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WHITEPAPER

INFRARED SENSORS: FUNDAMENTALS OF NON-CONTACT TEMPERATURE MEASUREMENT

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TABLE OF CONTENTS

1 INTRODUCTION

Temperature is one of the physical quantities most frequently measured in many industrial applications and processes. In general, a distinction can be made between non-contact and wetted temperature measurement principles. Temperature measurement in contact with the medium is usually carried out using a PT100 thermoresistor as a measuring sensor, which is connected to an evaluation unit or to a display unit for determining or visualizing the measured temperature.

In many areas, however, such solutions cannot be used, e.g. because measurements are not to be made in contact with the medium, the devices are disturbed by the heat radiation of an object, or they become so dirty due to prevailing ambient conditions that no usable measurement results can be obtained.

In such and many other cases, the use of infrared sensors is recommended. These devices operate without contact and are therefore completely wear-free, since no system component, e.g. the measuring probe, requires contact with the medium or object to determine the temperature. Within optical sensors, such devices occupy a special position, so to speak, since they convert the infrared radiation emitted by objects into an electrical signal. This signal is amplified and transformed into a measured value linearized in proportion to the object temperature, which can be output as a switching or analog signal.

One of the most common tasks of infrared sensors is to determine the surface temperature of objects that are difficult to access or are moving, especially if they have a high thermal radiation. The potential applications of infrared sensors are therefore extremely wide-ranging, for example in forges, rolling mills or steel processing plants in general.

This white paper provides some essential basics on non-contact temperature measurement using infrared technology and, in this context, presents some concrete solutions from ipf electronic's rich portfolio of infrared sensors.

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2 COMPONENTS OF AN INFRARED THERMOMETER

Infrared (IR) thermometers are optoelectronic sensors that detect the infrared radiation emitted by a body without contact and therefore without wear, and calculate its surface temperature on this basis. An IR thermometer essentially consists of the following components:

- Lens (Optics)
- Spectral filter
- Detector
- Electronics (amplification, linearization, signal processing)

The properties of the lens or optics have a decisive influence on the beam path of an IR thermometer. The beam path is characterized by the following ratio: Distance (to an object) to spot size. The function and relevance of optics as an important factor for non-contact temperature measurement will be explained in more detail later in this white paper. The spectral filter is used to select the relevant wavelength range for the temperature measurement. The detector, together with the downstream processing electronics, has the task of converting the intensity of the emitted infrared radiation into electrical signals, e.g. to set a switching output on a sensor.

3 PRINCIPLE OF INFRARED TEMPERATURE MEASUREMENT AND EMISSIVITY

Every body emits a certain amount of infrared radiation depending on its temperature, the intensity of which changes accordingly with a change in temperature. The wavelength range of this so-called „thermal radiation“ used in infrared measurement technology is approximately between 1µm and 20µm. The intensity of the infrared thermal radiation emitted by each body or material depends on its temperature as well as on its radiation properties. The material dependent constant is called emissivity (ε- epsilon). It describes the ability of a body to emit infrared energy. The emissivity is known for most materials and can range from 0 to 100%. An ideally radiating body (a so-called „black body“) has an emissivity of 1.0. The emissivity of a mirror, however, is 0.1.

3.1 EMISSIVITIES OF DIFFERENT SUBSTANCES

The following two tables show the different emissivities of metals and non-metallic substances. It should be noted that the values in the tables are average values, since the actual emissivity of a substance depends, among other things, on the following influencing variables:

- Temperature
- Measuring angle
- Surface geometry (flat, convex, concave)
- Material thickness
- Surface condition (polished, oxidized, rough, smooth, etc.)
- Spectral range of the measurement
- Transmission properties of the material (e.g. for measurements on thin foils)

Table of emissivity metals

Material		Typical emissivity			
Spectral sensitivity		1.0µm	1.6µm	5.1µm	8 - 14µm
Aluminum	not oxidized	0.1-0.2	0.02-0.2	0.02-0.2	0.02-0.1
	polished	0.1-0.2	0.02-0.1	0.02-0.1	0.02-0.1
	roughened	0.2-0.8	0.2-0.6	0.1-0.4	0.1-0.3
	oxidized	0.4	0.4	0.2-0.4	0.2-0.4
	polished	0.35	0.05-0.2	0.05-0.2	0.05-0.1
	roughened	0.65	0.6	0.4	0.4
	oxidized	-	0.3-0.7	0.2-0.7	0.2-0.6
Chromium	-	0.4	0.4	0.03-0.3	0.02-0.2
Iron	not oxidized	0.35	0.1-0.3	0.05-0.25	0.05-0.2
	rusted	-	0.6-0.9	0.5-0.8	0.5-0.7
	oxidized	0.7-0.9	0.5-0.9	0.6-0.9	0.5-0.9
	forged, dull	0.9	0.9	0.9	0.9
	melted	0.35	0.4-0.6	-	-
Iron, cast	not oxidized	0.35	0.3	0.25	0.2
	oxidized	0.9	0.7-0.9	0.65-0.95	0.6-0.95
Gold	-	0.3	0.01-0.1	0.01-0.1	0.01-0.1
Haynes	alloy	0.5-0.9	0.6-0.9	0.3-0.8	0.3-0.8
Inconel	electropolished	0.2-0.5	0.25	0.15	0.15
	sandblasted	0.3-0.4	0.3-0.6	0.3-0.6	0.3-0.6
	oxidized	0.4-0.9	0.6-0.9	0.6-0.9	0.7-0.95
	polished	0.05	0.03	0.03	0.03
	roughened	0.05-0.2	0.05-0.2	0.05-015	0.05-0.1
	oxidized	0.2-0.8	0.2-0.9	0.5-0.8	0.4-0.8
Magnesium	-	0.3-0.8	0.05-0.3	0.03-0.15	0.02-0.1
Brass	polished	0.35	0.01-0.5	0.01-0.05	0.01-0.05
	rough	0.65	0.4	0.3	0.3
	oxidized	0.6	0.6	0.5	0.5
Molybdenum	not oxidized	0.25-0.35	0.1-0.3	0.1-0.15	0.1
	oxidized	0.5-0.9	0.4-0.9	0.3-0.7	0.2-0.6
Monel (Ni-Cu)	-	0.3	0.2-0.6	0.1-0.5	0.1-0.14
Nickel	electrolytic	0.2-0.4	0.1-0.3	0.1-0.15	0.05-0.15
	oxidized	0.8-0.9	0.4-0.7	0.3-0.6	0.2-0.5
Platinum	black	-	0.95	0.9	0.9
	-	-	0.05-0.15	0.05-0.15	0.05-0.15
Silver	-	0.04	0.02	0.02	0.02
Steel	polished sheet	0.35	0.25	0.1	0.1
	stainless	0.35	0.2-0.9	0.15-0.8	0.1-0.8
	heavy plate	-	-	0.5-0.7	0.4-0.6
	cold rolled	0.8-0.9	0.8-0.9	0.8-0.9	0.7-0.9
	oxidized	0.8-0.9	0.8-0.9	0.7-0.9	0.7-0.9
Titanium	polished	0.5-0.75	0.3-0.5	0.1-0.3	0.05-0.2
	oxidized	-	0.6-0.8	0.5-0.7	0.5-0.6
	polished	0.35-0.4	0.1-0.3	0.05-0.25	0.03-0.1
Zinc	polished	0.5	0.05	0.03	0.02
	oxidized	0.6	0.15	0.1	0.1
Tin	not oxidized	0.25	0.1-0.3	0.05	0.05

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Table of emissivity non-metals

Material		Typical emissivity			
Spectral sensitivity		1.0µm	2.2µm	5.1µm	8 - 14µm
Asbestos		0.9	0.8	0.9	0.95
Asphalt		-	-	0.95	0.95
Basalt		-	-	0.7	0.7
Concrete		0.65	0.9	0.9	0.95
Ice		-	-	-	0.98
Earth		-	-	-	0.9-0.98
Paint	non alkaline	-	-	-	0.9-0.95
Plaster		-	-	0.4-0.97	0.8-0.95
Glass	Slice	-	0.2	0.98	0.85
	Melt	-	0.4-0.9	0.9	-
Rubber		-	-	0.9	0.95
Wood	natural	-	-	0.9-0.95	0.9-0.95
Limestone		-	-	0.4-0.98	0.98
Carborundum		-	0.95	0.9	0.9
Ceramics		0.4	0.8-0.95	0.8-0.95	0.95
Gravel		-	-	0.95	0.95
Carbon	not oxidized	-	0.8-0.9	0.8-0.9	0.8-0.9
	Graphite	-	0.8-0.9	0.7-0.9	0.7-0.8
Plastic >50 µm	opaque	-	-	0.95	0.95
Paper	any color	-	-	0.95	0.95
Sand		-	-	0.9	0.9
Snow		-	-	-	0.9
Textiles		-	-	0.95	0.95
Water		-	-	-	0.93

All data without guarantee

To ensure that the infrared sensors operate as accurately as possible, the emissivity of the material to be measured can usually be preset on the devices. If the emissivity is too high, the IR thermometer will detect a temperature that is lower than the real prevailing temperature, provided that the measured object is warmer than the environment. If the emissivity is low (e.g. when measuring reflecting surfaces), there may be a risk that interfering infrared radiation from objects in the background of the measuring range (e.g. flames, heating systems, etc.) will falsify the result. To minimize measurement errors, the IR thermometer (sensor) should therefore be shielded against any reflective radiation sources, among other things.

3.2 METHOD FOR DETERMINING UNKNOWN EMISSIVITIES

If the emissivity of a substance is not known or if the average values in the tables above are not sufficient for setting an IR thermometer, the emissivity of an object can be determined by various methods. In the following, three methods will be briefly presented.

First, the actual temperature of an object can be determined, for example, with a thermocouple, contact sensor or similar solution. Then the temperature is measured with an IR thermometer and the emissivity is changed until the displayed measured value corresponds to the initially actually determined temperature.

For temperature measurements up to +380°C, it is possible to apply a special plastic sticker (emissivity sticker) to the measuring object, which completely covers the corresponding measuring spot. After the emissivity is set to the value 0.95, the temperature of the sticker is measured. Subsequently, the temperature of a directly adjacent surface on the measurement object must still be determined. Finally, the emissivity can be set so that its value matches the previously measured temperature of the sticker.

If the application allows, matte black paint with an emissivity higher than 0.98 can also be applied to the surface of an object under test. Then the emissivity of the IR thermometer is set to the value of 0.98 and the temperature of the surface covered with black paint is measured. Following this, only the temperature of a directly adjacent surface needs to be determined. Finally, the emissivity setting is changed until the measured temperature corresponds to the temperature previously determined on the colored surface.

When using the methods presented here, it should be noted that the object to be measured must always have a temperature that differs from the ambient temperature.

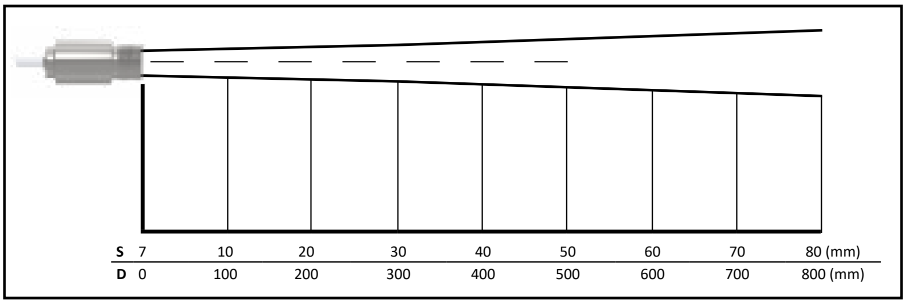
4 MAXIMUM DISTANCE, OPTICS AND SPOT SIZE

The possible maximum distance between the measuring head and an object to be measured depends on the size of the object and the optical resolution of an IR thermometer. As already mentioned in chapter 2, the choice of the right optics for the measuring head of an IR thermometer is of particular importance, because it determines not only the possible setting ranges for the switching threshold, but above all the size of the measuring spot over which the temperature on or at an object is to be determined.

The detection area of an optic with standard focus (SF: Standard Focus) forms a cone shape from the front edge of the measuring head. Exceptions are the optionally available, special attachment optics with so-called Close Focus (CF) for certain instrument models. Such optics initially focus the beam path to a certain distance so that even the smallest objects can be detected. Beyond the smallest focus, the beam path then enlarges again, as can be seen in the figures below for IR sensors with „closed focus".

In general, however, it can be said: The further the SF optics of a sensor head is away from the target, the larger the area (measuring spot) for which the sensor evaluates the temperature. In this case, it always determines the average temperature in relation to the area under consideration. To avoid measurement errors, the object should therefore completely fill the measurement spot, which is defined by the focus of the optics and the respective distance to the object. This means that the evaluation area of the sensor must always be the same size as or smaller than the measurement object. Moreover, the temperature detected by an infrared sensor is only correct if the measured object has a surface with uniform temperature distribution.

LT10H | G5L| P7| Optics: SF | D:S: 10:1



LT10 | Optics: CF1 | D:S: 10:1 |3.0mm@30mm | D:S (far field)= 3:1 3:1

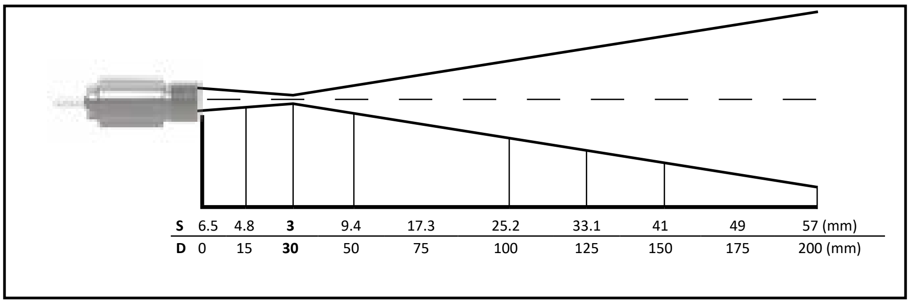


Fig. 1: Beam paths of optics with standard focus (SF) and so-called closed focus (CF) at a resolution of 10:1. (all images: ipf electronic gmbh)

5 INFRARED SENSORS FOR DIFFERENT APPLICATIONS

In the following chapters, some concrete device solutions from ipf electronic are presented, whereby the portfolio contains a whole series of non-contact temperature sensors. These are so-called compact devices as well as two-part systems in which the actual measuring head is separated from the evaluation electronics.

5.1 COMPACT DEVICES WITH MEASURING RANGES UP TO +1030°C

The compact devices from ipf electronic are essentially characterized by the evaluation electronics already integrated in the sensor. Mounting and installation of the devices, which are operated at a distance of around 2 to 8 meters from the measured object, is therefore unproblematic. The compact IR thermometers are adjusted manually. The various instrument versions differ mainly in the built-in optics and the maximum adjustable switching thresholds or measuring ranges from +300°C to +750°C. All compact devices in stainless steel housing (protection class IP67) have a diameter of 60mm, a switching frequency of 10Hz and can be used at ambient temperatures from-20° C to +75°C.

An exception is the **OI12C758** in IP63 with a diameter of just 12mm (length 87mm). This sensor for ambient temperatures up to +80°C is not only one of the smallest solutions among the compact devices, but is also designed for an extremely wide measuring range from-40°C to +1030°C. The very short response time of only 25ms is also convincing.

Fig. 2: Selection of compact optical temperature sensors (from left): the OI12C758 with a measuring range up to +1030°C, the OI810143 (measuring range up to +300°C) and the OI810142 (measuring range up to +750°C).

5.2 TWO-PART SYSTEMS FOR HIGHER REQUIREMENTS

The two-part systems from ipf electronic consist of a measuring head that is connected to separate evaluation electronics with a connecting cable. In practical use, the evaluation electronics can thus be installed in a thermally less critical area, while the actual sensor or measuring head is, so to speak, on site. The measuring heads of the two-part systems can therefore withstand much higher ambient temperatures of up to +180°C compared to the compact devices. The measuring head of the **OI98E239** system is even designed for ambient temperatures up to +250°C without cooling.

Some of the measuring heads of the two-part systems from ipf electronic are among the smallest in the world with a high optical resolution of 22:1. The measuring ranges of the solutions extend from -40°C to +975°C and are freely scalable. Parameters are set using the keys on the evaluation unit. The **OI98E240** system, whose measuring range is specified from +385°C to +1600°C, is also an exception here.

Fig. 3: The measuring head of the OI98E239 (measuring range -40°C to +975°C) is designed for ambient temperatures of up to +250°C (left). The measuring range of the OI98E240 (right) extends from +385° C to +1600°C.

5.3 IMPORTANT MEASURED VALUES FOR PROCESS-RELIABLE PROCEDURES

In the introduction of this white paper it was briefly mentioned that the measured value supplied by an infrared sensor can be output in a switching or analog signal. Among the compact devices from ipf electronic, the **OI12C758** has both a switching and a freely scalable analog output (0 V...5V or 0V...10 V). The two-part systems instead integrate an additional analog output (0/4...20 mA, 0...5/10V) in addition to the switching output without exception.

The temperature-proportional signal from these outputs can be used, for example, to monitor a specific temperature range in certain processes. A good example of this is the further processing of forged components, where the measurements taken by an infrared sensor on the red-hot metal parts can be used to readjust the temperature in a furnace in order to reliably form the components in a die. Other potential applications for the two-part systems include temperature measurements on smoothing and embossing calenders, automatic casting machines, laser welding, laser cutting and semiconductor production on wafers, to name just a few examples.

6 CORRECT ASSEMBLY AND MORE FOR BEST RESULTS

Just as important as the selection of an optimal infrared sensor for a specific application is the choice of the correct mounting accessories in order to achieve truly reliable results in temperature measurement. Therefore, ipf electronic offers a range of mounting accessories, e.g. for the two-part systems, in addition to the wide range of sensor solutions. Among other things, mounting brackets and mounting bolts that can be adjusted in one axis are available for mounting the sensor heads. Both solutions can also be combined with each other. In addition, it is also possible to fasten the measuring head with a mounting fork that can be adjusted in two axes. In order to prevent contamination of the optics, the above-mentioned solutions can be equipped with additional air purge attachments in standard design or with lateral air outlet.

Fig. 4: A range of accessories is available for mounting the measuring heads for the two-part systems. Left: a mounting bracket and next to it a mounting bolt (each adjustable in one axis) as well as the combination of both solutions (adjustable in two axes). Far right: a mounting fork that can also be adjusted in two axes.

Fig. 5: To prevent contamination of the optics, either standard air purge attachments (left) or air purge attachments with lateral air outlet can be used. The laminar air purge attachments (right) prevent the object from cooling down at small measuring distances.

7 SUMMARY AND CONCLUSION

Industry has an immense number of applications and processes in which the temperature of various objects, materials and media must be determined. In many applications, however, the use of sensors in contact with the media is not sufficient, because the heat radiation of the objects to be measured clogs the devices or the prevailing ambient conditions simply do not allow the use of such sensors.

In such and many other cases, ipf electronic's non-contact and thus completely wear-free infrared sensors for precise temperature measurements can not only be real alternatives, but may also be among the few truly feasible solutions. Among other things, due to their high working distances, the devices are particularly recommended when, for example, the surface temperature of moving or difficult-to-access objects with high heat radiation is to be determined.

For non-contact temperature measurement using infrared technology, ipf electronic offers both compact devices with fully integrated electronics and two-part systems whose amplifiers or evaluation electronics are connected to the actual sensors via Teflon-coated connecting cables. The compact devices can be used in an ambient temperature range from -20°C to +75°C (**OI12C758** to +80°C) and are designed for an extremely wide range of applications due to their maximum adjustable switching thresholds or measuring ranges from +300°C to +750°C (**OI12C758** from -40°C to +1030°C). Far higher ambient temperatures of up to +180°C (**OI98E239** up to +250°C), on the other hand, can be withstood by ipf electronic's two-part systems with separate sensor and amplifier. These solutions are equally convincing due to their freely scalable measuring ranges from -40°C to +975°C (**OI98E240** from +385°C to +1600°C).

The question of which device or system is best suited for a specific application is not always easy to answer, however, because many influencing factors play a decisive role in the selection and thus design and configuration of an optimal solution.

Therefore, it is usually advisable to first contact a specialist from ipf electronic for the area of temperature sensors in order to jointly determine the concrete requirements of a solution for a specific application. ipf electronic's wide-ranging experience in very different industrial sectors proves time and again that this approach is often the most effective and at the same time the fastest way to reach the goal. At the end of the successful cooperation, there is a device solution that not only fulfills all current customer requirements, but is also capable of mastering all future requirements and challenges of an application.

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