Temperature Measurement in Induction Heating Applications – Methods and Innovations

by Albert Book

Pyrometers are used to measure temperatures in induction heating processes. One can choose between single-wavelength and dual wavelength techniques. This article explains how these two techniques differ with regard to function, optics, and operability, and how each will impact measurement data. Furthermore, the latest technological advances are described.

Advanced induction heating systems are widely employed in today's forging industry for hot-forging applications. Prior to forging, steel is heated to a temperature between 1000 °C and 1250 °C. The required process temperature depends on the carbon content and the specific alloying elements of the steel. Hot forging requires uniform heat distribution across the width and the length of the workpiece. The billet is heated to a temperature above its recrystallization temperature. There are various ways to heat metal in hot forming. These include induction, gas and oil fired furnaces, infrared radiation and electrical resistance heating. Induction heating offers distinct advantages: quick heat up, uniform heat distribution, and precise temperature control.

Significance of temperature measurement

Steel billets, by far, represent the majority of hot-formed billets, although other materials including titanium, aluminum, copper, brass, bronze, and nickel are also induction heated for hot forming. Steel alloy grades are not necessarily always of the same precise composition. For example, most plain carbon and low alloy steels can have a carbon content of about 0.05%. Variations in the steel's carbon content can result in deviations of 90 °C in the solidus temperature. Hence, the optimal forging temperature within a single grade can vary, depending on the precise chemical composition of the steel.

Steelmaking operations have improved over the years and the steel that is obtained from a reputable supplier will often have a very consistent chemical composition. Nevertheless, the possibility of variations in the chemistry of a given steel demand precise temperature control. Successful forging operations require an awareness of the steel's specific physical properties which permit precise adjustment of process control parameters.

Fig. 1 *Billet rejection based on temperature*

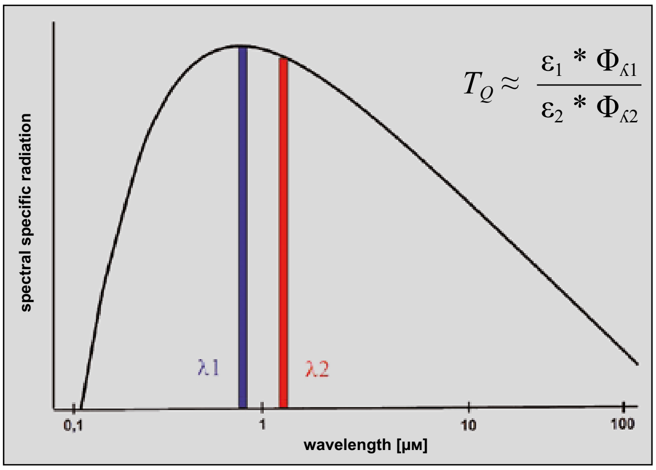

Fig. 2 *Two-colour pyrometers detect radiation at two wavelengths and produce a temperature reading based on the ratio of these intensities.*

Factors which influence billet temperature

Both the amount of power applied to the billet as well as the production rate of the induction line will determine the temperature of the heated billet. The heating power controls the amount of current provided to the induction coil. The electrical energy is transformed into heating energy inside the billet by the help of induction coil box. The speed at which the billets are pushed through the induction line will dictate the temperature of the billet as well. Other parameters which will influence temperature and process efficiency are the diameter of the induction coil box hole and the cooling rate of the heater coil.

Pyrometer Temperature Measurement

For temperature control, induction heating systems use pyrometers, also known as infrared thermometers. These instruments measure temperature without contact and have no wearing parts. Based on Planck's radiation law, a pyrometer captures the infrared radiation and converts it to a temperature value.

Within milliseconds, and from a safe distance, a pyrometer detects the temperature of the billet at the moment it exits the inductor. The temperature data serves as a process control variable or as criteria for rejecting billets whose temperatures were not within the permissible range (**Fig. 1**).

Two different techniques

Pyrometers can be divided into single-colour and two-colour pyrometers. Single-colour instruments detect infrared radiation at one spectral waveband. The two-colour technique lets the pyrometer detect the radiated infrared energy simultaneously at two separate wavelengths. The pyrometer calculates the temperature based on the ratio of these two intensities (**Fig. 2**).

Both kinds of pyrometers—single-colour and two-colour—are employed in induction heating processes. Selecting the right instrument will depend on a number of factors: required accuracy, desired device versatility, ease of operation and purchase price.

Impacts on the measurement and factors to consider

Dust, smoke and steam

When particles and partial obstructions in the line of sight weaken the signal at each of the two wavelengths to the same degree, the ratio of the two intensities of a two-colour pyrometer remains constant. The measurement will not be impacted. A two-colour pyrometer continues to yield highly accurate and reliable temperature data even at signal attenuation of up to 90%. With a one-colour pyrometer, attenuation will immediately lead to a faulty measurement.

Contaminated lens

A protective quartz window attached to the pyrometer or the glass of a furnace porthole will not affect a two-colour measurement. In order to obtain accurate temperature readings using a single-colour pyrometer, the transmissivity of the specific glass must be considered by adjusting the emissivity or transmission setting. A dirty lens leads to signal attenuation and produces temperature readings which are inaccurately low.

Signal attenuation

Obstructions in the line of sight or dust and dirt on the lens will reduce the amount of infrared energy reaching the sensor. The latest two-colour pyrometers feature a signal intensity monitor, a function which triggers an alarm when a user-configured signal attenuation threshold is exceeded. This feature ensures the reliability of the measurement data. Routine lens inspections become unnecessary because the pyrometer itself indicates when the lens has become too dirty. This is not technically feasible for single-colour pyrometers.

Small targets

With single-colour pyrometers, the object to be measured must be larger than the pyrometer's target spot. The single-wavelength technique produces a temperature reading based on the average of the entire infrared radiation captured within the spot. When the object does not completely fill the spot, the sensor will receive radiation emitted from background objects as well. If this background is cooler than the object, the temperature reading will be too low.

This is not the case with two-colour pyrometers. If the targeted object does not fill the spot, the reduced signal will not influence the temperature reading. With the two-colour technique, a pyrometer will still produce accurate temperature readings when the object itself is up to 80% smaller than the circular target spot. The percentage that needs to be filled depends on the material's surface emissivity and it's temperature.

Ideally, the actual position of the object within the target spot should not make any difference. The pyrometers available on the market differ, however, in terms of quality. If the billet is captured closer to the peripheral rim rather than in the center of the spot, this would affect the measurement. Instruments which feature simply designed optics, poor error correction capability and cheap sensors will exhibit temperature reading increases of 20 - 30 °C -- even when the actual billet temperature remains constant. (**Fig. 3**).

Applications in which the billet's diameter is hardly wider than the diameter of the pyrometer's target spot will require especially precise alignment.

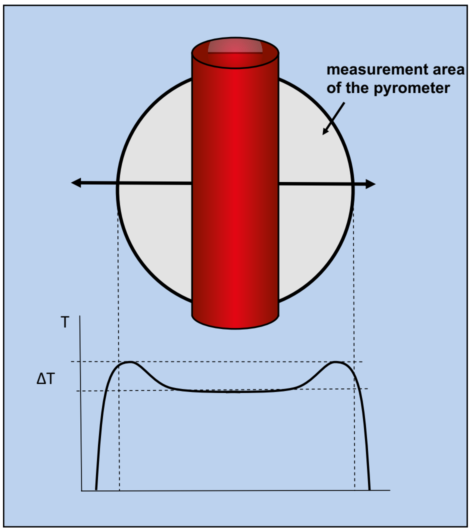

Fig. 3 *Simple two-colour pyrometers will erroneously indicate an increase in temperature if the billet is in the peripheral area of the target spot.*

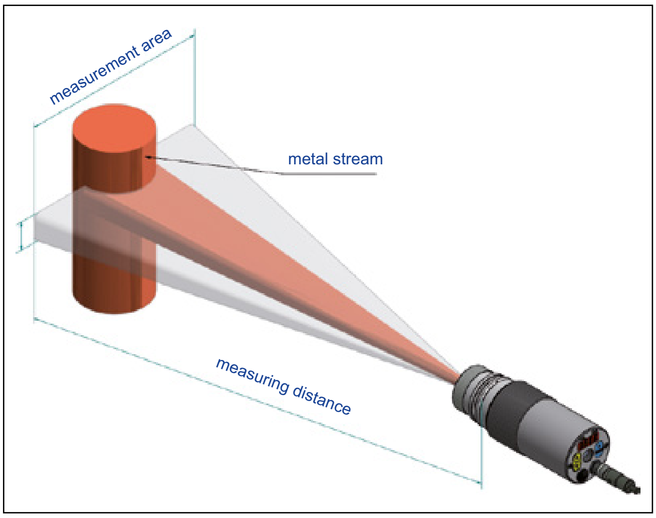

Fig. 4 *Rectangular measurement area enables easier alignment*

A two-colour pyrometer is much easier to use in such situations. It is much less sensitive to the effect of partial illumination within the spot and thus the precision of the alignment is not nearly as crucial to the accuracy of the data.

Pyrometers which feature a rectangular measurement area have recently emerged on the market. These instruments are even easier to focus onto the target object because they permit an even wider range within which the object may move (**Fig. 4**).

Distance to the target and size of target object

Another difference between the two pyrometer techniques is the degree to which changing target size and distance will influence the temperature reading.

When measuring at a single waveband, the focus distance must be precisely maintained in order to yield accurate results.

Induction heating systems often utilize single-colour pyrometers with fix focus optics. When selecting the installation position, the exact focus distance must be observed. In actual practice, however, the required focus distance may not be feasible due to installation constraints or instruments with adjustable focus capability are sometimes adjusted incorrectly.

The situation becomes worse when the induction line processes billets of varying sizes. When the billet diameter changes, the distance between sensor and target changes as well, and some of the billets will be out of focus.

The degree to which incorrect focusing will lead to measurement error depends on both the size of the object and the quality of the pyrometer's optical system. When the pyrometer's measurement spot is only slightly larger than the target object, this can lead to substantial error, particularly with single-colour pyrometers.

The chart below (**Fig. 5**) shows how the pyrometer's temperature reading changes according to the diameter of the billet. If, for example, the billet diameter doubles from 16 mm to 32 mm, a pyrometer with high quality optics will indicate a temperature increase of only 1 °C. In contrast, a pyrometer with simple, inexpensive optics will indicate a temperature increase of 6 °C. Assuming the billet's actual temperature is 1000 °C, and based on a diameter of 16 mm, the superior instrument will generate a measurement error of 1.2 °C whereas the temperature reading of the inferior instrument will deviate by 10 °C.

When two-colour pyrometers are employed, errors and deviations resulting from factors such as a varying distance or size, or incorrect focusing will be negligible.

Pyrometer optics

The „size of source effect" (SSE) specifies the optical factor which influences the accuracy of the temperature measurement.

A pyrometer's SSE indicates the quality of its optics by showing the target spot size with reference to the amount of energy the sensor receives from the radiant target. For a true comparison of the quality of pyrometer lens systems, one must compare the SSE curves. If manufacturers specify a target spot size with reference to 90% of the total radiant energy received, a pyrometer featuring high-grade optics will achieve a spot diameter of Ø10 mm whereas a low-grade lens system will have a larger spot size of Ø14 mm (**Fig. 6**). With reference to 95% of total energy, the superior optics will achieve a spot size of Ø11.5

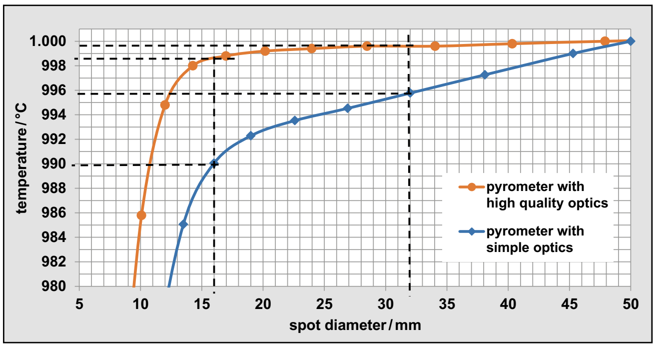

Fig. 5 *The effect of target object size on the temperature reading*

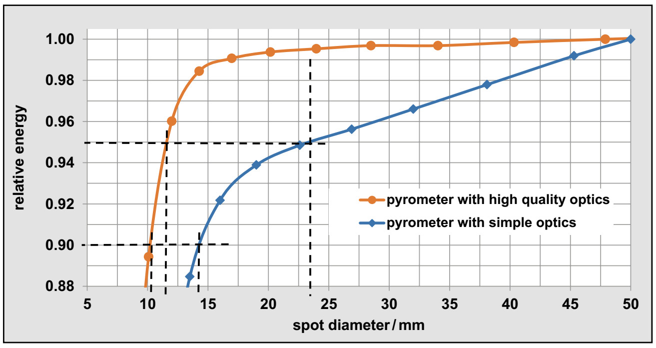

Fig. 6 *Comparison of the SSE curves of two pyrometers with high quality and simple optics*

mm whereas the spot obtained by inferior optics will increase considerably to Ø 23 mm. This illustrates why manufacturers of pyrometers which feature less sophisticated lens systems will, in their data sheets, specify the SSE based on a smaller percentage of relative energy in an attempt to suggest a smaller spot size.

The position and size of the target spot is either indicated by a spot light or can be viewed by through-the-lens sighting. The latest pyrometers on the market now feature an integrated video camera for sighting and monitoring (**Fig. 7**).

A video camera makes it much easier to maintain correct alignment and focusing because the target can be viewed from the control room. The video camera's TBC (target brightness control) dynamically adapts the light sensitivity to the target object captured within the measurement spot to produce a high-contrast image of the target. The temperature reading and the circled target spot are superimposed onto the image.

A separate digital display unit is not needed to show temperature data. Sometimes a laser is used to indicate the target. The disadvantage of laser sighting is that the laser pinpoints the position of the target spot but not its exact size.

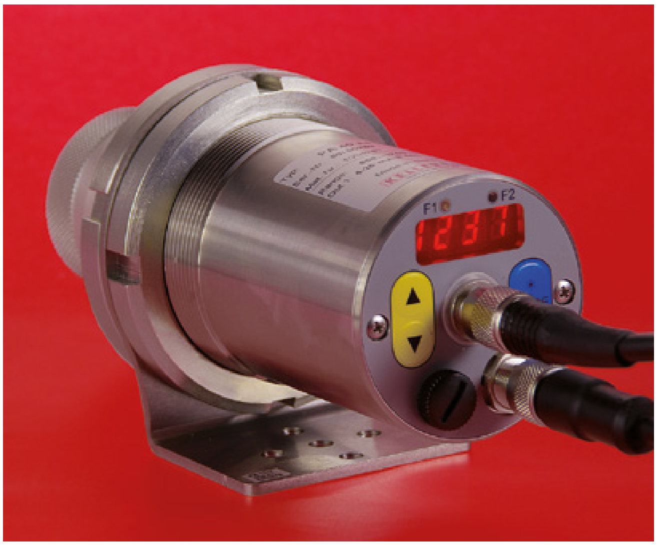

Fig. 7 *Latest innovation: pyrometer with built-in video camera and TBC feature*

Pyrometers with inexpensive or simply designed lens systems will correct for aberrations in the visible range but not in the infrared spectrum. In this case the target spot as indicated by the viewfinder will not correspond to the actual spot size and focusing distance of the measurement. The pyrometer operator runs the risk of an incorrectly focused target.

The measurement uncertainty which stems from the quality of a pyrometer's lens system is often underestimated. The potential for measurement error due to poor quality optics is much bigger than commonly assumed, however often disregarded when pyrometer comparisons are made. Instead, pyrometer purchase considerations often place undue emphasis on the manufacturer's data specifications regarding metrological error.

Two-colour pyrometers are generally much less susceptible to optical impairments to the measurement than instruments measuring at a single waveband.

Surface characteristics

The emissivity of a material's surface is another significant aspect to consider in pyrometer measurement. The effect of emissivity on the temperature reading is quite different for single and dual waveband techniques. For single-colour pyrometers, the wrong emissivity setting will directly produce inaccurate data. In actual practice, emissivity varies according to material and surface characteristics. It is difficult to avoid error. The potential for error will depend on the sensor's spectral response. The shorter the wavelength, the smaller the influence of emissivity on the measurement (**Fig. 8**).

In applications where the effect of emissivity must be kept as low as possible, narrow band pyrometers with a spectral response of ≤ 1 *μ*m are usually the best choice. The limitation of these pyrometers lies in their measuring range which starts at approximately 500 – 600 °C; they cannot be used for low-temperature applications.

Two-colour pyrometers have the advantage that emissivity fluctuations (when they are equal at both wavebands) will not have any effect whatsoever on the temperature indication. Thus, when two-colour instruments are used, the target's specific material characteristics and surface properties can be disregarded.

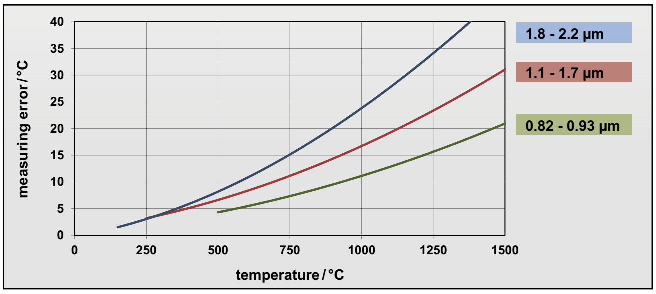

Fig. 8 *Measurement error of single-wavelength pyrometers with different wavelength when emissivity changes by 10 %*

Temperature reading and data communication

Induction heating systems in Europe are commonly equipped with a temperature measuring device. The process control system ensures that process parameters are maintained. Billets that have not reached forging temperature or have been overheated automatically end up as rejects.

In countries which employ less advanced technologies it is still common to find flame heating which does not permit precise temperature measurement. Induction heating is becoming more popular, however, and forging operations are increasingly switching to induction heating lines. In the process of retrofitting their equipment, forging companies often purchase a temperature measuring instrument as a stand-alone device. For such applications, it is beneficial to use an intelligent digital display unit to enhance the pyrometer's rapid signal processing to automatically generate accurate billet temperature data. The display unit, by means of switch relays and valves, controls billet sorting based on the configured process temperature. This may or may not include separate sorting equipment, depending on how the production line is configured. More recently the market has seen the emergence of display units which can count and log the number of accepted and rejected billets. This recorded data can be exported to a connected PC or the user can choose a wireless data communications option such as a Smartphone with Bluetooth interface. A forging company which employs a self-sustained (non-integrated) temperature measurement device will only detect billet irregularities after the accept/reject data has been recorded and evaluated; only then can the operator intervene in the production process.

Conclusion

Precise temperature control is essential towards achieving the highest possible efficiency in induction heating of billets.

Single-colour pyrometers yield good results when production parameters such as target size, focus distance, material and surface properties remain constant, and when the measured object is at least 3 to 5 times larger than the pyrometer's spot size –provided that the pyrometer itself is equipped with a high-grade lens system which can minimize the potential for optical error. Selecting a short-wavelength pyrometer will also help reduce the extent to which the object's surface properties might impact the measurement.

If, however, maximum data accuracy and ease of focusing are desired, a two-colour pyrometer will be the instrument of choice. Especially applications which involve varying process conditions or line-of-sight impediments such as steam, dust or dirt will benefit greatly from the dual-waveband technique. In most situations, two-colour pyrometers are far superior to single-colour pyrometers.

Budget considerations also play a role in purchase decisions; depending on its features, a two-colour pyrometer will cost 50 – 100 % more than a single-colour device.

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