The continuous annealing line is used to modify the grain structure of steel through heat treatment, changing properties including hardness and strength.

The process involves several stages, focused on controlled heating and cooling to produce steel with the required qualities. Accurate temperature monitoring and control in each zone is essential for process and quality control.

To ensure the accurate, edge-to-edge temperature monitoring required, a solution has been devised that overcomes the challenges caused by surface reflections and strip emissivity.
VERTICAL CAL FURNACES

Most high-volume strip annealing lines use Vertical Continuous Annealing Line (CAL) furnaces, which are designed to heat and cool the steel strip in a series of controlled temperature sections.

These sections heat and clean the strip then anneal, heat treat and condition the steel to produce the desired grain structures and properties for the end use application.

Many CAL furnaces precede hot-dip metal coating operations, and in the case of a hot dip coating line, the strip is then cooled before exiting the line and entering the zinc pot.

The furnace’s nitrogen/hydrogen reducing atmosphere strips any residual oxygen atoms from the steel surface to prevent the possibility of future sub coating oxidisation.

Traditionally, single point radiation thermometers (pyrometers) have been used to measure the strip temperature at various locations throughout the furnace to provide for verification and closed loop control.

As product tolerances continue to tighten and as more advanced steels emerge, simply measuring the centreline temperature along the process leaves too many unknowns about the overall edge to edge temperature uniformity of the strip. The use of process thermal imaging systems, particularly thermal linescanners, are fast becoming the proven method of comprehensive temperature measurement.
TEMPERATURE MEASUREMENT CHALLENGES

For flat strip metal, edge-to-edge temperature variations can cause significant quality problems, and multiple pyrometers have been used to provide more coverage. Once multiple sensors are used, measurement costs increase, and there are still unmeasured gaps on the product.

In addition, separate, single-point pyrometers each have their own unique calibration – e.g. they may have an accuracy specification of ±0.3%, so one may be within specification and measuring 0.29% high, and another may similarly be within specification and reading 0.29% low. In this example, there is almost a 0.6% difference between the two sensors, which have both passed the manufacturer’s ±0.3%, accuracy testing.

TWO OF THE CHALLENGES FOR ACCURATE NON-CONTACT TEMPERATURE MEASUREMENTS ARE:

1. Varying emissivity caused by various surface finishes and alloy types
2. The presence of higher background temperatures in heating sections

Non-contact radiation thermometers or scanners are unable to differentiate between the radiation emitted from a surface and the radiation reflected from the surface that originates from the background.

For instance, if the strip emissivity was 0.30, this would mean that the emitted energy was 30% and the reflected component was 70%. Emissivity = 1.0 minus Reflectivity (E=1-R). So, if the background is hotter than the strip, then 70% of what the thermometer is measuring will be reflected energy originating from the higher-temperature background, and the resulting temperature readings will be incorrectly high.

Fortunately, the design of CAL and CGL furnaces makes it relatively easy to make a pyrometer reading that is independent of background reflections and uncertain strip emissivity.
In 1984, researchers at Nippon Kokan, Japan, discovered that the cavity formed where a strip leaves a transition roll has a very high and stable emissivity, regardless of the steel’s emissivity value.

Because the cavity has an emissivity of almost 1.0, and $E=1-R$, this means that the technique is also valid for heating sections where the background temperature is significantly higher than the strip temperature.

This cavity is widely known as a wedge (see figure 2). The multiple specular reflections produced within it integrate to produce a black body environment.

Further studies, conducted in 1986 by AMETEK Land Infrared researchers, found that the typical wedge emissivity was 0.995. The wedge emissivity is also quite stable over a range of pyrometer wavelengths. For best results, the strip should be in contact with the roll for 25% or more of its circumference before detaching. Results in this survey were verified using an AMETEK Land Gold Cup pyrometer.

Single-point pyrometers work well in viewing and measuring point temperatures within a wedge cavity.

Linescanners now take this technique to a new level of performance. If a linescanner is aimed to scan the entire length of the wedge it will produce a very accurate temperature profile of the strip from edge to edge.

Linescanners are particularly good for measuring full width temperatures on processes that have linear movement. These devices consist of an extremely fast response speed radiation sensor that views the end of an inclined mirror (see figure 3).

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**WEDGE CAVITY MEASUREMENTS**

**FIGURE 2: A PYROMETER SIGHTING INTO THE HIGH-EMISSIVITY WEDGE CA VITY**

**FIGURE 3: A LINESCANNER MEASURING ACROSS THE STRIP**
The mirror is attached to a high-speed motor that rotates. In this way, the pyrometer’s view scans along a path, allowing it to “see” and measure objects along that scanned line. The scanner view is through a durable sapphire window that seals the instrument’s enclosure.

In a fraction of a second, a linescanner can measure a temperature profile through an 80- or 90-degree scan angle and sample 1000 discrete temperature points during that scan. That is like having 1000 radiation spot pyrometers positioned across the process, all with the exact same matched calibration. Because the linescanner’s single sensor makes all those temperature measurements, there are no differential accuracy errors like there are with separate single point pyrometers. So, if the scanner indicates one edge of the strip is three degrees hotter than the other edge, it really is.

Uneven heat distribution across the strip width can cause flatness issues that otherwise may not occur if temperatures were balanced and uniform.

The matrix of burners in a Direct Fired Furnace section heats the strip across its width. If using a single point centrel ine pyrometer, an assumption is made about the resulting heating uniformity across the wide strip.

The furnace heating zones have either multiple radiant tube heaters or induction heaters that if aligned with strip travel can be modulated to heat the strip edges and centre at different rates as necessary.

A scanner can detect any cross-strip temperature variances and feed those measurements back to the furnace control system to modulate the heaters.

Linescanners are well suited to wedge measurements because they have very narrow fields of view and focusable optics which enable them to sight deep into a wedge cavity. For example, at a distance of 5 metres away, a scanner will have a small target spot diameter of just 1 cm.

In the cooling sections, gas nozzles across the strip width control the temperature profile of the strip. Scanners provide the ability to associate lanes of temperature values along the strip. Each scanner measurement lane location matches a cooling nozzle’s area of influence. Each lane temperature output is then fed back to the furnace control system. Linescanners are used at several locations along the process.

Linescanners are commonly installed at the exits of cooling sections, where they verify the uniformity of strip cooling as well as confirming the overall exit setpoint temperatures.
With the development of Advanced High Strength Steels (AHSS), and their rapid adoption in the automotive sector, there is growing demand for superior temperature measurement methods in CAL furnaces which process these steels.

AHSS grades differ from standard steels because of their complex chemistries and the precise heat treatment stages necessary to produce their well-defined grain structures. Uniform edge-to-edge temperature distribution is critical to attain the desired mechanical properties.

Many AHSS steels are annealed in CAL furnaces and then later coated in an electro-galvanizing process. The electro-galvanizing can provide a thinner coating which further enhances the lightweight characteristics of the AHSS product.

On CGL furnaces, linescanners are used in the overaging section to ensure the cross-profile temperature of the strip is uniform as it approaches the zinc pot (see figure 4).

In the case of a CGL, a uniform temperature cross-profile prior to coating will cause the molten zinc to adhere to the strip effectively, and with an even thickness, across the entire width. These short-wavelength scanners also allow the use of affordable quartz sighting windows. The combination of high speed, scanning single-point sensors and narrow precise optics allow linescanners to produce high resolution process thermal images within vertical annealing lines for real time monitoring and control, regardless of strip emissivity and background reflections.
RECOMMENDED PRODUCTS

SPOT GS PYROMETER

An advanced, non-contact infrared spot pyrometer specifically designed for the continuous, highly accurate measurements of coated steel strip temperature during the galvanneal reaction.

The SPOT GS combines AMETEK Land’s cutting-edge SPOT technology with specialised software algorithms to deliver the accurate measurements needed for close monitoring of the reaction zone, enabling automated furnace management and tighter product control.

**FEATURES**
- Self-contained single-sensor solution
- Specialised Galvanneal and Galvanized algorithms
- Easy plug-and-play installation
- Integrated webserver and video camera – fully remote-controlled
- Modbus/TCP interfacing following Industry 4.0 requirements
- Advanced mirror optics
- Outstanding accuracy and reliability

**BENEFITS**
- Highly precise temperature readings
- No separate processor required
- Digital temperature readings for live process control
- Industry 4.0 ready
- Scratch-resistant sapphire protection window
- Working up to 70 °C (158 °F) without additional cooling
- Faster, more accurate measurements
- Highly reliable temperature measurements even under very rough environmental conditions

LSP-HD LINESCANNER

A compact, highly accurate infrared linescanner, the LSP-HD range is designed to provide high-definition thermal images of moving processes at unrivalled scan speeds.

This delivers industry-leading imaging definition, detecting the slightest temperature differences and so supporting improved process control and product quality, delivering extreme homogenous thermal profiles and images, based on a one detector technology.

All LSP-HD scanners feature rugged sapphire protection windows that resist scratches, acids and solvents, and have a robust scanner assembly with only one moving part. A wide range of accessories complete the scanner family ready for use in very arduous industrial environments.

Plug-and-play industrial Ethernet connection provides real-time processed data, allowing module assembly problems to be identified and analysed quickly.

The scanner can work independently or by using the extended WCA (Windows Control and Analyse) Scanner software for detailed monitoring analysis and data capturing.

A wide range of models are available, each optimised for different industrial applications across temperatures from 20 to 1500 °C (68 to 2732 °F).

**FEATURES**
- High-resolution optical system
- 150 Hz scan speed with 1000 samples at all scan frequencies
- Easy installation with single Ethernet cable
- Range of data output formats
- Independent operation or with advanced WCA scanner software

**BENEFITS**
- Real-time thermal displays for accurate results
- Industry-leading scan speeds
- Extremely high homogenous temperature profile and thermal images – detects even the smallest temperature differences
- Installation costs significantly reduced
- WCA can handle up to eight scanners
AMETEK LAND SOLUTIONS FOR VERTICAL CONTINUOUS ANNEALING LINES

Our in-house service centres provide after-sales services to ensure you get the best performance from your system. This includes technical support, certification, calibration, commissioning, repairs, servicing, preventative maintenance and training. Our highly trained technicians can also attend your site to cover planned maintenance schedules and repair emergency breakdowns.

**SPOT GS**
An advanced, non-contact infrared spot pyrometer specifically designed for the continuous, highly accurate measurements of coated steel strip temperature during the galvanneal reaction.

**LSP-HD**
Ethernet-controlled compact infrared linescanner, designed to produce advanced thermal imaging in moving processes.

**FIXED SPOT THERMOMETERS**

**LINESCANNING**

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