MEASUREMENT

50 years of flatness control with ABB's Stressometer

For 50 years, ABB's Stressometer system has helped rolling mill operators improve quality and productivity. The technology has evolved greatly over the past half-century and it is worth reviewing the innovation that has been a key ingredient in over-coming the many challenges that arise in rolling mills.

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On April 14th, 1967, Asea, a predecessor of ABB, delivered the world's first strip flatness measurement system for a metal rolling mill. The customer who received this new product – the so-called Stressometer – was the Canadian aluminum company Alcan (now Novelis). Using it, Alcan was immediately able to make huge strides in productivity, profit and quality. After many technical enhancements and breakthroughs since 1967 – and more than 1,200 systems delivered – ABB is now highlighting the 50th anniversary of Stressometer →1.

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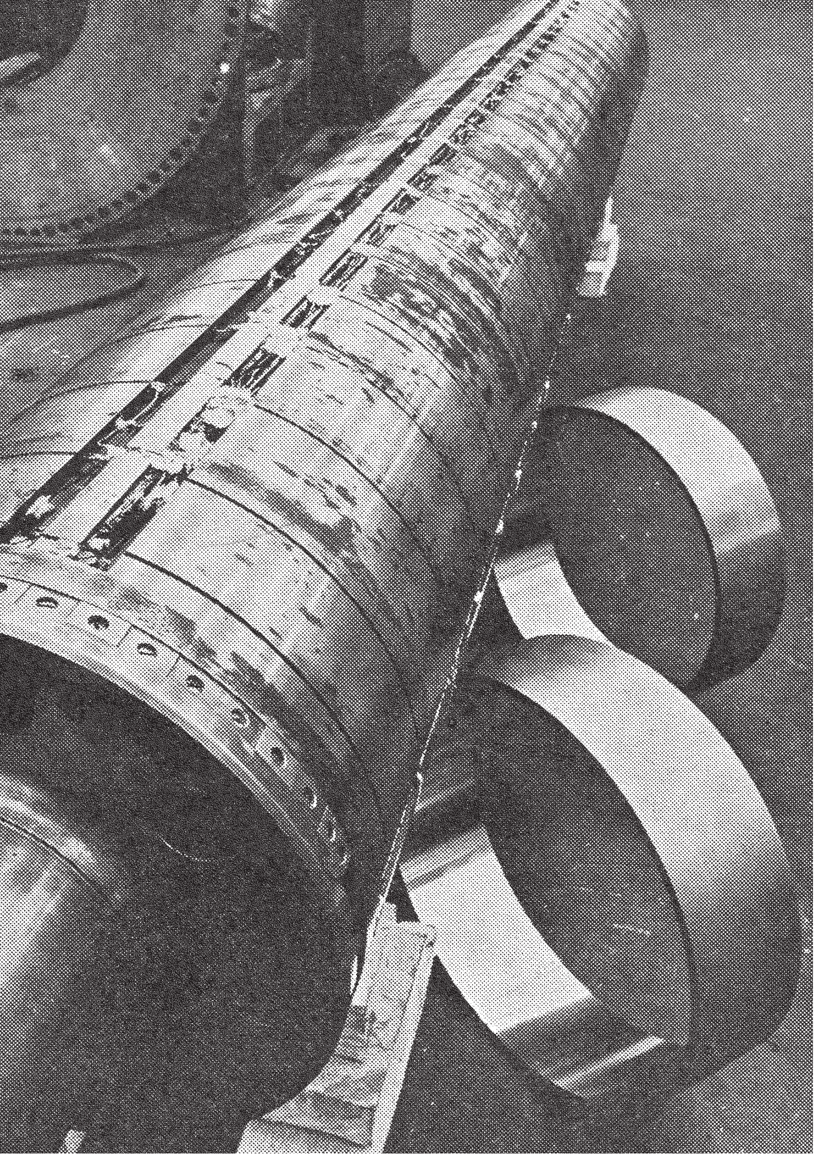
ABB's Stressometer has its roots in Pressductor® technology. Pressductor is a transducer, developed by Asea and patented in 1954, that measures mechanical force using the magnetoelastic effect. This effect exploits the fact that the magnetic properties of some materials are influenced by mechanical forces applied to them. Because Pressductor transducers are not reliant on physical movement or deformation, they combine sensitivity with an extraordinary tolerance to overloads and virtually no built-in limit to the number of load cycles. ABB Pressductor transducers produce high-power, low-impedance AC signals that are very resistant to electrical interference and earth faults.

In the mid-1960s, Alcan of Canada and Asea started a joint development to make a sensor that would measure strip flatness.



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01 For 50 years, ABB's Stressometer system has helped rolling mill operators improve quality and productivity. Shown is the operator room in an aluminium tandem cold mill equipped with two Stressometer systems.

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02 First Stressometer roll, delivered to Alcan Kingston, Canada in 1967 (from "ASEA Veckobladet" April 14, 1967)

As the demands of metal strip processing increased in the 1960s, interest arose in finding a way to measure flatness during cold rolling to achieve an automatic flatness control (AFC). Up until then, flatness during cold rolling had been manually controlled through visual and audible observations by the operator.

In the mid-1960s, Alcan of Canada and Asea started a joint development to make a sensor that would measure strip flatness. A decision was made early on to base the product on a mill-duty measuring roll equipped with Pressductor sensors. The first system was installed in 1967 in Alcan's cold rolling mill in Kingston, Canada, where it underwent comprehensive tests →2.

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The idea was to control the transversal stress distribution in the strip, thus improving strip flatness. The assumption was that a controlled strip stress distribution, ie, strip flatness, would lead to improvements in strip quality and mill productivity. The hypothesis turned out to be correct: By using the Stressometer equipment and a flatness control system, Alcan substantially improved the flatness of the rolled strip, achieved higher yield, reduced the number of strip breaks, and raised productivity through higher mill speed and shorter pass times. In other words, the new product was a resounding success.

50 years of customer collaboration
In the 50 years since that first installation, the demand from strip users, and from other types of rolling mills, for ever more sophisticated flatness control has increased dramatically. ABB has, therefore, in collaboration with customers, continuously developed the Stressometer system →3. The improvements enable mill operators to fully utilize the rolling mill to produce a high-quality strip with maximum yield while keeping maintenance needs to a minimum.

The Stressometer system of today is designed for both hot and cold rolling, and handles thickness and product ranges from 0.005 mm aluminium foil up to 12 mm stainless steel.

What is strip flatness control in a rolling mill?
Flatness control is about controlling the roll gap in the mill so that it exactly matches the thickness profile of the incoming strip. If there is a mismatch, then flatness problems will arise →5.

The Stressometer measures the force distribution (Fi) on the roll →6. Using strip tension (T), width (w), length (L) and thickness (t), the stress distribution in the strip can be calculated. When this value is divided by Young's Modulus, the (un)flatness distribution can be derived. The flatness distribution is measured in I units, which correspond to the relative elongation distribution multiplied by 100,000, ie, one I unit corresponds to an elongation of 1 mm on a 100 m strip.

Stress: $\Delta\sigma i = \frac{Fi-\bar{F}}{\bar{F}} x \frac{T}{w x t}$ [N/mm^2]

Unflatness: $\frac{\Delta Li}{L} = \frac{-\Delta\sigma i}{E}$ [x10^5=I units]

The I unit was introduced by ABB in the 1960s as a way of quantifying flatness and has since become the de facto, industry-wide flatness measuring unit.

STRESSOMETER DEVELOPMENTS

1967	World's first flatness system delivered to Alcan Kingston, Canada →4
1970	Improved measurement resolution: 52 mm zone width from 84 mm
1976	First microprocessor-based system (Intel 8080)
1977	World's first digital closed-loop flatness control (Kobe Steel, Japan)
1980	World's first flatness control system for a cluster mill (Outokumpu)
1982	Resolution improved further: 26 mm from 52 mm
1989	Digital color-graphic human-machine interface (HMI)
1989	World's first flatness control based on actuator models
1990	New technology for measurement of strip width and edge position – MSS (millmate strip scanner)
1993	Measurement and compensation for strip temperature in steel applications
1994	New transducer and roll for foil applications
1998	World's first HMI based on a Web browser for industrial applications
2001	New generation with future-safe architecture (FSA)
2002	Seamless roll for surface-critical applications
2006	Predictive flatness control
2007	Foil roll with 26 mm resolution
2011	Flatness control with automatic process identification
2013	Optimal coordinated control through ESVD for cluster mills
2014	Digital maintenance-free signal transmission (DTU)
2017	Fully digital system RoHS (restrictions on hazardous substances) compliant

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How does the Stressometer technology work?
The Stressometer measuring roll is the key to successful flatness measurement and control. It consists of a solid core with four axial grooves that accommodate a large number of Pressductor sensors. Each measurement zone across the width has, therefore, four sensors. This four-sensor approach has been fundamental to the Stressometer design since the very beginning and confers upon the system the advantage of a physical, automatic compensation for both roll deflection and temperature change so no compensation software is needed and very fast measurement response time is achieved.

The roll is divided into 26 or 52 mm measuring zones. A hardened steel ring is shrunk onto each zone to protect the sensors and to present an appropriate surface to the metal strip being rolled. A digital transmission unit (DTU) provides contact-free power and signal transmission with the sensors in the roll →7. Each zone measures independently the local force directed radially from the strip.

Four measurements are obtained for each revolution of the roll, at speeds of 1 to 4,000 rpm. The Stressometer roll measures the entire strip force including the edge stresses. The actual strip flatness is presented in I units.

Stressometer innovations over the years
From the beginning, six main design principles were adhered to in order to secure a reliable, accurate and fast flatness measurement:

- The force measurement must be stiff – ie, the deformation of the strip and of the force sensor should be negligible. Thereby, a direct and reliable force measurement is achieved without any stress filtering due to strip deformation.
- Sensors with the same thermal expansion coefficient as the surrounding material must be used. This minimizes inaccuracy due to thermal effects.
- Sensors must function reliably and accurately for many years in a rolling mill without the need for recalibration.

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The improvements enable mill operators to fully utilize the rolling mill to produce a high-quality strip with maximum yield while keeping maintenance needs to a minimum.

- Measurement should be of the whole force distribution across the strip in one instant – ie, no force shunting to the roll body.
- The four-sensor principle. This enables measurement of the whole force distribution four times per roll revolution while keeping the measurement signal unaffected by temperature changes and roll deflection.
- The signal output from a measurement zone must be directly proportional to the strip coverage degree. This will enable accurate measurement of the strip edges.

03 The progress of ABB's Stressometer over the past 50 years.

04 Flatness measurement HMI from 1967. Nowadays, a computer or cell phone can be used as an operator station.

Necessary requirements on a modern flatness system

If the flatness control system is to make a difference to yield, pass times and number of strip breaks, it must comply with a number of tough requirements:

- Reliability is the most important requirement. The system must not cause any unplanned stops in the mill (planned stops are acceptable). In this respect, the Stressometer system has an MTBR (mean time between repair) that exceeds 20 years and utilizes a maintenance-free, contact-free signal transmission from the roll.
- Accurate measurement. Without an accurate measurement of the complete stress distribution, no flatness control can do a good job. (Stressometer system measurement accuracy is typically 0.5 I units.)
- The measurement must be unaffected by mill disturbances such as variable strip tension.
- The measurement must operate equally well at all mill speeds and include edges, and the head end and the tail end of the strip, regardless of the strip thickness.
- The measurement system must, within milliseconds and several times per rolled meter of strip, provide accurate outputs to the flatness control system.
- It is essential to visualize the actual flatness for the operator in an intuitive way.
- The system must, without any adjustments, be able to handle a wide range of products and it should never deteriorate the strip surface.

The Stressometer system of today is designed for both hot and cold rolling, and handles thickness and product ranges from 0.005 mm aluminium foil up to 12 mm stainless steel.

- The flatness control system must be able to simultaneously and efficiently use all mill actuators on all occasions and for all products. Since several actuator combinations might have the same flatness effect, the system must be capable of selecting the most efficient combination. No manual control should be needed. Here, the Stressometer system has advanced control facilities, including extended singular value decomposition (ESVD) and adaptive/predictive control →8.

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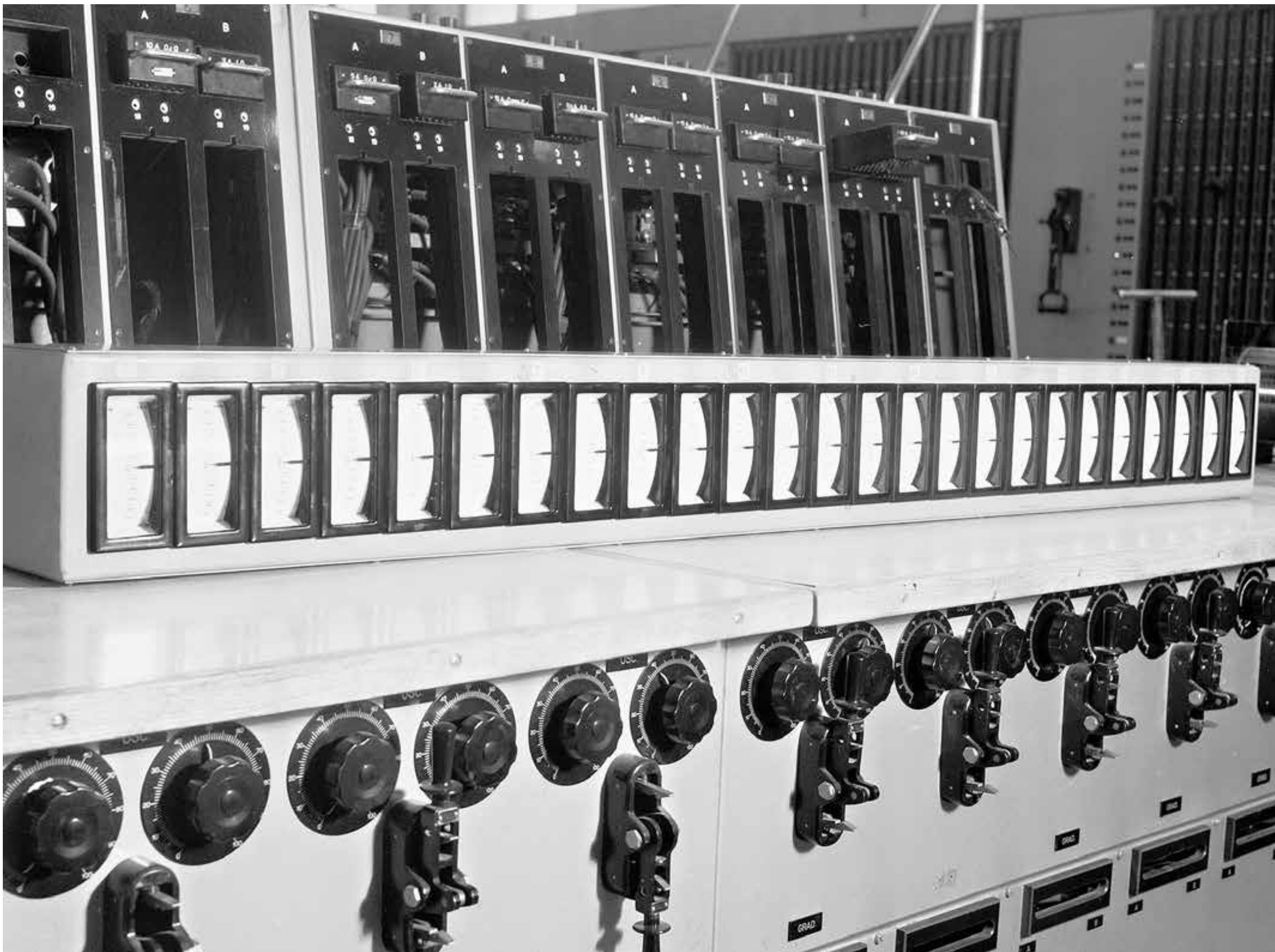

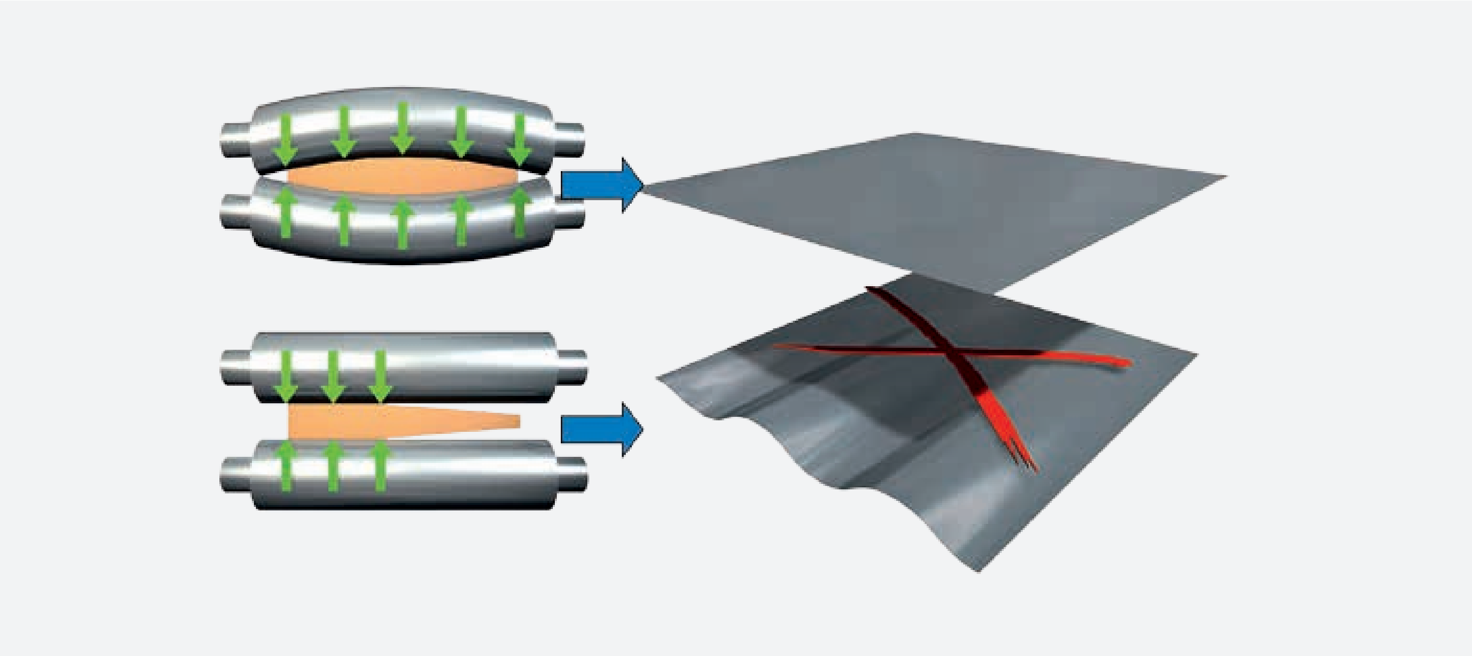

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Challenges and potential for flatness control
The rolling industry has faced many challenges over the past 50 years and there are sure to be more in the future. One ongoing challenge is to produce in a sustainable way so that environmental and climate effects are minimized. The Stressometer system improves quality and yield, which means less energy is needed per ton of finished product.

Another challenge is to provide facilities that can produce, within short delivery times, the increasing number of products, alloys and dimensions that the market wants – and short-run, custom requests for these. These demands make it necessary to switch within seconds from one type of product to a completely different one – without deterioration in quality or productivity.

Cost reduction is an area in which the Stressometer provides great potential: Rolling mill productivity is directly affected by yield achieved, pass

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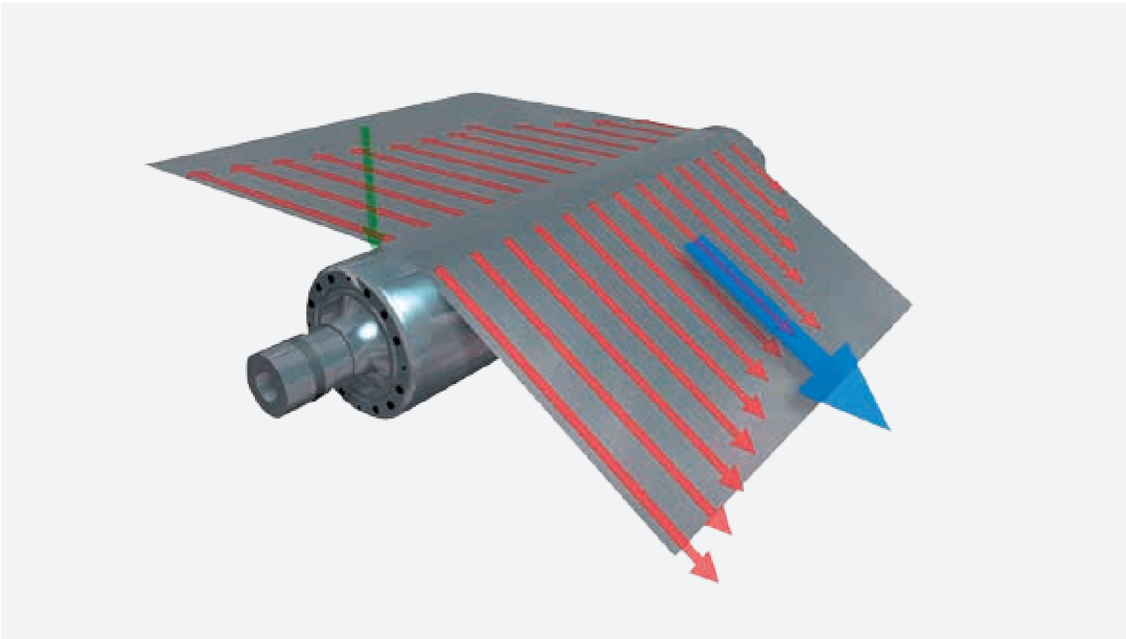
times and mill downtime due to strip breaks. In an aluminium cold mill, bottom line sensitivity (BLS) to a strip break is typically $10,000. For yield, BLS



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05 A match between the roll gap and the strip gives a flat strip. A mismatch results in non-constant elongation across the strip and, consequently, flatness problems.

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06 The Stressometer measures the force distribution on the roll.

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07 Stressometer signal processing hardware.

07a In 1967, three analogue circuit boards were needed to process the signals from one measurement zone.

07b Today, signal processing is completely digital and 80 measurement zones are processed in parallel by the DTU.

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08 Flatness control with ESVD.

08a Actuators.

08b Flatness effect.

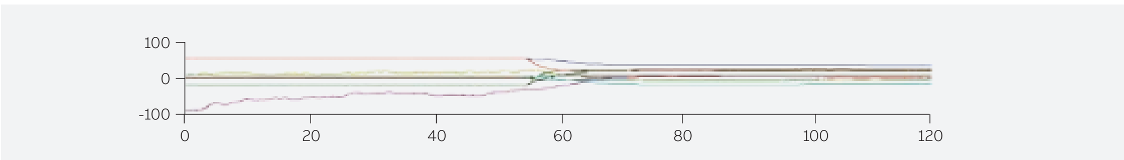
08c Mean flatness and control strategy.

is typically $150,000 per 0.1 percent and for pass time it is $100,000/s. With such substantial sensitivity factors, every improvement, no matter how small, brings with it a significant financial payoff.

The 50 years of development of the Stressometer system have led to significant enhancements in the product:

- Use in any hot- or cold-rolled product
- Extremely high roll reliability with MTBR of over 20 years
- Improvements in resolution, accuracy, response time and visualization
- Expansion of flatness control to a general concept that includes all existing mill types, with an optimal use of the available actuators

Further customer collaborations will establish how quality and productivity can be taken to the next level – perhaps by extending flatness control to upstream and downstream operations. This then includes control of the strip profile during hot rolling so that consistent and controllable flatness can be achieved downstream. Systems in the future will also be securely connected to the so-called IoPTS – the Internet of People, Things and Services. This connectivity will enable ABB to also remotely assist customers in the pursuit of the optimal long-term operating performance of their rolling process. ●



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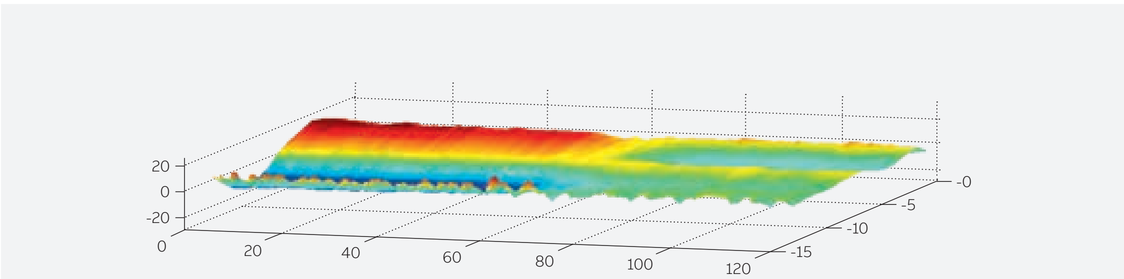

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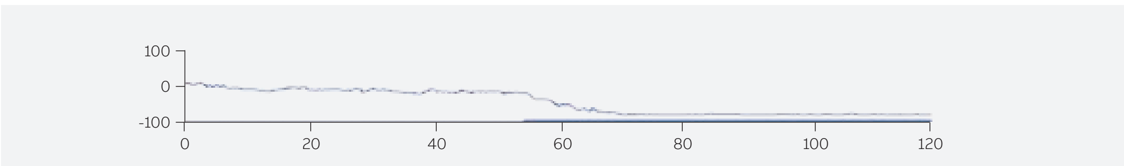

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