Safe and Wear-free Temperature Measurement in Induction Heating Systems

by Ralf Körholz

Temperature is the most important process parameter for induction heat treatment. Nevertheless, a precise and long-time stable determination of the temperature is often not quite that simple. A contact measurement with thermocouples is not really practicable in a running production process with moving parts or inductors. Infrared thermometers capture the temperature of the object from its thermal radiation without any contact and are ideal for these measuring tasks. A prerequisite, however, is the correct selection and the correct use of the devices. The following article describes the conditions and the latest technological developments for a safe, precise and longtime stable temperature measurement with pyrometers in induction heating systems.

Even though the temperature in induction heat treatment processes is one of the decisive process variables to reach constant and reproducible conditions of production, measuring instruments are used partly due to the difficulties in the detection of the correct temperature. Instead, the heating process is controlled via the power of the inductor, the feed rate and the heating period. The contact temperature measurement with thermocouples bears some difficulties. In practice, it is not applicable as the measuring object or the inductor moves.

The dissipation of heat by conduction from the object to the thermocouple cannot be avoided when used with small pieces or with small heating zones. The response time of thermocouples is too slow for the fast heating-up time of inductive heating processes. Complicate mechanical solutions would be necessary to reach the workpiece with the contact probe for measurement. In addition, the thermocouple is subject to drift and aging. Therefore the accuracy decreases slowly and the reading values drift continuously. A long-term stable temperature measurement is thus not guaranteed.

This is why non-contact, wear-free and drift-free infrared thermometers are basically ideal to measure the temperature in induction heat treatment processes. These instruments measure the infrared radiation of the object to convert it into a temperature value. However, infrared temperature measurement is more complex than the contact-based method. The radiation energy emitted by the object depends on the material or the surface aspects. With a single colour (spectral) pyrometer, the instrument will display a lower value for the same real temperature when used with brass compared to steel billets at the same setting. The reason is the different emissivity of these two materials. The operator must indeed set the correct emissivity depending on the material he wants to measure. The very question is then how to determine the correct value of emissivity for a specific material and how constant the emissivity remains even at the same material, but at different temperatures and surface textures. As with the contact method, it can sometimes happen that the aiming could be difficult as the heating zone is not necessarily at the same position. For example, in a wire rod mill the wire may fluctuate and thus the position changes periodically. Thus the wire can be out of the field of view of the instrument. Despite of all the advantages of infrared measuring people sometimes forgo to use a temperature measuring instrument due to the difficulties of temperature measurement in induction heating processes. This is often done because of uncertainty and lack of knowledge. Instead the machine is driven by the electrical power, feed rate and heating period in order to create constant production conditions. There is no monitoring or proof about compliance of the given processing temperature then.

In case that the right infrared thermometer has been selected, the today's possibilities of the modern devices are being utilized and the users are also trained to the use, problems with non-contact temperature measurements can be solved and pyrometers can be used successfully for a correct detection of the temperature.

Devices with one-channel as well as two-channel measuring method are used for infrared temperature measuring. A single colour infrared instrument measures the infrared radiation at one wavelength and then computes the temperature. Disturbing infrared radiation changes, such as different emissivity values of the measured object, measurement on objects which are smaller than the spot size of the pyrometer, oxidation on the surface or the presence of dust and steam in the field of view have a direct influence on the measured value. The longer and more broadband the wavelength of the pyrometer, the greater is the error due to these disturbances (**Fig. 1**).

On the contrary, a two-colour instrument is much less influenced. It uses a double sandwich sensor that measures the radiation at exactly the same position and simultaneously at 2 close wavelengths. A ratio signal is computed from these two signals and is calibrated according to the temperature. In case of loss of infrared radiation as described above the ratio value remains constant and the two-colour pyrometer shows still an accurate temperature reading even up to a loss of energy of 90 %. Nonetheless, it may occur that the disturbance does not influence the two channels to the same degree. For these exceptions, the ratio method will lead to an even bigger measuring error.

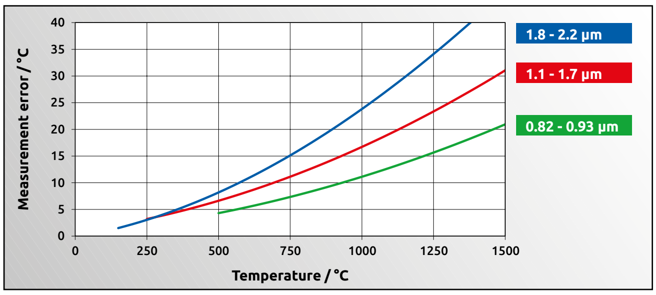

Fig. 1 *Measuring errors of single colour pyrometers using different wavelengths for an emissivity change of 10%*

For reasons of physics one should understand that the emissivity of metals depends on their temperature, their degree of oxidation and scaling and their surface roughness. The emissivity of steel alloys is much bigger than that of non-ferrous metals like brass, copper or aluminium (**Chart 1**).

Material	emissivity / %
Steal	84 - 87
Brass	25 - 35
Copper	50 - 60
Aluminium	15 - 25

Chart 1 *Emissivity of different metals*

The capacity to compensate the variations of emissivity makes the two-colour infrared thermometer more precise and secure when measuring iron and steel alloys. For that reason, they should be preferred to single colour models every time it is possible. State-of-the-art two-colour pyrometers use high resolution lenses. Together with a special software algorithm CSD (Clean Surface Detection), they are capable to differentiate the energy emitted by the oxidized zone from the free-scale zones. Today, high-performance microprocessors in the instruments allow measure in terms of milliseconds and can detect the presence of a new hot object to perform the measurement automatically. The temperature of each new hot object is

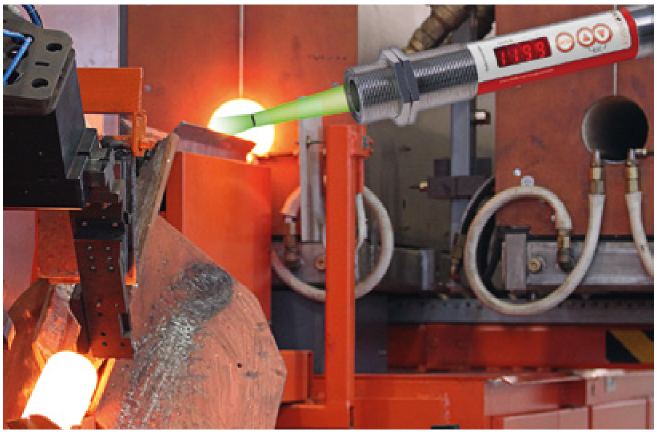

Fig. 2 *Billets which are too cold or too hot can be rejected by switching outputs*

displayed on the instrument and transmitted via the analogue output. Pieces which are too cold or too hot can be rejected by the production line thanks to the use of integrated switching contacts (**Fig. 2**).

In contrast to iron and steel, the wavelength-dependent emissivity influence of non-ferrous metals is much greater. Therefore, the measurement error of a two-colour pyrometer can be significantly larger. In that case, it is better to use a single colour pyrometer with a short wavelength detector. In **chart 2**, you will find an example where the emissivity of brass varies from a value of 25 % to 35%. The last column shows the deviation of reading for different type of instruments at a trues object temperature of 900 °C. For measurement of non-ferrous metals, it is not possible to completely compensate the influence of emissivity but you can minimize it by using a pyrometer with a short and narrow wavelength detector.

type of instrument	wavelength λ	deviation
single colour pyrometer	1.1 – 1.7 µm	±29 K
	0.82 – 0.93 µm	±10 K
two-colour pyrometer	0.95 µm / 1.55 µm	±26 K
	0.95 µm / 1.05 µm	±23.5 K

Chart 2 *Comparison of the measurement deviation*

An infrared thermometer is by essence an optical instrument. Whatever the improvement of the electronics, the quality of the complete optical elements is critical. In order to minimize the measurement deviations caused by the optical components devices with a high-resolution and qualitatively high-end optics are necessary especially for small objects, which are hardly larger than the measurement area of the pyrometer. To avoid optical errors fix focus instruments have to be mounted exactly at the focal distance. For devices with a focusable lens, the focus distance must be adjusted appropriately. However it can happen in practice that products with different diameters are heated up thus the measurement distance varies. As experience teaches, the measurement distance or focus of the devices does not get adapted through the operator, which means that the devices are partly run out of focus distance. Distance and size of the object dependent measuring errors can be greatly reduced by the use of a device with high-quality optics with means with a small size-of-source effect (SSE), as you can see in the graphic (**Fig. 3**).

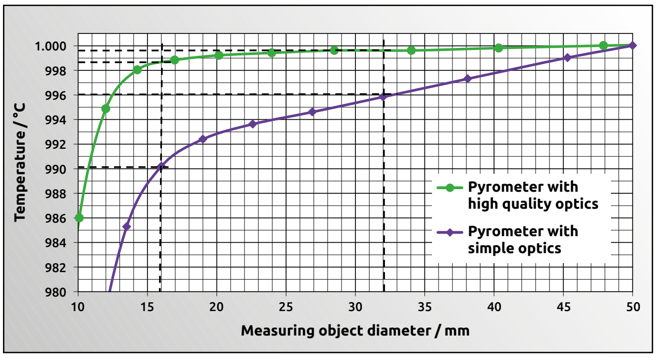

Fig. 3 *Comparison of the optical measuring error of a high quality and an inferior quality pyrometer*

The figure shows the SSE curve of two different pyrometers with high and inferior optical components. If the size of the object doubles from 16 mm to 32 mm, the temperature reading of the high quality infrared pyrometer changes from 998.7 °C to 999.7 °C. The deviation is only 0.9 K. In comparison the measured temperature of an inferior instrument rises from 990 °C to 995.8 °C, which means even by 5.8 K. Based on the true temperature of 1000 °C and an object diameter of 16 mm, the measurement error of the high-quality device is 1.2 °C but 10 °C for the simple instrument which means an uncertainty of 1 % just because of the change of the size of the sample.

The correct alignment, the right focal distance as well as the exact measuring area can be visualized by an LED spot, a through-the-lens sighting or video camera. A laser is less suitable than a spot indicator because, unlike the LED spot light, the laser can only show the center of the measuring spot but does not inform the user of the true size of the measuring area. Moreover, the red colour of the laser will vanish when the object reaches medium high temperature. For this reason, the use of a green LED is highly advised.

To minimize the influence of emissivity changes on the surface of an object, the pyrometer should be installed directly at the very exit of the furnace and perpendicularly to the conveyer.

Background radiations emitted by day or artificial light and other hot sources in the immediate surroundings of the measured object have a negative effect when measuring on shiny metals with high reflection at temperatures less than 400°C. For this kind of application, special devices with a blocking filter have to be used to stop the influence of stray light.

Small objects or moving objects like wires or rods are difficult to measure because of the difficulty to make a correct alignment. The new Panorama pyrometer features a rectangular field of

Fig. 4 *Panorama pyrometer with a rectangular measurement area for a safe temperature measurement*

measurement that makes the alignment very easy. As long as the wires move within this rectangular field of view, a correct measure is ensured (**Fig. 4**).

In the course of the introduction of Industry 4.0 the digital interface replaces step by step the well-known and classic 0/4-20 mA analogue output. This enables the evaluation of additional measuring data, the use of monitoring functions as well as the remote control of smart sensors. Therefore the new IO-Link interface technology evolves more and more standard in machine and plant control due to the high speed communication, the simple wiring by screwed connectors and the universal application in all well-known Fieldbus systems (**Fig. 5**).

Conclusion

New developments in infrared temperature measurement technology in the last few years have led to solutions for the difficulties of temperature measurement with infrared-thermometers. As a result, significant improvements regarding trustable and reliable temperature measurement in heat treatment processes have been performed by using correct and state-of-the-art instruments.

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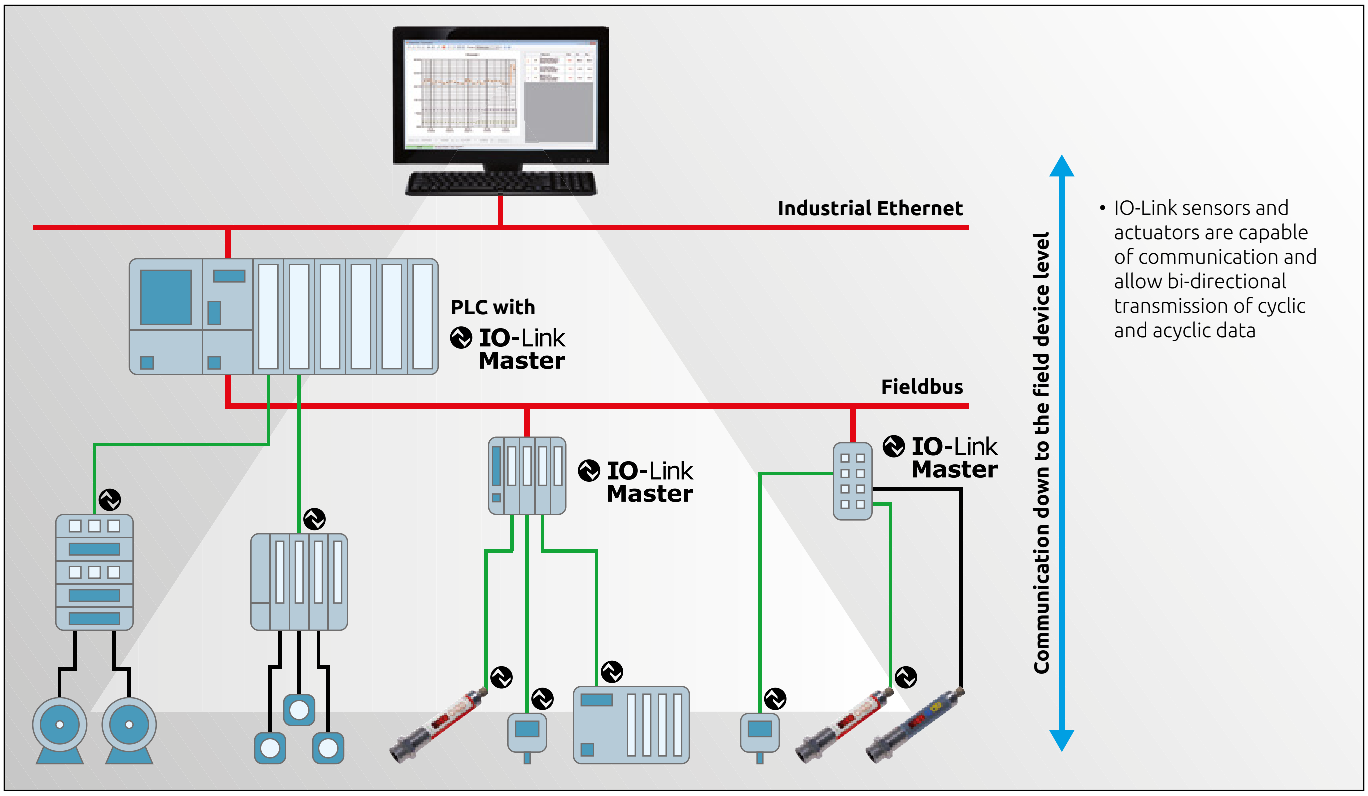

Fig. 5 *Novel IO-Link digital interface for integration into all well-known Fieldbus systems*

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