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Signalling a foundry mould filling degree with infrared sensors

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Abstract

A contactless method of measuring a foundry mould filling degree in course of its pouring with liquid metal is suggested. The concept is based on infrared radiation of molten metal appearing in venting and flow-off holes. As the detector, an infrared channel receiving diode is applied. Three solutions were tested. In the first solution, the diode is placed at the calculated distance from the radiation source, in a housing that suppresses the scattered signal. The housing contains the electronics, while power supply and control signals are delivered by conductors. A diode actuation threshold is established in order to obtain high resolution and repeatability of the results. On the output, a miniature relay transmits the signal to the control system. In the second solution, the measuring system is supplied with a battery and the signal in transmitted through a plastic optical fibre. In the third solution, the optical fibre serves as an energy carrier. The optical system focuses the infrared radiation and introduces the energy to the optical fibre. On the other end of the fibre, a phototransistor amplifies the signal, forms it and transmits to the control system. Some experiments were carried out. Their results permitted noting disadvantages and advantages of individual solutions. It was evidenced that the measurement results obtained using the infrared radiation are independent on a constructional design. The solutions utilising optical fibres proved to be more useful in industrial conditions. Targets and further directions of research works using transceivers for wireless data transmission are presented.

Keywords: Infrared sensors, Foundry mould, Filling degree.

1. Introduction

The infrared radiation, called also thermal radiation, is emitted by any body that has temperature higher than absolute zero.

There are many examples of infrared (IR) radiation, both in science, industry and in everyday life. It is used in structural research (organic particle spectroscopy), medicine (diathermy and thermophotography), biology (infrared microscopy), observations in darkness (noctovisors, alarm sensors) etc. Of high importance in scientific and medical applications, as well as in police investigations is thermography (imaging process in medium infrared band, e.g. at counterfeit detection in criminology and work of art expert's opinion). In practice, the infrared radiation is also used in laser scanners, range-finders, CD readers, optical fibres and RTV remote control.

In the paper, an application of infrared radiation for signalling the filling degree of a foundry mould with molten metal is presented.

2. Analysis of measuring and signalling the molten metal presence

The IR radiation is characteristic for the bodies having black or dark surface and temperature from ca. -10 °C up. It covers the range of electromagnetic radiation between visible light and radio waves, within the wave length from 780 nm to 1 mm. To characterise the IR radiation, one can distinguish three sub-ranges:

- near – infrared from 0,7 to 5 μm
- mid – infrared from 5 to 30 μm
- far – infrared from 30 to 1000 μm

Total power Φ emitted by a black body at temperature T is described by the Stefan-Boltzmann law [1]

$$\Phi = \sigma \cdot T^4 \quad (1)$$

where: σ – Stefan-Boltzmann constant
T – temperature in Kelvin degrees

It results from (1) that the energy flux depends on the fourth power of temperature. This means that small temperature changes result in large energy changes, which significantly influences the radiation detectors.

The following IR detectors can be distinguished: thermal, radiational, ultrasonic, pyroelectric, photon counting. For IR radiation detection, commonly used are photodiodes or phototransistors characterised by higher sensitivity. The most commonly used are the detectors of wavelength 940 nm. According to the relationship (1), these detectors are highly non-linear. Such sensors are not suitable e.g. for measuring the distance between the object and the detector, but can be useful for signalling the radiation source (an object presence).

In the case of signalling the molten metal presence in a foundry mould, the merit is not the signal value but the presence of the radiation source, so it was decided to use an IR sensor of the far-infrared range. This choice is additionally supported by the fact that radiation of cast steel, e.g. at 815 °C, is 100 000 times higher in infrared than in the visible band.

The detection system should have features of a window discriminator that is insensitive in the range of low temperatures. In addition, it should transmit a signal with no oscillation to the control system after a certain threshold value is exceeded. The input signal should be compatible with the industrial controller standard, which means transmitting a single pulse or information on the foundry mould filling condition. As the measurement point, it is most favourable to choose the flow-off hole, present in most of foundry moulds for technological reasons. The flow-off filling level corresponds to the mould filling degree and – as demonstrated below – can be forecasted.

In order to determine the design freedom of the signalling probe, two basic approaches to the solution of the radiation presence can be distinguished: direct measurement and indirect measurement. In the direct measurement, the sensor is located close to the radiation source and detects the signal source. In the indirect measurement, the IR radiation energy is transferred through an optical fibre for a certain distance, where is detected.

1.1. Direct measurement

Figure 1 shows a schematic presentation of a signalling probe and its arrangement in relation to the flow-off hole of the foundry mould.

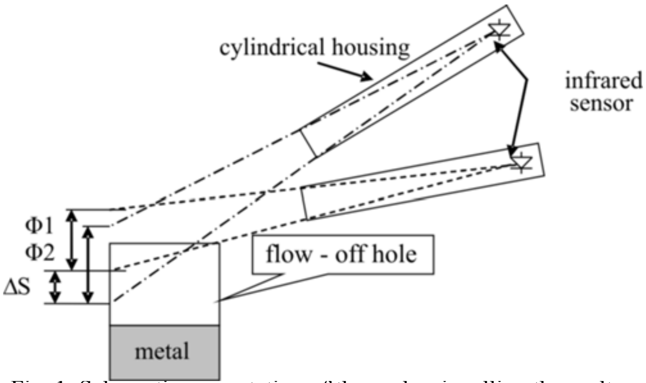

Fig. 1. Schematic presentation of the probe signalling the molten metal presence

The probe consists of a cylindrical housing with a photodiode inside. Internal surface of the housing is black and mat, so it permits absorbing the scattered radiation. This way, the sensor "sees" a small area only of the flow-off hole. Because of high sensitivity, the sensor reacts immediately when the molten metal reaches this area. The measuring channel consists of the sensor, amplifier, window discriminator WD, threshold system TS and signal generator G. The system is so sensitive that it detects a radiation source at a distance of 12 m. The changeover error was within ±5 mm after reaching the photodiode visual field. Two signal outputs in form of a single impulse were provided. One of them was with the TTL and adjustable duration Tm.

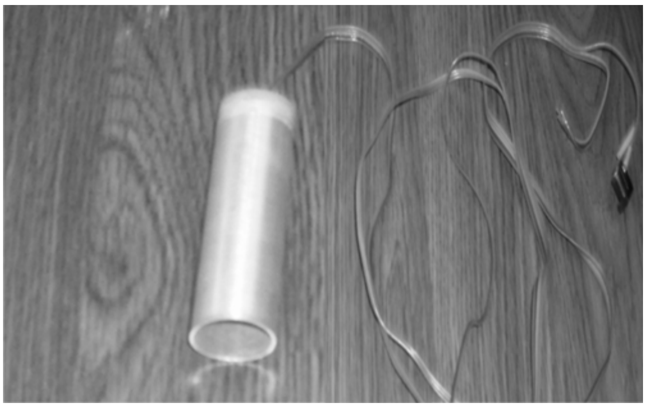

Fig. 2. Infrared sensor in cylindrical housing

As an alternative, an ohmic output of a miniature relay Teledyne was applied. In the case of two measuring systems, two output signals are generated. If the distance ΔS between their changeover points and the time increments Δt between two successive signals are known, then, at stable pouring, the mould filling time can be approximated.

A disadvantage of the direct measurement methods are the power supply cables and the cables connecting with the industrial controller at a long distance. This is why an option was forecasted, with 3 V battery supply and signal transmission by plastic optical fibre and TOX173 couplings (Fig. 3). This permits transferring a single impulse at a distance of dozens of metres and data transmission at 1.6 Mb/s at a distance of up to 10 m. Capacity of the battery is sufficient for at least 200 measurements.

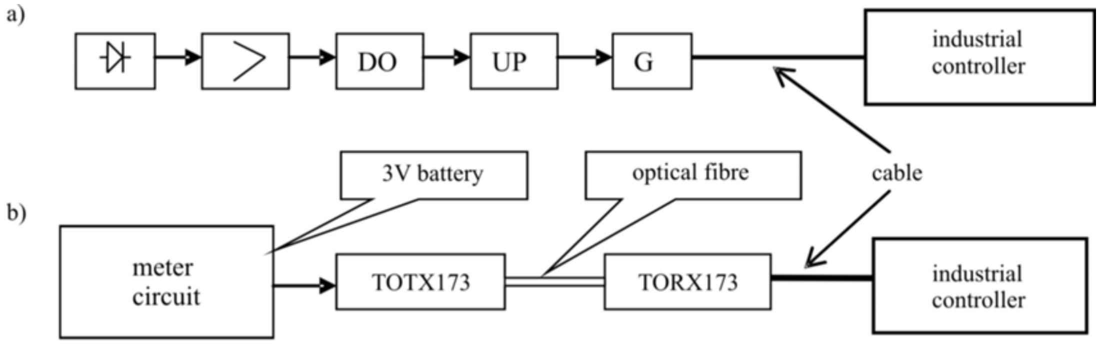

Fig. 3. Radiation source detection path: direct measurement with external supply (a), direct measurement with optical-fibre data transmission (b)

1.2. Indirect measurement

Indirect measurement consists in transferring energy from the IR radiation source to the measuring channel located at a long distance (Fig. 4). Since glass transmits the IR radiation in a small degree only, the optical system should be made of germanium and include an optical amplifier and a system of introducing the energy to the optical fibre. It appeared that, with polished face of the optical fibre, the energy transmitted from molten metal is sufficient to activate the sensor at the other end of the optical fibre 10 m away, which allowed resigning the germanium lenses. As the sensor, a phototransistor FT KM-4457P3C was applied.

An advantage of the developed solution is small surface area (1 mm^2) of molten metal seen by the optical fibre, which permits precise determination of the mould filling degree. On the other hand, using two or three measuring systems permits determining precisely – by approximation – the moment when the mould is completely filled with molten metal.

2. Conclusion

Characteristics of the IR radiation and its detectors are presented. It was found that the presence of liquid metal can be signalled by IR radiation detectors (photodiodes) operating in the near-infrared range, i.e. the wavelength of 0,7 to 0,5 µm.

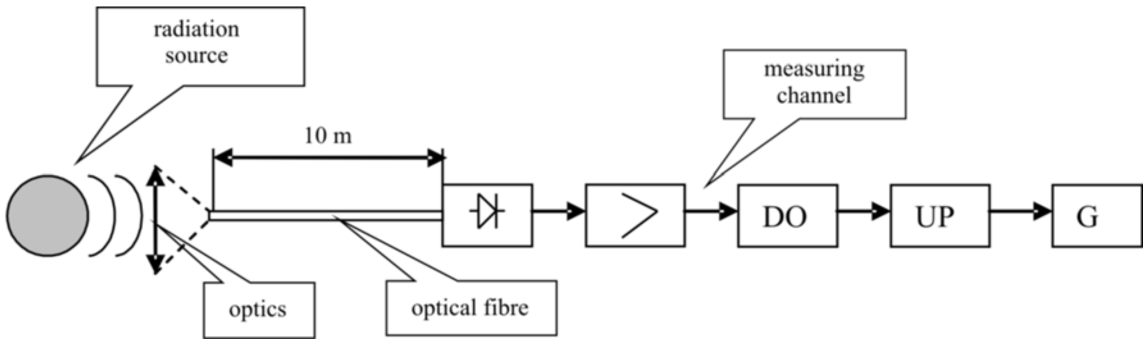

Fig. 4. Indirect measurement of foundry mould filling degree

In this IR range, most commonly used are the detectors of the wavelength of 980 nm. A detection system was characterised, which can be used for signalling the filling condition of a foundry mould poured with molten metal.

Two versions of developed and built measuring systems are presented: direct and indirect systems, designed for signalling the presence of liquid metal in the mould. It was found on the grounds of experimental research that the developed signalling probes permit detecting an IR radiation source (molten metal) at a distance up to 12 m. The presented signalling probes can find an application in automatic pouring stands.

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