

Optical measurement of liquid metal temperatures

by **Albert Book**

Temperature is one of the most critical process parameters affecting the resulting quality, strength and working properties of a metal casting. Thanks to modern infrared thermometers, the temperature of molten metal can be accurately monitored continuously and without contact at various stages of production. The benefits: non-contact temperature detection requires far less use of immersion probes and results in reduced scrap.



Fig. 1 Conventional temperature measurement of liquid metal using an immersion probe

Disadvantages of previous temperature measurement techniques

The temperature of liquid metal is commonly measured using thermocouples (**Fig. 1**). The probe is dipped into the melt. Data accuracy is subject to the precision with which the foundry operator performs the measurement. Temperature readings will vary, depending on the immersion depth and the position of the probe. A slag deposit on the sensor element may also lead to substantial measurement errors. Because the immersion technique uses thermocouple tips which require frequent replacement, a foundry incurs operating costs for expendable parts which can amount to several thousand euros annually.

To avoid these disadvantages, attempts were made to detect temperature by optical means using so-called infrared thermometers, also known as pyrometers. For many years now, infrared measurement has been very effective in many industrial applications, including the steel, ceramic, glass and cement industries.

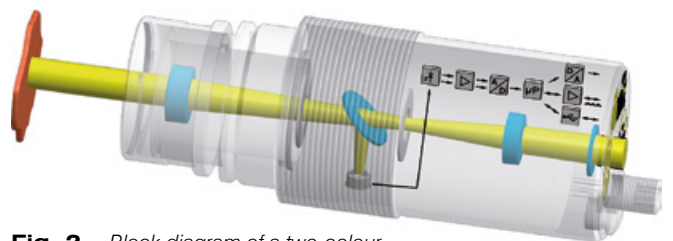


Fig. 2 Block diagram of a two-colour (ratio) pyrometer with through-the-lens sighting

Principles of Pyrometer Temperature Measurement

In the early 20th century, Max Planck established the principles of infrared heat transfer. In pyrometry, a sensor captures the infrared thermal energy radiated by an object's surface (**Fig. 2**).

The amount of energy an object's surface radiates is a function of its temperature and of the material's ability to emit this radiant energy, known as emissivity. After amplification and linearization, a pyrometer produces an electrical output which is proportional to temperature. A lens inside the pyrometer is focused on a specific target, and the instrument only detects the energy radiated from that spot. The focal length and the shape of the lens determine the field of view as well as the spot size, relative to the distance to the target.

Optical Temperature Measurement of Metal

Liquid metal presents a unique challenge due to the composition of the surface. The formation of slag and oxide is often inevitable. At identical temperatures, oxides and slag will radiate a greater amount of thermal energy than a clean, shiny liquid metal surface. To achieve reliable and accurate temperature data, it is essential that a pyrometer only detects and processes the infrared radiation from the surface which is free of oxides and slag. The use of state-of-the-art two-colour (ratio) pyrometers which feature a special ATD function (automatic temperature detection) makes this possible. These modern instruments detect infrared radiation at two different wavelengths at the same time and from the same target spot. From the ratio of these two intensities an electric signal is generated which is proportional to temperature. Special signal processing ignores the slag and oxides floating on the surface and filters out the temperature detected from the pure liquid metal.

In harsh industrial environments ratio pyrometers are preferred over spectral or singlewavelength pyrometers because the dual wavelength technique is much less sensitive to signal attenuation caused by dust or steam in the field of view.

Different systems for various points of measurement

Steel mills and foundries require temperature control at numerous manufacturing stages. Each of these molten metal applications presents a distinct challenge for a temperature measurement system.

a) Blast furnace and cupola furnace

At the passage where liquid metal is transferred from the blast furnace/cupola furnace to the forehearth, temperature is typically measured at irregular intervals by means of a thermo-



Fig. 3 Measurement at the tap hole of a blast furnace, carried out at considerable distance

couple. In contrast, pyrometers detect temperature continuously (**Fig. 3**). Thus, the foundry operator can immediately intervene in the melting process, if necessary. On-site conditions require that a pyrometer be installed at a considerable distance to the target. This is possible if the instrument features high-resolution optics and superior imaging properties. With smaller target spots, the pyrometer can easily identify and ignore slag and oxide, producing extremely reliable temperature data. Through-the-lens sighting or a laser spot light facilitate aiming and indicate the exact spot. More recently, pyrometers can also come equipped with a built-in video camera which enable continuous remote monitoring from the control room.

b) Melting furnace and forehearth

Temperature is of crucial importance as the molten metal passes from the melting furnace or forehearth to the transfer ladle or pouring ladle (**Fig. 4**). The liquid metal must be poured



Fig. 4 Transfer of molten iron from the melting furnace into the pouring ladle

into the mold within a limited time to minimize heat loss. When cooling exceeds 10 °C per minute, the minimum permissible pouring temperature might be violated. Because this application requires some distance between the instrument and the point of measurement, pyrometers with superior optical resolution and a circular field of view are used. The ATD function not only filters out the infrared radiation from slag and oxides, it also automatically detects the start and end of each pour. When the ladle has finished pouring, the temperature data is displayed and transmitted to a data communications network. Alternatively, data can be logged and archived by CellaMevis standalone PC software. CellaMevis provides online graphic images of temperature readings at a PC and saves them at periodic intervals with a timestamp.

c) Automated casting machine

The temperature of the liquid metal at the time of pouring is crucial to the quality of the casting. If the melt is too hot, the sand core will be damaged. If the melt is not hot enough, the fluidity will be inadequate, and the liquid might not distribute properly within the mold. This is especially true for thinwalled or intricately shaped castings. There is the risk of casting defects such as shrink holes and cold shut. The stability and strength of the manufactured workpiece as well as its subsequent working properties will be greatly influenced by the pouring temperature. Therefore, it is absolutely essential that temperatures at this point in the process are accurately detected and precisely controlled.

At fully automated casting lines, temperature is commonly controlled by infrequent immersion of the probe into the melt. At semiautomated operations, the temperature of the liquid metal is usually only measured once for each newly filled ladle. The thermocouple is dipped into the ladle before pouring begins, that is, before the molds are filled. Depending on the number of castings poured from one ladle, there may be a considerable time offset between ladle temperature measurement and the last mold filled from the content of that ladle.

The ladle operator decides how many castings can be poured from one ladle, basing his decision on the flow behavior of the melt and his empirical knowledge of heat loss and cooling time. Actual temperature tests using measurement instrumentation – to assure that the required process temperature is maintained right down to the last filled mold – is rarely performed.

With optical temperature detection at metal casting operations, a pyrometer is focused on the free falling liquid metal stream just as it is poured into the mold (**Fig. 5**). The ATD func-



Fig. 5 Optical temperature detection at a casting machine

tion automatically identifies when the pour begins and adapts the measuring time to the duration of the pour stream.

A temperature reading is produced for each cast workpiece, providing continuous verification of compliance with temperature requirements.

If, for example, operations are disrupted due to a functional disturbance, and during this time, the liquid metal in the ladle cools to below the minimum permissible temperature, production can be halted to avoid producing castings which would end up as scrap.

The challenge of temperature detection at casting machines

Compounding the problem: the position of the liquid metal pour stream fluctuates. The pouring point is influenced by factors such as the tilt angle of the ladle or the stopper rod in the tapping hole of bottom pour ladles (**Fig. 6**).



Fig. 6 Position of pour stream varies with the tilt angle of the ladle

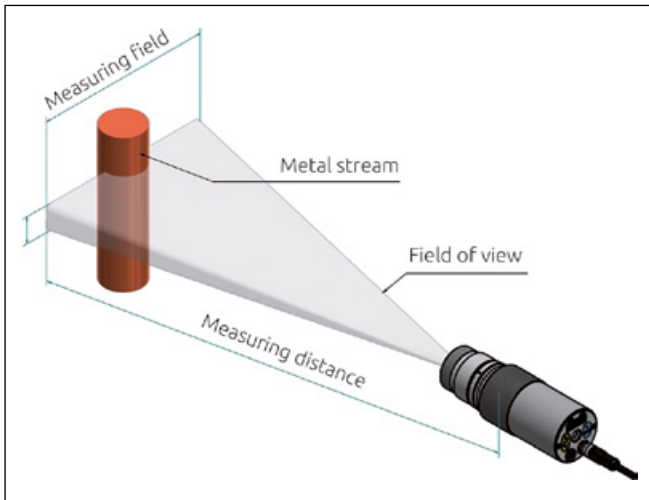


Fig. 7 Pyrometer featuring rectangular measurement area

The solution: a pyrometer which features a rectangular measurement area which captures the pour, even when the liquid stream moves within this area (**Fig. 7**).

The most suitable pyrometer for the task will depend on the specific conditions of casting process. Parameters such as the pyrometer-to-target distance, the diameter of the pour stream, or the zone of pour fluctuation will determine which optical system is required to achieve precision measurement. Temperature data is transmitted and saved for each produced item via analog or digital interface.

Integrated video camera monitors the target

Because the position of the pour stream can vary with the tilt angle or due to clogging and wear of the pouring nozzle, an optical measurement technique is essential. A built-in video camera is ideal for target sighting because of the difficulty in safely accessing the installed pyrometer during running operations. State-of-the-art cameras feature TBC (Target Brightness Control). The light exposure of the image is not averaged over the total illumination, but rather based on the specifically targeted measurement area. The result is a high-contrast image of the bright pour stream in front of a dark background. The image of the molten metal pour stream at the video display terminal will always appear at optimum exposure.



Fig. 8 Video image shows targeted measurement area and superimposed temperature reading

With modern pyrometers, the video signal also transmits the measurement data so that the temperature reading is superimposed onto the screen (**Fig. 8**). Additional cables and electronics for remote indication of the temperature data are unnecessary.

Conclusion

The latest optical measuring systems enable automatic and continuous monitoring and archiving of liquid metal temperatures at various stages of manufacture. By using pyrometers – which require no maintenance and do not contain parts subject to wear – foundries eliminate the need for expendable thermocouple tips, thus reducing their operating costs.



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