to provide ultra-smooth roll force cylinder movement throughout the coil.

The DIGI-IMPACT^{TM} time based AGC system applies traditional Massflow, feedforward and feedback algorithms, all while operating in the time-domain instead of the traditional length domain. Time-domain operation allows the system to easily define and enforce a maximum frequency response and other filters which are sensitive to the speed of the mill. This ensures no abrupt movement of the roll force cylinder even in the case of big incoming deviation.
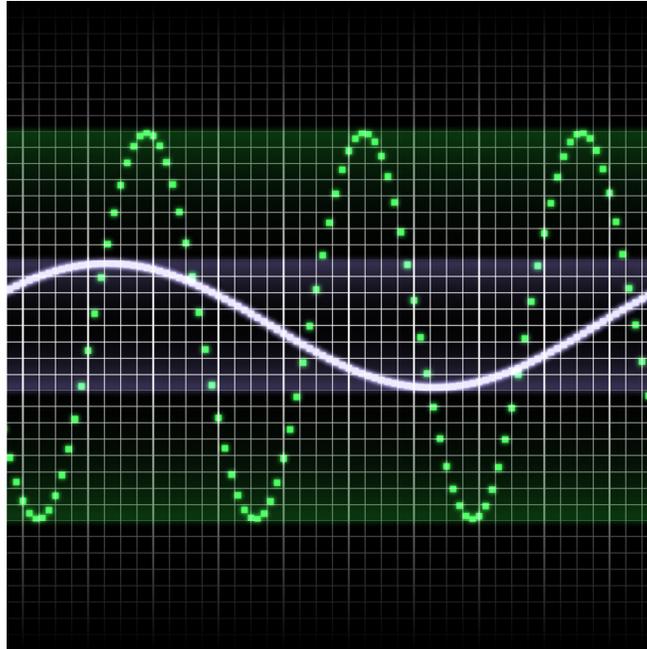

Figure 2. PWM technique.

Incoming strip is divided into very small portions similar to the small dots shown in Figure 2. Lines are interpolated between samples and roll position corrections initiated based on the interpolated points of each sample line. This technique of intra-sample interpolation reduces the average correction delivered by converting the signal into small discrete parts. This approach is similar in principle to the PWM technique, where a signal's energy is distributed through a series of smaller pulses rather than a continuously varying signal. The technique of intra-sample interpolation is used in the design of the time domain AGC algorithm to control the peak value and frequency of the output signal to the roll gap controller. The correction is very accurate, has a fast response and is especially effective at lower strip speeds.
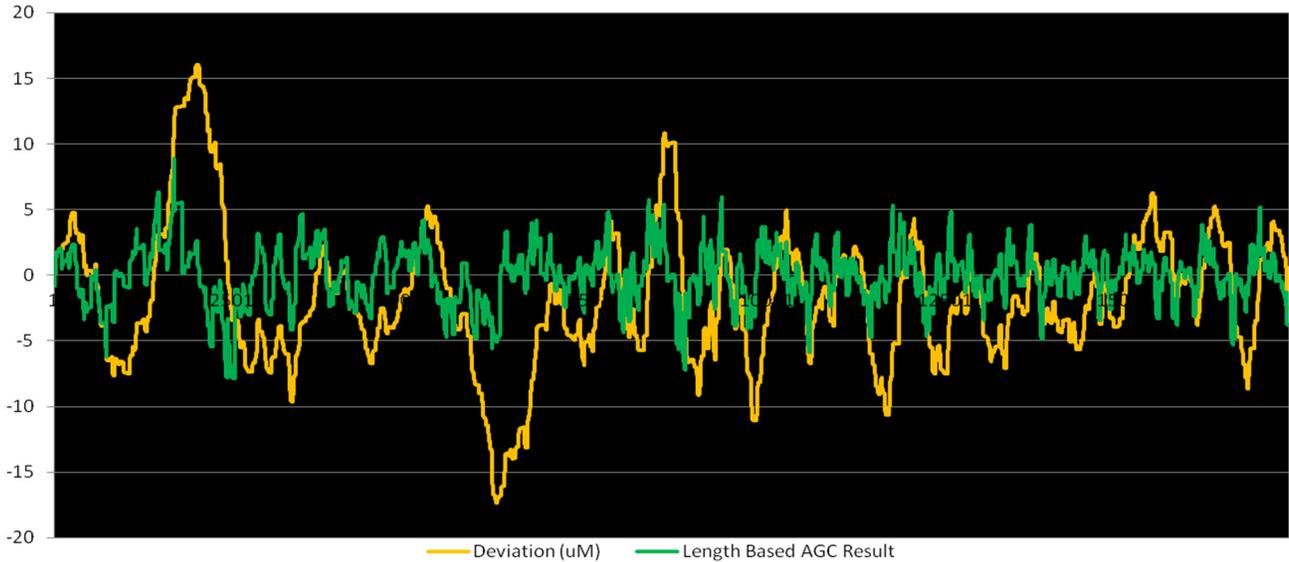
Figure 3. Length-based analysis of actual incoming material.

Figure 3 shows the results of a simulation using typical Length based AGC calculations on a 10-meter sample of actual material. This would be the result from a typical length based AGC system. The end result is a significant improvement in overall material thickness variation, but with a noticeable lack of improvement on the higher frequency variation. An incoming "Well Defined" high frequency component can still be observed in the output. This high frequency component is typically outside the capability of most length based AGC systems and therefore not removed.
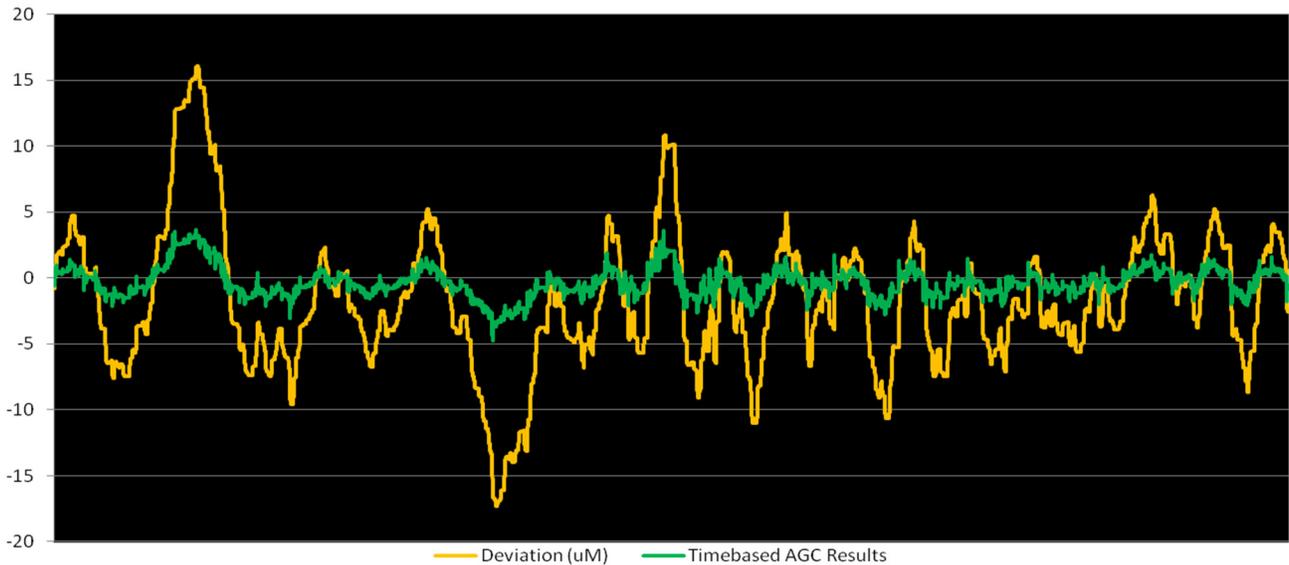

Figure 4. Time-based analysis of actual incoming material.

Figure 4 shows the simulation results using the variation from that same piece of material and applying Time-Based AGC calculations to it. The difference is increased fine grain control of the roll force cylinders which provide improved gauge tolerance performance, even in the presence of high frequency variations.

In order to stabilize the incoming tension during AGC operation, the system also sends a compensation signal to the entry reel drive to provide a "feed forward" anticipation of the impending strip speed change due to large thickness corrections. The system is smooth on the reel drives as well because the tension compensation signal introduced follows the extremely fine grain movement of the roll force cylinders.

Figure 5. AGC HMI screenshot.

Figure 5 is an actual screenshot of the AGC HMI installed on a 1250 mm wide 1400 MPM 6HI Reversible Cold Rolling Mill installed at Aarti Steel, Nepal. The mill is rolling ultra-thin gauges up to 0.076 mm on a regular basis with more than 99% of the coil within tolerance and a Cpk Value of more than 4 consistently.
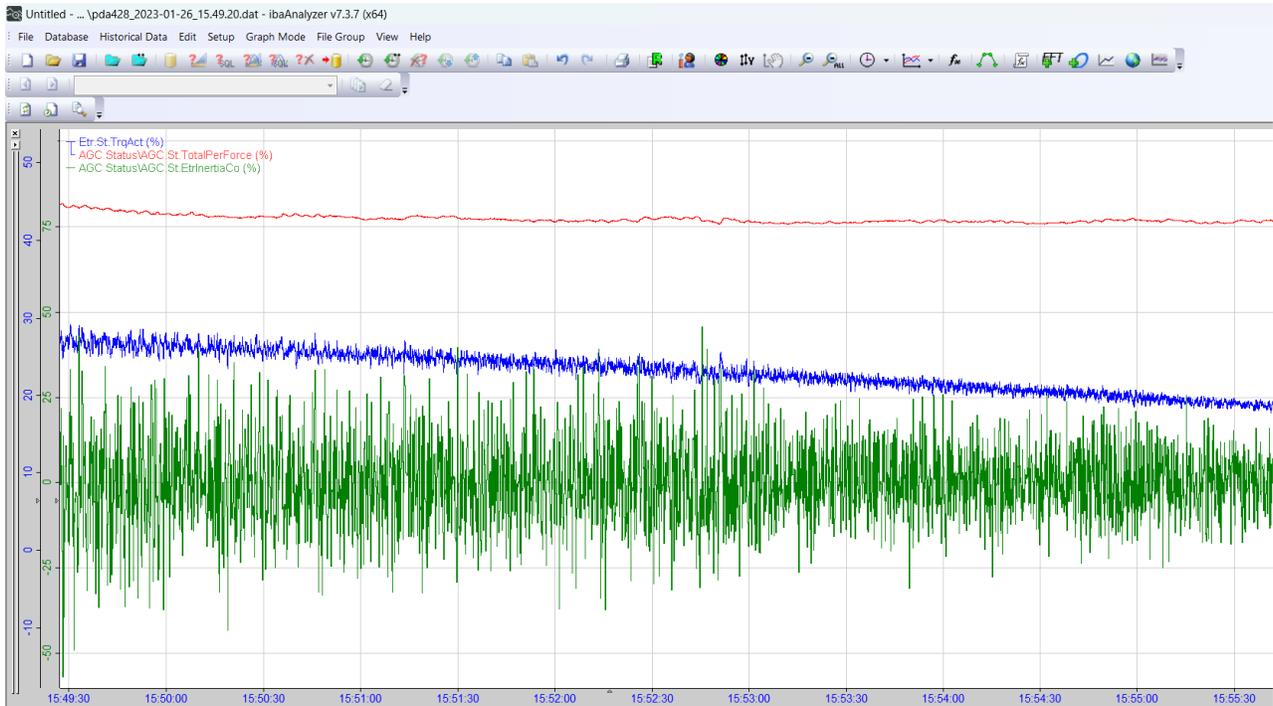

Figure 6. IBA screenshot from 6HI cold mill.

The compensation signal sent to the entry reel can be seen green color in Figure 6. The entry tension in blue and the roll force in red. It can be seen clearly that the time domain AGC is very smooth on the roll force cylinders movement. It aids in reduced high frequency components introduced in to the material by the system. The end result is higher quality material with less overall variation pass after pass.

The reports of first pass rolled on a coil and the final pass rolled are attached in Figure 7 and Figure 8 respectively to demonstrate how the time based AGC improves the overall gauge tolerance pass after pass. The in tolerance coil has moved up to 99.69% from 86.47% and the Cpk value from 0.25 to 5.39.

What is Cpk? Cpk is a Process Capability Index. The term index is used because the value is a comparison or ratio. It is the ratio of the tolerance (allowed variation) compared to the process variation (produced variation) expressed in terms of ± 3 standard deviations. Process capability index (Cpk) is a statistical tool, to measure the ability of a process to produce output within customer's specification limits. In simple words, it measures producer's capability to produce a product within customer's tolerance range. For the sake of simplicity, let's assume that the process is centered on the product specification. How many defective parts per million (parts out of tolerance) would we expect for different values of Cpk?

Table 1. Expected Number of Defective Parts

Cpk	Parts per million defective
1.00	2,700.0
1.10	967.0
1.20	318.0
1.30	96.0
1.40	26.0
1.50	6.8
1.60	1.6
1.70	0.34
1.80	0.06
2.00	0.0018

It should be noted that a Cpk of 2 equates to roughly two parts per billion defective!

Gaurang Products is a company based in NCR, New Delhi, is having two 4 HI Reversible Cold Mills installed with the DIGI-IMPACT™ AGC system. Gaurang is able to supply 102 sheets for a bundle weighing 1 ton of 1250 x 2500 x 0.4 mm sheets in respect to 100 sheets by a reputed brand. They also supply 1.2 x 900 mm sheet for drum application. The weight of the drum made from sheet from Gaurang is 20.05 Kg against 20.20 Kg from a very reputed brand.

It needs to be mentioned that for a particular customer who has three cold mills, the end users were demanding the material from a particular mill only. On in-depth internal analysis, it came out that the material from mill with time domain AGC was more in demand. The customer was actually forced to replace the AGC on other mills also.

To assure optimum performance of the AGC system it is necessary for the operator to adjust some system parameters during the pass. To assist the operator in this endeavor, a screen has been developed that displays the entry and exit thickness in real time. Entry thickness deviation is "Lined Up" with the same piece of material exiting the mill. This "Alignment" on the graphic display allows the operator to make a positive determination of the performance of the system.

The operator interface software retrieves and displays thickness data stored by the AGC PLC processor. This data is presented to the operator in real-time on the graphics display. Exit data is also stored to the HMI PC hard disk for printing quality reports and SPC/QC data printouts. All printouts are generated from skeleton files created in Microsoft Word and stored in a Rich Text Format (RTF). This allows printouts to be easily software configured and customized by the customer.

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Customer IN HOUSE
Pass Entry Thickness: 2.200mm
Pass Exit Thickness: 1.553mm

Initial Weight: 18,000kg
Coil Start Thickness: 2.200mm
Coil End Thickness: 0.192mm

Calc Weight: 26,497kg
Pass Length: 1,485M
Coil Width: 1,464mm

Alloy: 1006 **Shift:** A **Pass Number:** 1
Upper Tol: 0.005mm **Pass Started:** 18-Dec-22 11:23:19
Lower Tol: -0.005mm **Pass Finished:** 18-Dec-22 11:39:31
Operator: BIJJU **Pass Run Time:** 00:16

Passes Rolled: 7
Coil Started: 18-Dec-22 11:23:19
Coil Finished: 18-Dec-22 12:29:59 PM
Coil Run Time: 01:06

Coil Head Length: 24M

Off Gauge Above 101M (6.80%)
In Tol: 1,284M (86.47%)
Off Gauge Below 100M (6.73%)

Average Thickness: 1.5528mm **Min:** 1.492mm At 1,426M
Average - Target: -0.0002mm **Max:** 1.607mm At 1,448M

SubGroup Size: 5, Sample Interval: 300mm **StdDev:** 0.0021mm
UCL XBar: 1.5557mm **UCL R:** 0.0105mm
X Double Bar: 1.5528mm **RBar:** 0.0050mm
LCL XBar: 1.5499mm **LCL R:** 0.0000mm
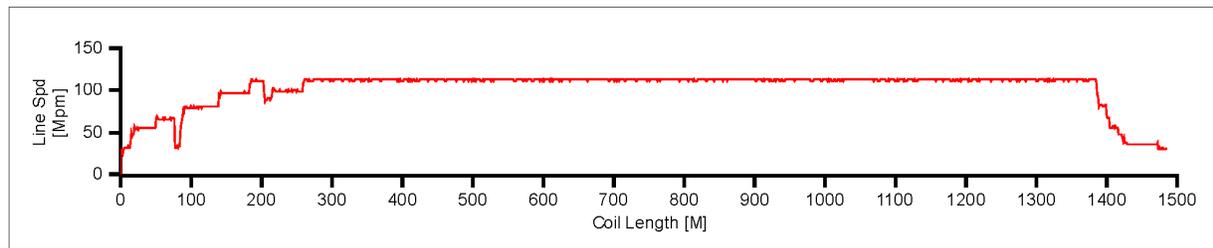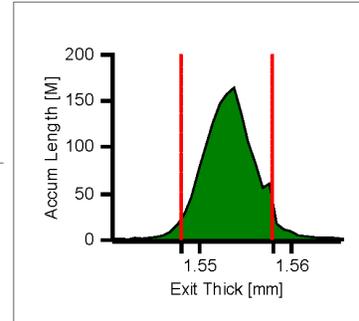**Cp:** 0.778 **Cpk:** 0.25 **Cr:** 128.61%

Thickness Distribution
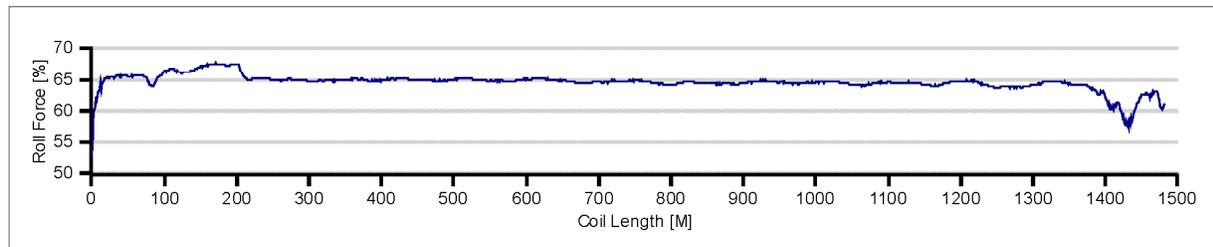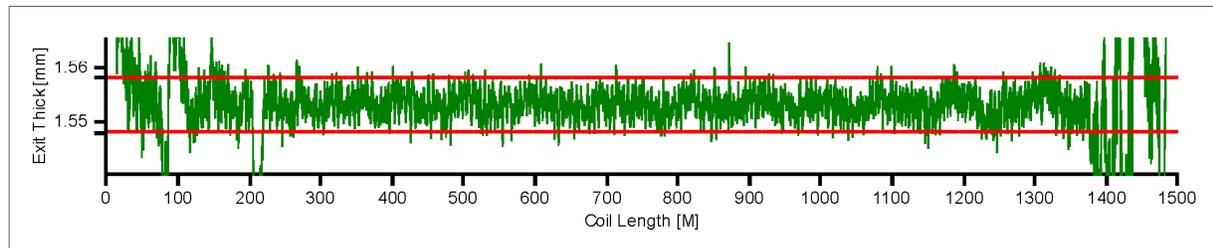
Figure 7. First pass coil report.

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Customer IN HOUSE

Pass Entry Thickness:	0.272mm	**Coil Start Thickness:**	2.200mm	**Calc Weight:**	24,463kg
Pass Exit Thickness:	0.192mm	**Coil End Thickness:**	0.192mm	**Pass Length:**	11,087M
				Coil Width:	1,464mm

Initial Weight: 18,000kg

Alloy: 1006	**Shift:** A	**Pass Number:**	7	**Passes Rolled:**	7
Upper Tol:	0.005mm	**Pass Started:**	18-Dec-22 12:18:35	**Coil Started:**	18-Dec-22 11:23:19
Lower Tol:	-0.005mm	**Pass Finished:**	18-Dec-22 12:29:59	**Coil Finished:**	18-Dec-22 12:29:59 PM
Operator:	BIJJU	**Pass Run Time:**	00:11	**Coil Run Time:**	01:06

Coil Head Length: 28M

Thickness Distribution

Off Gauge Above 10M (0.09%)
In Tol: 11,052M (99.69%)
Off Gauge Below 25M (0.23%)

Average Thickness: 0.1920mm **Min:** 0.185mm At 10,939M
Average - Target: 0.0000mm **Max:** 0.214mm At 11,087M

SubGroup Size: 5, Sample Interval: 300mm   **StdDev:** 0.0001mm

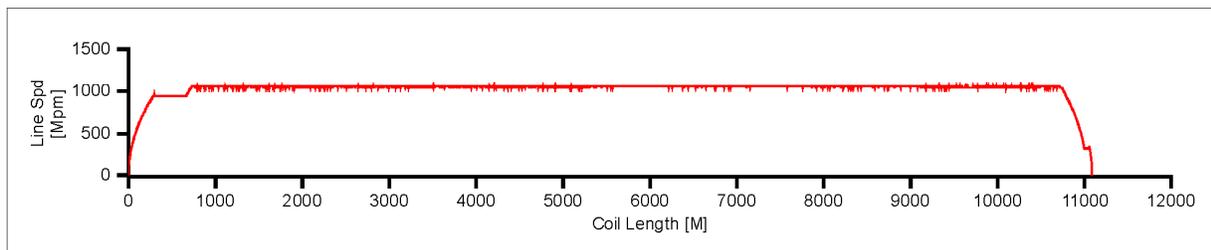|			
UCL XBar:	0.1921mm	**UCL R:**	0.0005mm
X Double Bar:	0.1920mm	**RBar:**	0.0002mm
LCL XBar:	0.1919mm	**LCL R:**	0.0000mm
Cp: 16.205	**Cpk:** 5.39	**Cr:** 6.17%	

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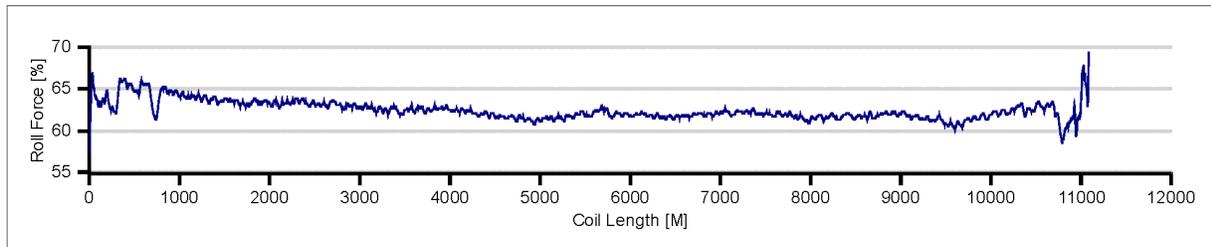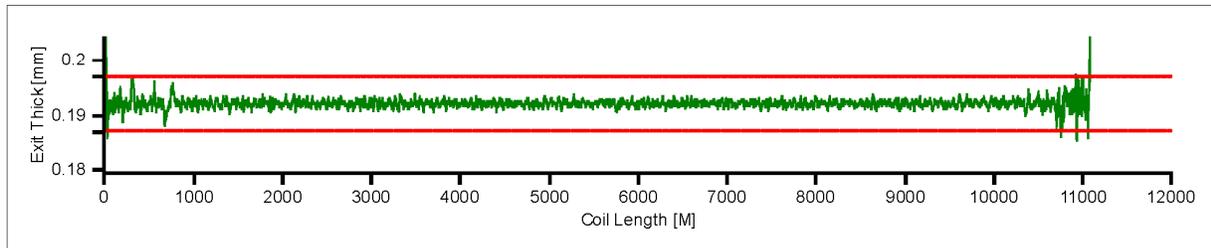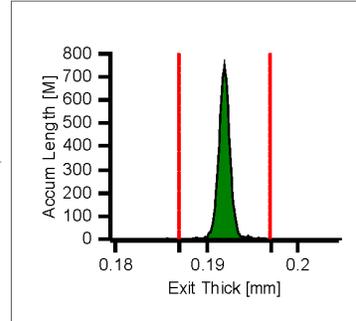
Figure 8. Final pass coil report.

CONCLUSION

The advantages of the time domain Automatic Gauge Control can be summarized as:

- Better overall reduction in thickness deviation
- Better response on slow speeds resulting in small coil ends
- Reduced tension disturbance during large incoming thickness variations
- Reduced high frequency components introduced into the material
- Fine grained control of roll force cylinders during rolling

ACKNOWLEDGMENTS

REFERENCES

1. Siddharth Tyagi, "Optimal Time-Domain Pulse Width Modulation in Power Electronics", Digital Repository at University of Maryland, July 13, 2021.

2. "A Guide to Using Cpk", The Association for Manufacturing Technology, 7901 Westpark Drive, McLean, VA 22102, 2002.