INDUSTRIAL HEATING

The International Journal of Thermal Processing
MARCH 2018

Industry, Universities Collaborate 11

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A bnp media Publication • Vol. LXXXVI • No. 3 • www.industrialheating.com

Process Thermal Imaging in the Modern Hot-Rolling Mill

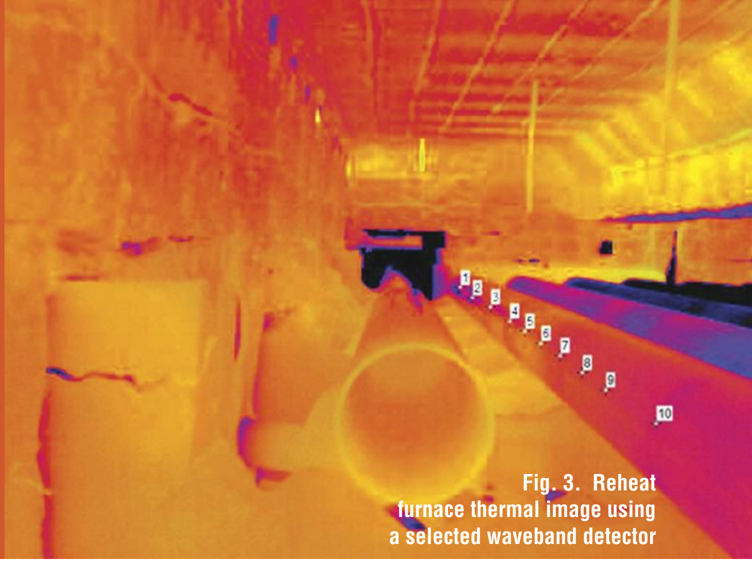

Fig. 3. Reheat furnace thermal image using a selected waveband detector

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Single-point radiation thermometers, also referred to as infrared pyrometers, have been widely used in steel hot-rolling mills for more than 60 years. They offer many advantages compared to contact sensors such as thermocouples.

Single-point radiation thermometers are installed at a distance, and they view the infrared radiation that is emitted by the target object. Their noncontact nature allows them to operate out of harm's way. Because they don't touch the surface, they can accurately measure moving objects, whereas thermocouples suffer from a frictional effect, generating heat and eroding the thermocouple. Pyrometers also feature extremely fast response speeds of a few milliseconds. This makes them very useful for measuring fast-moving strip or rod.

For furnace temperature-measurement applications, pyrometers measure the products in the furnace and not the furnace atmosphere. Noncontact pyrometers outlast contact sensors. They have very fast response speeds and are low maintenance. For some applications, a single-point pyrometer provides enough information for process control. In a hot-strip mill, a single-point pyrometer will measure a stripe (longitudinal profile) along the strip centerline.

With continuous, customer-driven requirements for higher-quality products, it is increasingly difficult to make premium-quality flat products with single-point temperature measurements.

Process Thermal Imaging

Two families of process thermal-imaging systems provide more complete temperature measurements in static and moving product environments.

2-D Thermal-Imaging Cameras

The first family of process thermal-imaging systems is based around 2-D thermal-imaging "cameras." Their radiation detector consists of a matrix of tens of thousands of pixels, each of which is a noncontact temperature sensor. Its focal-plane array then looks through a filter and lens at the thermal scene.

These process thermal imagers differ from portable thermal imagers in several important ways. Portable imagers use very low-power drain detectors. They sacrifice high-quality measurements to extend battery life in a portable imager. Process thermal imagers are built to operate in harsh industrial environments, providing years of continuous thermal imaging. Temperature-measurement accuracy across the entire scene is very important. Power use is not a design factor because they are powered by continuous power supplies. A process thermal imager is capable of viewing and measuring multiple targets in a scene simultaneously.

Figure 2 shows a process thermal imager measuring multiple strands at the exit of a caster. Fifteen areas of interest have been placed on the thermal image, and each is outputting a signal based on the peak temperature in each area.

Figure 3 shows the inside of a reheat furnace filled with pipes. By selecting the correct wavelength, the imager does not see the burners. At the top left of the roof, the image shows cold

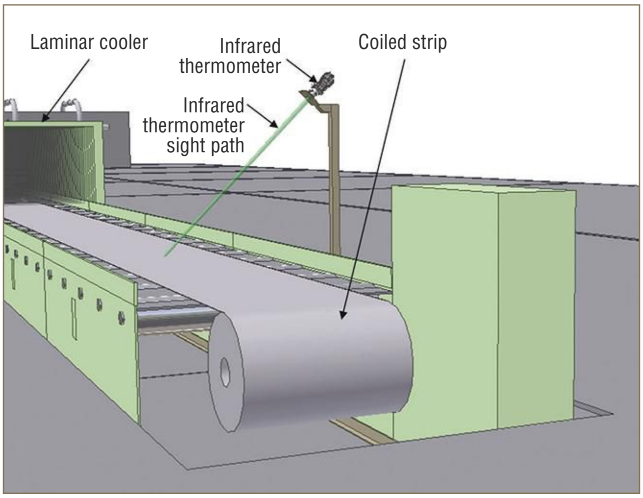

Fig. 1. A single-point pyrometer measuring the centerline temperature of a hot strip.

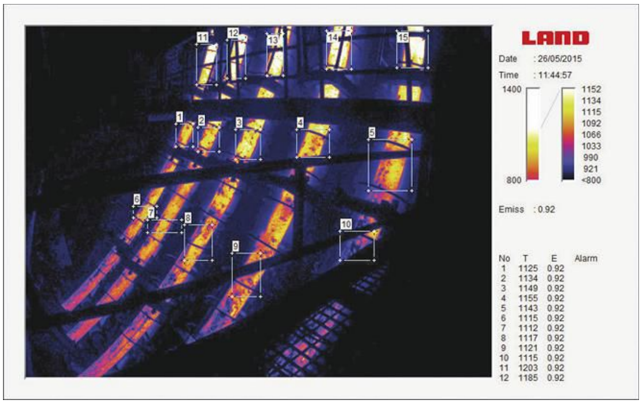

Fig. 2. A five-strand caster exit area. Three temperature-measurement areas are located on each strand.

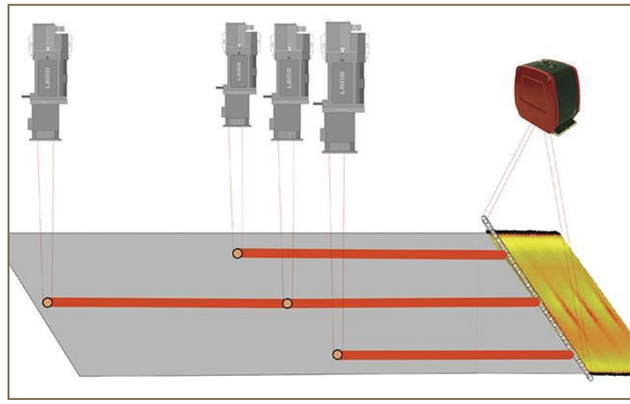

Fig. 4. Comparing a single pyrometer, three pyrometers and a scanner

holes, which are the burners with the cold fuel entering. It also shows the heating effect on the furnace roof (yellow stripes), but the flames themselves are invisible. Once the correct pipe temperature is reached, the pipe is pushed from the furnace. Not only can the imager measure the product temperature, it also shows the temperature balance within the furnace.

Line Scanners

A second family of process thermal imagers has evolved that is specifically designed to measure temperatures from edge to edge of moving products. These are commonly known as line scanners, or simply scanners.

Scanners consist of an extremely fast-response-speed radiation sensor that "looks" at the end of an inclined mirror. The mirror is attached to a high-speed motor that rotates. In this way, the pyrometer scans through a viewing angle, allowing it to "see" and measure objects along that scanned line. The scanner view is usually through a durable sapphire window that seals the enclosure. For flat products, edge-to-edge temperature variations can cause significant quality problems, and multiple pyrometers are required to provide more coverage.

Once multiple sensors are used, measurement costs increase and there are still unmeasured gaps. For example, pyrometers may have an accuracy specification of +/-0.3%, so one may be within specification and measuring 0.29% high and another may be similarly within specification and reading 0.29% low. In that example, there's almost a 0.6% difference between the two sensors, which have both passed the manufacturer's +/-0.3% accuracy testing. At 1200°C, that is over 7°C difference. Figure 4 shows the different measurement areas from single-point pyrometers versus a scanner.

In a fraction of a second, the scanner can scan a temperature profile through an 80- or 90-degree angle and sample 1,000 discrete temperature points. That is like having 1,000 radiation spot thermometers across the process with each one having the exact same matched calibration. Because a single sensor makes all those temperature measurements, there are no differential accuracy errors like there are with separate pyrometers. So, if the scanner indicates one edge of the strip is 3°C hotter than the other edge, it really is.

Compared with a process thermal-imaging camera, a scanner is superior for products with a linear movement. Conversely, a scanner isn't capable of producing a thermal image of a static scene, such as the inside of a furnace, and a process thermal-imaging camera is best suited to that environment.

Fig. 5. A scanner is mounted at a continuous caster exit, after the straightener, just before the slab is cut. The red water-cooled protective enclosure houses the scanner and is mounted above an angled heat-deflecting plate.

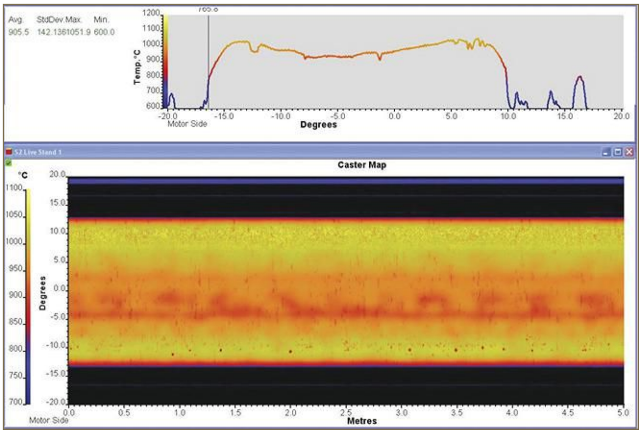

Fig. 6. Thermal image and cross profile of slab produced by scanner software

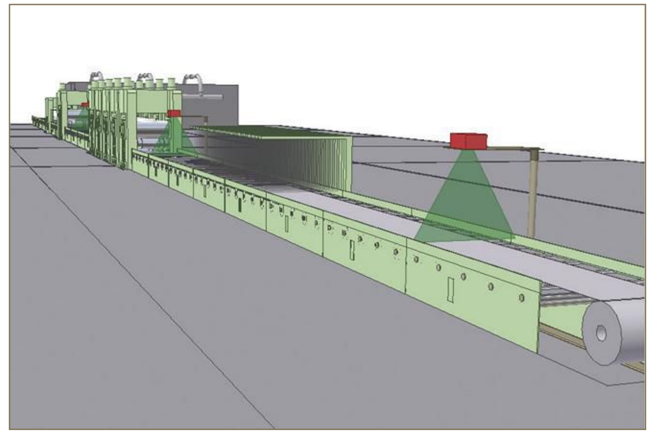

Fig. 7. Scanner rapidly measuring temperature profiles across the strip preceding the coiler

Scanners operate at frequencies up to 150 scans per second and measure 1,000 data points in each scan, producing a cross profile. They are ideal for fast linear-moving products in a rolling mill. These profiles are rapidly stacked together to provide a real-time thermal image of the product. This high-density thermal image is extremely useful in understanding the thermal properties of a product.

Figure 8 is the thermal image from a scanner in the same location. Notice the operator side of the strip is approximately 50°F colder than the centerline and drive side. The temperature profile produced by a scanner at the last finishing stand showed a flat temperature profile, so it was easy to determine that the problem was caused in the laminar cooling section. The red stripe marked on the image shows the area that would have been measured with a single-point pyrometer, which would not detect the temperature imbalance. Scanner zone outputs across the whole width of the strip provide signals to feed back to edge-masking controls in the cooling section.

Scanners typically communicate with PC software that provides displays of thermal profiles and images. The software also has comprehensive database and archive capabilities, which help analyze the thermal data more easily. Scanners also can communicate directly with PLCs and distributed control systems. Alternatively, scanners can provide analog or digital outputs for edge-to-edge temperature control.

In-Process Sensors

Many mills now frequently have multiple scanners along the length of a process line. These scanners can track product from the exit of a reheat furnace, past the descaler, into the roughing and finishing mills and then to the coiler. These systems provide a complete understanding of the process along with any areas in need of improvement. Single-point pyrometers are incapable of revealing edge-to-edge temperature variances. They only reveal a centerline temperature profile.

Another common measurement position for a scanner is inside a continuous-annealing line after the last control zone and before the strip enters the snout just before coating. At this location, a scanner provides detailed edge-to-edge thermal-profile data. Scanner zone outputs are fed to a control system to adjust the heaters necessary to achieve the correct temperature profile in the last control zone. Once a uniform temperature profile is achieved, the molten zinc will naturally coat the strip with an even thickness.

Figure 9 shows a thermal image from a scanner measuring coated strip. Notice the banding caused by an eccentric roll that

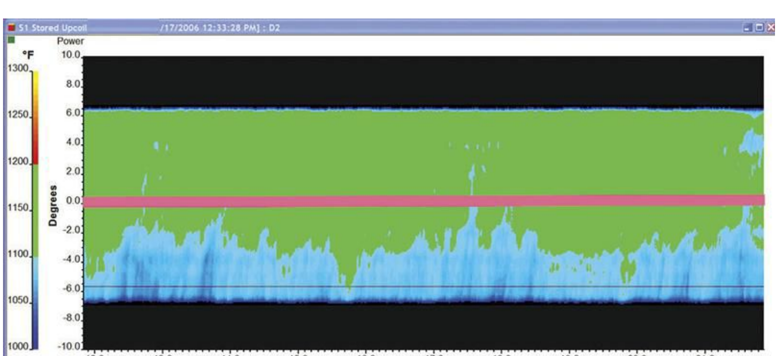

Fig. 8. Cold operator side caused by improper cooling. The red stripe shows how a single-point pyrometer would miss the problem.

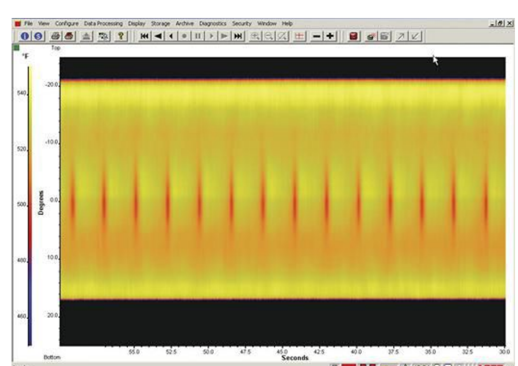

Fig. 9. Coated strip showing cold stripes caused by an eccentric roll.

was conducting heat away from the strip. By comparing the X-axis time scale and line speed, it was easy for the mill to identify which roll was causing the problem.

Flat-rolled products can suffer from uneven grain size caused by uneven temperature distribution. Camber problems can result from uneven temperature distribution. By producing steel with the required temperature characteristics from edge to edge, less scrap is produced, resulting in quality steel and higher yields. In addition, the addressable customer base for the steel is larger, and the producer can command higher prices.

Line scanners typically cost the equivalent of three pyrometers but have far-better features, capabilities and accuracy along with providing 1,000 measurements. Line scanners are simple to install and require just one cable that carries both power and Ethernet signals, so installation costs are minimized.

Conclusion

In today's world, markets require higher quality and companies expect improved profitability. Complete temperature measurement with line scanners and process thermal imagers provides a total picture of the product's temperature distribution. With this information, more-precise process control is possible, resulting in improved-quality products and satisfied customers.

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