TECHNICAL REPORT

Parts with a thermal fingerprint – process monitoring and control based on inline thermography

Inline thermography delivers insights into the quality of parts, quality fluctuations and the possible necessity for mold temperature adjustments.

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Mold temperature is one of the key variables and process parameters in injection molding. It influences the surface reproduction of the plastic part on the cavity wall and has a decisive effect on the length of time required for sufficient cooling of the plastic material. Temperature distribution inside the mold also has a significant effect on the warpage of plastic parts and consequently their quality. Therefore a consistent, high quality of complex parts requires even tempering of different mold elements. For example, component attributes checked in the product development and release process, such as dimensional stability and mechanical strength, can only be ensured in series production if mold temperatures as well as all other material and process parameters remain constant. An analysis of the deviations between set values and actual values and their attribution to the temperature control circuits inside the mold enables the creation of a closed-loop control circuit.

As a result of many years’ cooperation between WITTMANN BATTENFELD (A) and the SKZ (plastics research center in Wurzburg), inline thermography has been developed, a quality assurance tool based on IR temperature measurement.

Thermal images – from offline to inline

Thermal images of plastic parts have been used in the development and optimization of injection molding tools including troubleshooting for many years. For instance, a thermal analysis can help to identify flaws in existing molds and components and verify their simulation-assisted optimization during the sampling phase of new molds.

Furthermore, the use of modern infrared cameras, which are both inexpensive and robust, also makes economic sense in the series production of high-quality plastic parts. Today, optimally used infrared cameras can help to visualize deviations in temperature control systems immediately, recognize and separate start-up scrap and defective parts and regulate mold temperatures accurately.
**Prerequisites for using inline thermal images**

Thanks to their high (about 95%) and relatively constant emission rate in the relevant infrared spectrum (commonly available bolometers operate with wave lengths ranging from about 7 to 14 μm), plastic parts are ideally suited for infrared temperature measurement. In contrast to steel with its low emission coefficients and high reflection rates, fairly precise absolute and highly accurate relative readings can be achieved for plastic parts without any additional steps or appliances. A comparison between the surface temperatures in series production and the original values measured during product release enables simple visualization of changes in temperature as well as the localization of temperature control circuits, control of scrap gates and automatic mold tempering.

Fig. 2 illustrates the local differences in temperature caused by the failure of a temperature control circuit (the hotter area appears in red at the bottom) between a reference part (top left) and the part just produced (top right).
An accurate comparison between thermal images taken within the cycle and reference pictures requires precise timing of the interval between demolding and taking the thermal photograph as well as exact positioning in front of the infrared camera for every shot. A signal generated by the handling system triggers the camera system with absolute repeatability as soon as the correct position for the shot has been reached, as illustrated by the schematic diagram in fig. 3 below.

Fig. 2: SKZ screen shot – inline thermography software.

Fig. 3: Circuit diagram of inline thermography.
Another important prerequisite for the use of inline thermography integrated in series production is optional screening of several different views of molded parts in every cycle and comparing them to the corresponding reference pictures. This enables, for example, shots of an article from all sides and consequently an analysis of the relevant temperature control circuits (fig. 4).

![Fig. 4: Five lateral views (inline thermal images) of a molded part.](image)

A series of several thermal images per cycle can also be used to measure molded parts with large surfaces in several segments or with a focus on special areas, and thus increase the accuracy of imaging. If, for example, a part with a size of 800 × 200 mm is measured by only a single shot with a camera resolution of 160 × 120 pixels, each pixel of the sensor (bolometer array) covers an area of roughly 5 × 5 mm on the molded part. Shots from a closer distance may be necessary for accurate detection of imperfectly molded segments (fig. 5).
Fig. 5: Picture of an 8 mm aperture taken from various distances.

In many cases, a comparison between reference temperatures and the actual temperatures also enables the automatic detection of imperfectly molded parts. The missing heat input from “short shots” generally leads to a clearly visible local temperature deviation, as shown in fig. 6.

Fig. 6: Imperfectly molded part (defective area shown in black on the bottom left of the part).
Thermographic quality monitoring and quality switches

Local temperature deviations on the surface of parts can have causes such as:

- Fluctuations and malfunctions in the temperature control system.
- Fluctuations in melt temperature (can also be due to changes in injection speed).
- Changes in injection or holding pressure.
- Mold temperature changes in the start-up phase.
- Incomplete filling of the mold (“short shot”).

Such deviations frequently have an effect on parts geometry, mechanical strength values or surface attributes. Monitoring part temperatures in series production may therefore be a convenient supplement to other quality assurance tests for high-grade injection-molded parts. Setting local limit values makes it possible to detect any values exceeding or falling below such limits and trigger appropriate action. Examples of using inline thermography to control quality switches are automatic detection and separation of start-up scrap, or targeted machine shut-off whenever certain set temperatures are exceeded.

Automatic mold temperature adjustment on the basis of thermal images

Based on the possibilities described above of localizing the spheres of action of individual temperature control segments in combination with the corresponding set values from the reference images of a good part, a closed-loop control circuit can be established. Here, the system deviations derived from the comparison between set values and actual values are converted by a PID algorithm into parameter settings for mold temperature control (schematic diagram see fig. 3). The flow rates of the temperature control system, which are recalculated in this way for every cycle, can be adjusted via the control valves mounted directly on the mold. This enables correction of temperature deviations on the molded part within only a few cycles.
Applications and cost-effectiveness

Many requirements for faultless production of high-grade molded plastic parts can only be fulfilled with the help of modern techniques for optimal process control and inline quality monitoring. Inline thermography offers great potential in this area. If the temperature control parameters in the form of thermal images, which have been derived from the product release following an optimal sampling process with appropriate tooling, are directly transferred to series production, possible changes in the temperature control system and in the mold can then be detected in good time by means of SPC charts, and costly downtimes can be avoided through appropriate maintenance action. Early detection of quality deviations also prevents the production of rejects and their delivery to customers.

The relatively low costs of hardware and software for the professional use of thermal imaging in series production mostly pay off within a very short time. In addition to injection molding machines and peripheral equipment, WITTMANN BATTENFELD also offers the necessary components for inline thermography as described above.

Two different variants are available, namely an open-loop version to display thermal images and “short shots” including a signal to operate a scrap gate, and a closed-loop version, which, in addition to the functions of the above-mentioned variant, enables the adjustment of mold temperature control.
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