Meaning and influence of temperature during forge heating

by Albert Book, Alexander Ulferts, Frank Andrä

Maintaining the exact temperature plays an important role for the forge heating. In the event of failing in maintaining it, the waste rate for defective parts increases dramatically and often leads to significant problems in the subsequent forming process.

It is thus all the more important to measure the temperature correctly. To achieve this, you have to choose the right product from all possible pyrometers. The following report deals with the basics of modern inductive forge heating and describes the importance and influence of temperature measurement on the forged part. The devices and functions suitable for precise measurement are here explained.

The efficient heating of semi-finished goods directly before hot forming or warm forming processes in a forging press is increasingly coming to the fore in times of ever-scarcer resources of fossil energy sources. Innovative approaches in the heating process lead to a significant increase of process efficiency and to a reduction of energy loss. Inductive systems like the modular InductoForge™ (**Fig. 1**) offer a modern and individually controllable multi-zone heating of the forging blocks. Classical inductive systems often use a converter and offer very limited possibilities to control the coil capacity precisely. With varying distances of the coil windings the energy input can be changed precisely along the heating line, however, this dimensioning remains static. Neither to different production scenarios nor to changes in the semi-finished product geometry can be reacted dynamically. Here, multi-zone systems have a clear advantage. By the separate controlling of the energy per inductor a locally adapted performance profile can be adjusted along a heating line. The adaptation of the frequency for billets in the temperature range below the Curie point brings about an optimization of the heat source distribution in the workpiece and an efficient temperature distribution by a specific alteration of the electromagnetic penetration depth. The aim of heating is to achieve a homogenous heating of the semi-finished product in shortest time and with minimum energetic expense at the end of the line. In many cases the exceeding of the temperature difference from the surface to the core of +/- 25 K is not allowed.

As an example, **Fig. 2** shows the temperature gradient along a heating line consisting of 3 modules. Very often, the

Fig. 1 *Modular forge heating system* **InductoForge**™.

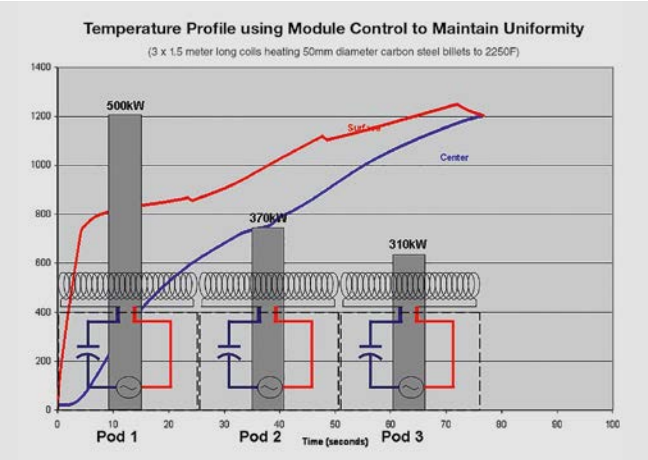

Fig. 2 *Temperature distribution along a forge heating line in the multi-module mode.*

highest value achieved in the first module is memorised, while a considerably reduced value in the last module ensures thermal compensation in the semi-finished product. In practice, with a number of 2 modules, it is still relatively easy to manually record and adjust the process. However, from a number of 3 modules this will be increasingly complex and finding an optimum becomes a gamble. Computer-aided systems such as IHAZ by Inductoheat offer a model-based controlling of the process. Here it is possible to calculate and evaluate a process change in advance. As input variable the system handles the geometrical parameters of the semi-finished product, admissible temperatures and the material characteristics. The temperature profile along the line and the necessary coil currents and capacities are made available as output variable. A typical calculation is shown in **Fig. 3**.

For each module the coil currents are summarized here, which can be transferred to the machine control after successful

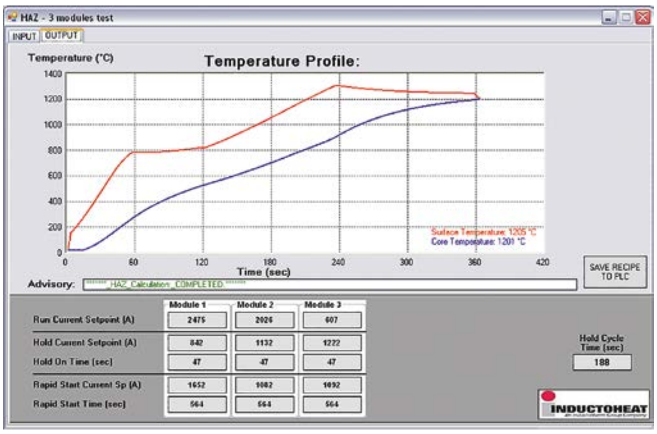

Fig. 3 *IHAZ system for the automatic layout of the inductive forge heating process.*

calculation. Beside the coil currents for the regular heating process parameters for the cold starting of the plant and the holding mode can be determined. In many cases all billets remain in the line after interruption of the production process. After cooling down, the heating line can be restarted elegantly, if all blocks in the line warm up when stationary to the respective average temperature of the zone. Depending on the diameter of the billet and the feed rate, part of the billets can be used directly for forging. The same applies to the holding mode of the plant. Disturbances at the press often lead to the interruption of production for an average time of 5 to 15 minutes; in this case the heating line will be stopped and losses as consequence of temperature radiation to the brickwork will be reduced by active inductive compensation. After restart of the process a larger part of the billets, which are in the inductors, can be re-used for the forging process. The part of billets within the tolerance range of the permissible forging temperature also depends considerably on the mass and the feed rate in the production process. By using intelligent approaches, it is possible to minimize scrap after restarting production.

The energy-efficient design of forging plants requires a higher degree of effort for the thermal isolation of the process. With increasing temperature the thermal losses in fourth power rise analogous to the Stefan Boltzmann law due to the radiant heat arising in the inductor. For this reason, the coils are lined with a suitable material or ceramic tubes are pushed into the inner diameter of the inductor. A temperature measurement within the line can be realized only with great effort. For this reason the non-contact temperature measurement is often preferred at the exit of the heating line. By continuous comparison of the determined temperature of the model and the real temperature of the workpiece, all degrees of freedom are open to readjust the temperature of the semi-finished materials. Variations of the material composition or the microstructure make this necessary on a case-by-case basis.

The experience made with realized projects often shows the following during the temperature measurement: The attractive cost saving in the temperature measuring technology leads more frequently to the decision to use pyrometers working with the same wavelength. The use of protective gas in the heating line is avoided in many forging processes. Consequently, during the heating process larger particles of scale are produced on the surface. The non-contact measurement of heat radiation at the surface is therefore often influenced; parts of the measuring point are shielded by scale so that only part of the radiation reaches the measuring instrument. As a consequence the measured temperature is wrong which may deviate from the

Fig. 4 *Scale particles on the block surface often lead to irritations with the contactless measurement of the surface temperature.*

real value by 200 K. During the transforming process, this often leads to changed flow behaviour of the material and problems with the final quality and in extreme cases to damages to the transforming tool. **Fig. 4** shows in an impressive way the possible development of scale on the surface after the heating up process. In order to defuse this situation of the variances in the measuring process, the situation was discussed and analysed in cooperation with Keller.

By changing the equipment the measurement and further processing could be clearly improved. In the following, the non-contact temperature measurement which is very important for the inductive forge heating is explained and discussed in more detail.

Temperature measurement with pyrometers

For measuring the temperature of forging blocks, pyrometers have been proven for many years. They measure the infrared radiation of the objects and calculate the temperature according to the Planck's law of radiation.

The radiation is measured contactless from a safe distance and is therefore non-destructive for the workpiece. Within a few milliseconds the temperature is measured and used to sort out blocks with an unacceptable temperature or as a controlled variable for the heating process.

Pyrometric temperature measurement

When selecting the devices you can choose between two measuring methods. Spectral pyrometers measure the infrared radiation with one wavelength. Two-colour pyrometers measure the radiation with two wavelengths and determine the temperature (**Fig. 5**) from the ratio between the two radiation intensities. Both measuring methods are used in the forge heating process. The choice depends on the desired measuring accuracy, the desired flexibility of the device and the user-friendliness.

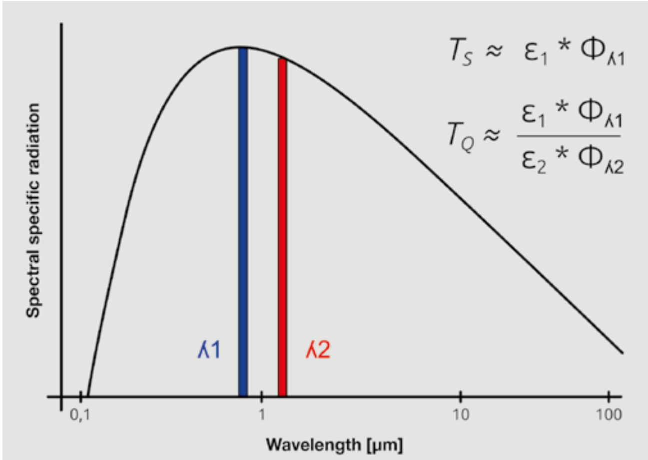

Fig. 5 *Spectral pyrometers measure thermal radiation at one wavelength and two-colour pyrometers at two wavelengths.*

Influences with the measurement of infrared radiation

Since the pyrometric temperature measurement is an optical measuring method, the reliability of the measurement on the surface and the intermediate media in the visual field can be strongly influenced by dust, steam and smoke.

With a spectral pyrometer, the contamination of the lens or the weakening of the infrared radiation in the visual field leads directly to a lower indication. When using a two-colour pyrometer the measured value is not influenced by a signal weakening, as long as the radiation ratio remains constant. Even with a degree of weakening of 90 % a two-colour pyrometer still delivers safe measured values.

One of the major challenges of contactless temperature measurement in forging processes is the scaling and oxidation of the surface (**Fig. 6**). The emissivity, i.e. the radiation ability of the forging block, is thereby extremely changed. For example, with an actual object temperature of 1200°C the measured value varies by 130°C with a change of emissivity between 40 % with bright metal and 80 % with scale. When using spectral pyrometers the measured temperature varies accordingly. In order to smooth the measured value, the average value is therefore often determined in the pyrometer or in the control system. However, the value obtained in this way deviates from the actual block temperature. The range of variation depends on the degree of contamination of the surface. As another alternative, a peak value memory in the pyrometer is used to determine the maximum value within a defined time period. Due to the higher emissivity of the scaled surface, even at a lower temperature, the pyrometer can indicate a higher measurement

Fig. 6 *Radiation ability of the forging block is extremely changed by scaling.*

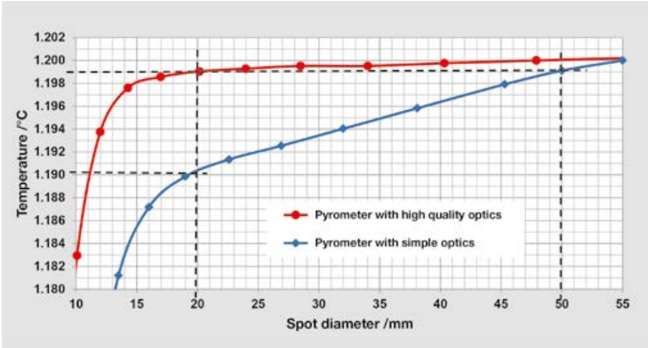

Fig. 7 *The higher the quality of the optics of the pyrometer, the less the measurement is influenced by scattered light.*

value than at the clean spot due to the higher heat radiation of the scaled spot. Therefore, the peak value does not automatically correspond to the block temperature on the clean surface.

In order to minimize the influence of the scale on the measurement, the so-called CSD (Clean Surface Detection) was developed. Based on the quotient measuring method and a very short measuring time, the software algorithm of the CSD function in the pyrometer is able to filter out particularly the measured values of the scale and oxide-free surface. The higher the optical resolution, i.e. the smaller the measuring field of the pyrometer, the more a device is able to detect even small hot spots. While the block moves past the pyrometer, the real temperature is automatically measured on the clean spots and is indicated.

Optical influences on the measurement

Another source of error in pyrometry is the optical imaging properties of the devices. The higher the quality of the lenses and the more optimized the optical structure by a suitable aperture system, the less the measurement is influenced by the so-called scattered light. This is radiation reaching the detector from the outside of the actual measuring field. The scattered light is like a blurred image and enlarges the measuring field. As the graph in **Fig. 7** shows, a pyrometer with a simple optical system still receives scattered radiation from a diameter of 2.5 times (50 mm) compared to the measuring field of ø20 mm of an optical high-quality pyrometer. Since a pyrometer determines the average value of the infrared radiation over the entire measuring field, a device with a small spot size diameter is much better in a position to detect even small hot spots of the clean surface. If blocks with different diameters are heated on a system, this leads to unreal temperature variations in case of devices with simple optics by changing the measuring distance. For aligning the pyrometer correctly and for adjusting it to the correct focus distance, a through-the-lens sighting device, a pilot light or a video camera (**Fig. 8**) are required. High-quality lens systems with minimal chromatic aberration are required to ensure that the visual measurement distance corresponds to the measurement distance for infrared measurement. Precise measurement of infrared radiation at the scale-free areas requires high optical resolution with minimal aberration. Particularly when measuring small billets whose diameter is barely larger than the measuring field of the pyrometer, a spectral pyrometer must be aligned very precisely to the target. A two-colour pyrometer is easier to handle, because it reacts less sensitive to the orientation due to the partial illumination effect. Maintaining the correct focus distance also has a less sensitive effect on the measured value with a two-colour pyrometer than with a spectral pyrometer.

Integration into control system

The analogue current output is often still used for the transmission of the measured values to the control system. However, with the introduction of Industry 4.0, interference-free digital signal transmission prevails more and more. The integration of devices with a manufacturer-specific, digital interface is inflexible and connected with a high programming expenditure.

With the introduction of the new IO-Link interface technology, a generational change takes place in the field of digital communication. With IO-Link a standardized, manufacturer-independent and fieldbus-independent communication concept

Fig. 8 *Two-colour pyrometer with focusable optics and through-the-lens sighting device for correct alignment and adjustment of the measuring distance.*

was developed. Devices with IO-Link interface can be easily integrated into all common fieldbus controllers by using standardized IODD drivers. In addition to the measured value, diagnostic information or fault messages such as the indication of a dirty lens or the operation at inadmissible ambient temperatures are transmitted to the control system.

Conclusion

With the demand for precise temperature control, nowadays it is no longer sufficient to rely on the visual assessment by the operator. A precise temperature measurement in modern forging companies is the precondition for an optimum and economic handling. Modern model-based systems for process design, analysis and control in combination with precise and robust measurement technology are indispensable in an industrial production environment and provide the basis for a secure connection to higher monitoring systems in the course of Industry 4.0. Experience-based approaches still have their legitimacy in today's world, but the analytical approach of the entire process provides tools that enable a profound understanding of the process and make potentials for the future identifiable and tangible.

Modern devices that are able to meet the requirements for accurate and reliable temperature measurement are the prerequisite for an optimum temperature-controlled production process. The use of two-colour pyrometers with high-quality optics, small measuring field and short measuring time is recommended to measure the temperature of the hot spots in the scale-free areas on the block. An additional advantage of two-colour pyrometers is the simple handling with regard to alignment and focusing.

Dipl.-Ing. Albert Book
KELLER HCW GmbH
Infrared Temperature Solutions (ITS)
Tel. +49 5451 85-320
albert.book@keller.de

Alexander Ulferts
Inductoheat Europe GmbH
Tel.: +49 7153 504-226
ulferts@inductoheat.eu

Dipl.-Ing. Frank Andrä
Inductoheat Europe GmbH
Tel.: +49 7153 504-210
andrae@inductoheat.eu

KELLER

Creating Solutions

infrared temperature solutions ITS

No 1 in terms of ACCURACY RELIABILITY INNOVATION

IO-Link

PROFIBUS

Keller HCW GmbH
Infrared Temperature Solutions (ITS)
Carl-Keller-Straße 2 - 10
49479 Ibbenbüren-Laggenbeck
Germany

www.keller.de/its
Tel. +49 (0) 5451 850
Fax +49 (0) 5451 85412
its@keller.de

Distributor

KROHNE INOR

INOR Transmitter Oy
Unikkotie 13
FI-01300 Vantaa
Puhelin +358 10 4217900
Faksi +358 10 4217901
myynti@inor.fi