Non-Contact Temperature Measurement for Wrought Aluminum

By Richard Gagg, AMETEK Land

Accurate temperature measurement is critical in aluminum rolling and extrusion processing. This article will address the importance of accurately measuring the temperature at various stages in the manufacturing of these wrought aluminum products, particularly rolled aluminum, presenting both challenges and solutions.

Sensor Types

There are two main sensor types: contact temperature measurement sensors and non-contact pyrometers. Contact temperature measurement sensors, such as thermocouples, work in direct contact with the material being measured. They are not suitable for continuous temperature measurement in manufacturing methods with moving products, such as rolling or extrusion. Since the temperature reading can vary depending on the amount of pressure applied, the probe must also be in contact for a few seconds in order to stabilize the product's temperature. Furthermore, contact probes can mar the surface finish of the final product.

Non-contact pyrometers—either radiation thermometers or process thermal imagers—have none of the surface contamination issues associated with contact probes and are ideally suited for moving products. Pyrometers can respond rapidly, usually in less than 20 ms. Their non-contact operation means that they can operate for many years with little or no maintenance, since they simply view the radiation that is emitted from the material surface. Non-contact process thermal imagers, which are able to provide a wider temperature scan of the material, are especially suitable for flat strips and slabs, where measurement of overall temperature uniformity is important.

Measurement Challenges

Aluminum alloys have unique emissivity and reflectivity characteristics that pose challenges in using conventional pyrometers. Emissivity is the ability of an object to radiate energy. Unlike other common metals (such as steel), aluminum alloys have a very low emissivity of less than 0.1. This means that less than 10% of the energy within the metal is capable of being radiated away from its surface. In other words, a person can stand close to a hot aluminum billet and not feel any heat. The billet would also not have the appearance of being hot, unlike steel (with a much higher emissivity value of 0.85) which appears red at high temperatures. In comparison, aluminum will still appear cold, even at temperatures as high as 600°C (1,112°F).

Due to this low emissivity, a pyrometer viewing the aluminum will receive a low signal, indicating a falsely low temperature reading. Therefore, the pyrometer signal needs to be compensated by applying an appropriate emissivity correction (gain) factor. For example, if the emissivity value of the aluminum alloy was 0.1, the signal would need to be amplified by a factor of 10 to indicate the correct temperature. Furthermore, the emissivity value of the aluminum will vary with the chosen wavelength, alloy grade, and surface condition, including changes based on developing oxidization. Any slight change in the emissivity will also need to be amplified by 10x in the emissivity adjustment amplifier.

With a lower emissivity, there is a corresponding increase in reflectivity (E = 1-R, with "E" representing emissivity and "R" reflectivity). For example, a household mirror (which has a rear surface coated with unoxidized aluminum) has an extremely low emissivity. This makes it difficult to see the surface material of the mirror; instead the viewer sees only their own reflection. Likewise, a pyrometer can pick up reflection errors, as the aluminum surface reflects radiation from its surroundings.

Solutions

Conventional single-wavelength pyrometers are unable to cope with the combination of low and variable emissivities that are prevalent with aluminum alloys. Alternative ratio pyrometer designs also are unsuccessful, as the emissivity at their two measurement wavelengths changes at variable rates. A ratio pyrometer's non-greyness adjustment cannot compensate accurately for various aluminum alloy types.

However, a few pyrometer manufacturing companies have developed accurate non-contact temperature sensors specifically designed for use with aluminum. These devices are a true step forward over the use of contact measurement probes. They are typically multi-wavelength devices that utilize signal conditioning algorithms that have been developed from extensive on-site data collection and analysis. The application algorithms are each specifically developed for the unique conditions found at various measurement locations, depending on whether the pyrometer is implemented in a hot rolling mill or an extrusion plant. Pyrometers designed for aluminum applications typically utilize short-wavelength detectors and filters that operate at wavelengths shorter than 2.8 μm.

Even with such sophisticated pyrometer designs, there are still methods of installation and fundamentals of operation that must be understood for reliable and repeatable results. For example, if the pyrometer is located in a very hot environment—typically above 70°C (158°F)—the user needs to cool the pyrometer with an optional protection jacket or plate. This will prevent drifting temperature readings or long-term damage. It is also a good idea to purge the pyrometer lens with air in order to avoid any build-up of dirt or oil.

Addressing Reflectivity: Shiny, low emissivity aluminum is a good specular reflector and the reflections off the surface follow a clear trajectory: the angle of incidence equals the angle of reflection. In other words, incoming light or radiation from an object in the surroundings hits the aluminum surface and is reflected in an equal and opposite direction from the surface. For example, both building window glass and the glass bulbs used for electrical lighting can transmit radiated energy in a broad wavelength, ranging from around 0.3 μm in the ultraviolet and through the visible spectrum to the near infrared and into the infrared at approximately 2.8 μm. That means that a pyrometer operating anywhere within that waveband can detect and measure energy that transmits through transparent windows and light bulb envelopes. That energy filtering through windows and light bulbs may then bounce off the highly reflective aluminum surface, creating an additional energy measurement that can falsely inflate temperature readings.

Reflections seen with the human eye are not the only ones that can affect temperature measurement. Most stray reflection sources exist in the infrared part of the spectrum, such as those from a nearby furnace or hot drive motor. The worst case regarding infrared reflections is sunlight shining through a skylight or window. In this case, the readings can vary dramatically as clouds pass by.

Fortunately, it is relatively easy to avoid a reflection error by simply determining the angle or direction of significant radiation sources, such as windows, skylights, lighting, or hot objects (Figure 1) and aligning the pyrometer so that it avoids viewing reflected energy from the aluminum surface. For example, angling the pyrometer slightly towards a shadowed area of the product being measured prevents any unknown reflection influences (Figure 2).

In some cases, the sources of the reflections may be so large or numerous that a radiation shield may need to be placed close to the aluminum surface (Figure 3). Such a shield, like a piece of corrugated metal sheet, will cast a shadow on the measurement area and prevent those reflections from contributing to the pyrometer's reading.

In certain situations, such as in cold rolling mills, the combination of low product temperature and low emissivity can make it extremely difficult to select the correct measurement position in order to avoid ambient reflections from the relatively hot surroundings. In these cases, the wedge technique can be applied. When aluminum strip partially wraps around a deflecting roll, the interface where the strip meets the roll is referred to as a wedge (or roll-nip). This cavity generates multiple reflections, which integrate to form a location with a very high and stable emissivity. Slight changes in strip surface condition or alloy types will have negligible effect on the emissivity within that cavity. Additionally, because of the high emissivity of the cavity, it is immune to reflections from the surrounding area.

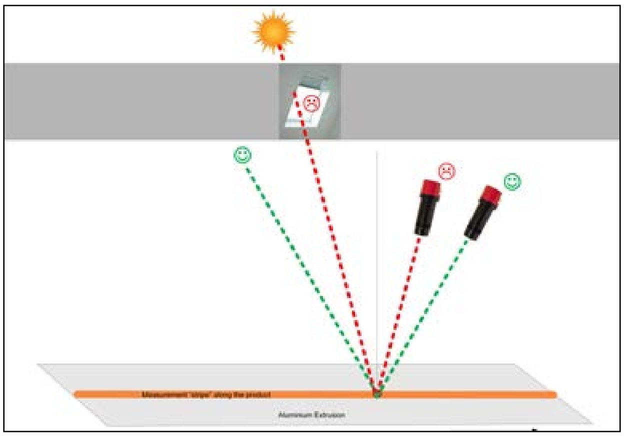

Figure 1. By understanding where reflections come from, a pyrometer can be aligned to avoid them.

Figure 2. A pyrometer positioned at a slight angle to avoid reflections on profiles as they exit the quench area.

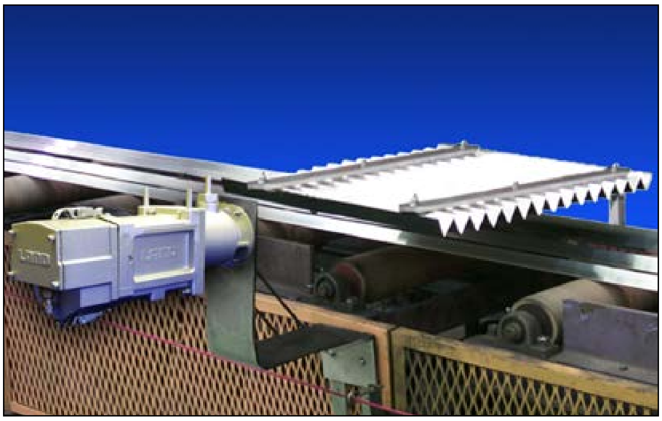

Figure 3. Reflection sources can be blocked with a radiation shield to prevent reflection effects.

A pyrometer aimed into the wedge cavity at a shallow angle will accurately measure the strip temperature (Figure 4). Therefore, the pyrometer does not need to be an application-specific type. However, it should have a relatively narrow field of view in order to maximize its ability to sight deep into the wedge. It is assumed that the strip and roll surface temperatures are the same when the aluminum strip is in contact with the roll for 25% or more of its circumference.

Process Thermal Imaging

With wide, thin products like aluminum strip, it is important to understand the temperature distribution across the entire surface. Assumptions derived from a single centerline temperature measurement may result in low-quality end products with camber or uneven grain size issues. Process thermal imaging is able to provide temperature measurement across the entire strip surface.

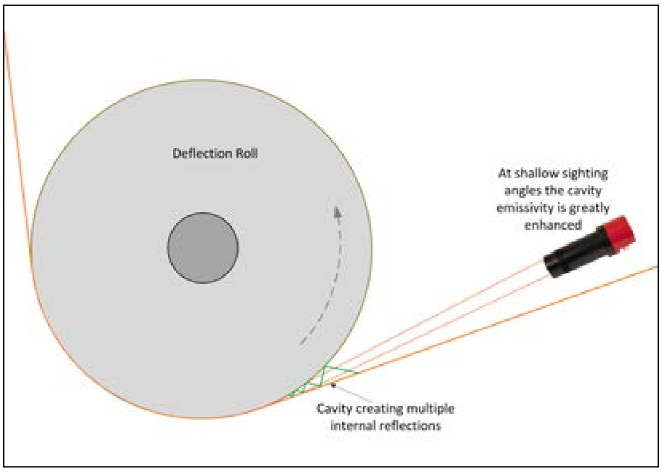

Figure 4. Pyrometer sighted into the high emissivity wedge formed by the strip contacting a roll.

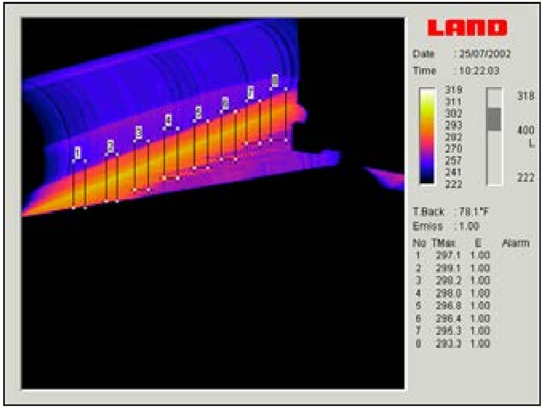

Figure 5. Thermal image showing areas of interest intersecting the wedge.

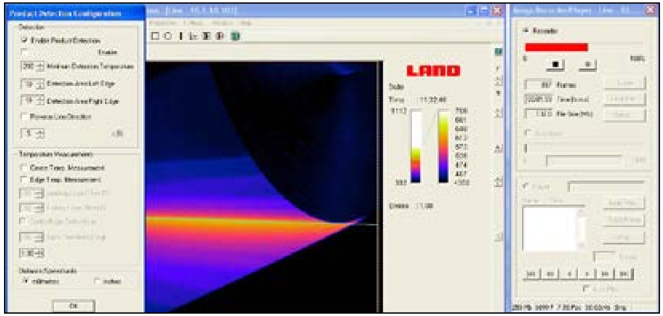

Figure 6. Thermal image of strip joining the coil.

Figure 5 shows the temperature measurement of a wedge cavity where aluminum strip meets a deflection roll. In the image, the temperature appears higher in the line of the wedge, but this is not because the temperature is actually higher. Rather it's that the emissivity is almost ten times higher at that point (very close to 1.0). The eight rectangles in the thermal image were selected by the end user as areas of interest to intersect the wedge. Each rectangle has a computational function, in this case "peak." Despite any slight movements of the strip upwards or downwards the peak temperature (in the wedge cavity) in each area of interest is accurately measured.

A similar measurement can be made by the thermal imager at the end of the rolling mill at the coiler (Figure 6). In this case, a process thermal imager views the wedge cavity that is formed where the strip joins the coil. The image software dynamically tracks the position of the wedge as the coil diameter grows. Lanes of data from one edge to the other can be defined, and those values fed back to the controls. These lane values are typically sent as OPC values or current outputs.

Thermal imaging can also provide a "line scanner" view of the strip. This view allows an operator to quickly visualize the temperature distribution along the entire strip from head to tail.

Conclusion

It is important to prepare for temperature measurement by spending time to understand the measurement environment regarding the ambient temperatures and potential sources of reflections. With those variables considered, a pyrometer or process thermal imager can be installed that will provide many years of accurate and repeatable temperature measurements. Once the temperatures of aluminum wrought products are accurately measured by non-contact means, both product quality and production yields will improve.