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Quality Rarely Comes Alone

Sulzer Mixpac Is Investigating the Efficiency of Sensor-Based Process Control Systems

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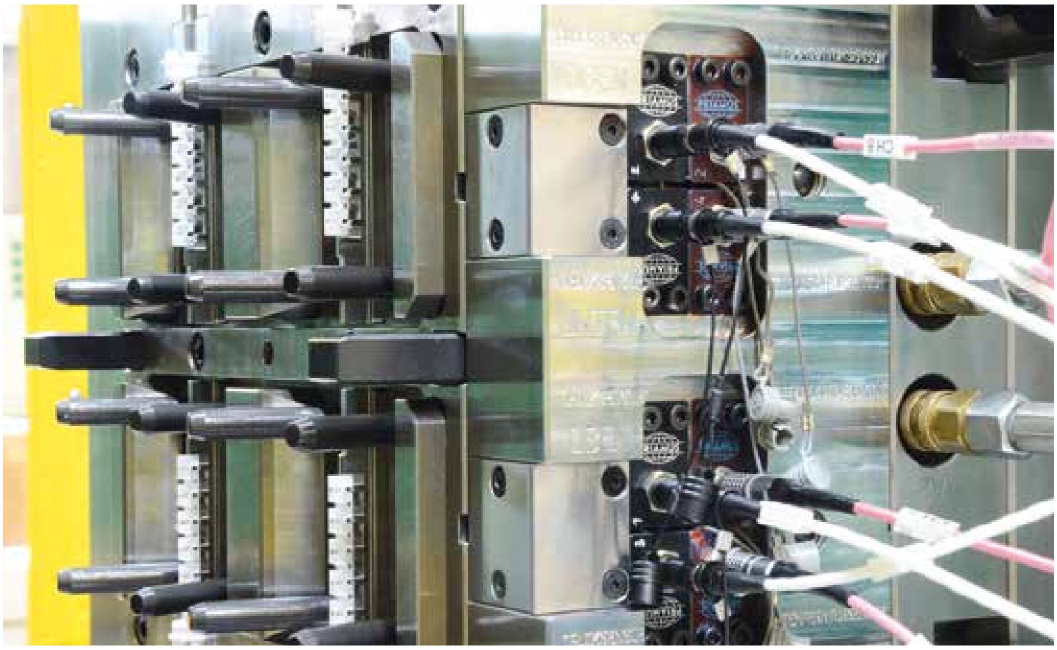
The injection molding world and its quality standards have changed over past years and decades. Even if one dogma or the other still stubbornly persists in the heads of some processors, there is one accepted principle: Without sensors in the mold or directly on the molded part, it is neither possible to identify and eliminate rejects, nor to selectively control and regulate changes in the process. However, this is the prerequisite for reliable, stable and automated production.



The 4-cavity hotrunner mold produces mixing elements for two-component compounds at Sulzer Mixpac (figures: Priamus)

One of the most frequent misunderstandings in the plastics industry is that it is possible to manage without supposedly expensive mold sensors if one measures the melt pressure in the machine nozzle. However, this approach proves to be not very efficient in many ways. In contrast to the molded part in the mold, the plastic melt in the machine nozzle never cools down during production. That makes it impossible to draw conclusions about the part quality – for example the shrinkage behavior.

Moreover, when shut-off nozzles are used, the melt pressure in the machine nozzle only provides information for as long as the nozzles are open. Apart from that, measurement of the melt pressure naturally does not allow analysis of the melt flow in multi-cavity molds or with large parts with multiple gates.

A mistake with much more far reaching consequences is that of the "fingerprint." Since the nineties, it has been repeatedly suggested that the process is OK as long as the cavity pressure profile – in the manner of a fingerprint – agrees with certain reference values. In practice, this theory is often reduced to the condition that the maximum pressure values should agree.

Under closer consideration, however, it is obvious that a different temperature balance – both in the melt and at the mold surface – can lead to completely different conditions. To put it in simple terms, the same cavity pressures do not necessary mean that the injection moldings, too, are identical. The consequence of this consideration is that the same cavity pressures on no account mean the same flow distances of the melt in the cavity. Balancing of multi-cavity molds based on a particular pressure threshold should therefore be performed cautiously.

Automatic Recognition of the Melt Front Is …

Since the early day of injection molding, the quality goal from the point of »

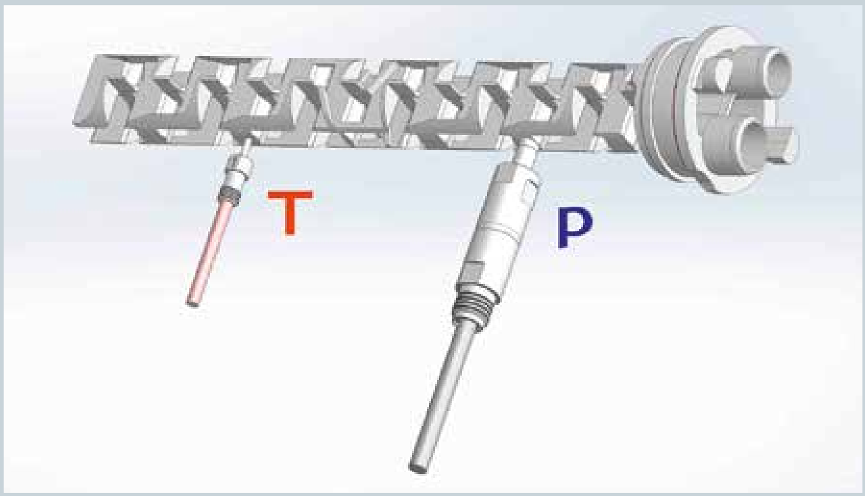


Fig. 1. In the injection molding of the mixing element, a cavity pressure sensor (p) and, before the flow-path end, a cavity temperature sensor (T), is installed in each cavity for monitoring and controlling the viscosity in the flow direction

view of the machine manufacturers has been reduced to one mantra: the more accurate the machine, the more precise the molded part. It is all the more remarkable that this principle appears to have been changing in recent years. Since Priamus System Technologies AG, Schaffhausen, Switzerland, as a manufacturer of quality monitoring and quality control systems has been pursuing a different strategy in recent years [1], the first machine manufacturers have now launched similar approaches on the market. They, too, work on the principle that, for a constant part quality, the machine parameters must be adapted during production to compensate for the constant fluctuations in the process [2].

Specifically, this concerns processes for automatic switchover to holding pressure and self-correcting automatic control processes in the machine control system and hotrunner. But in this case, the parameters that are controlled in the machine can only produce very limited success without feedback from the cavity. Automatic balancing of a hotrunner mold, for example, is still impossible without sensors in the mold.

To check the practicality of sensor-based process-control systems, Sulzer Mixpac AG, Haag, Switzerland, has already declared itself ready to employ and investigate various Priamus control systems. Sulzer is one of the technology leaders in output technologies for one and two-component materials. Its portfolio includes mixers, cartridges and dispensing equipment for metering, mixing and dispensing adhesives and sealants and coatings in the fields of health, dental, construction and industry.

For the practical tests, a 4-cavity hotrunner mold was equipped with a cavity pressure sensor (type: 6010BC) and a cavity temperature sensor (type: 4010B; manufacturer: Priamus in both cases). The sensors are arranged to ensure that the flow behavior or the viscosity respectively is determined, monitored and automatically controlled during production (**Fig. 1**).

The part itself is the mixing element EBT7.5-12-CV01, which is used for two-component compounds of all kinds, for example for manufacturing dental molds, temporary bridges or bone cement. The aim of the studies was to keep the part quality at the highest possible constant level under actual process conditions and disturbing influences.

… the Basis of Any Process Control

Every change to the process – whether due to changes in machine settings, unbalanced hotrunner systems or batch-related viscosity changes – inevitably involves readjusting the switchover to holding pressure, too. If the switchover is

<table>
<tr><th>Without process monitoring</th><th>Without process control</th><th></th><th>With process monitoring</th><th>With process control</th></tr>
<tr><td rowspan="7">Rejects are not detected
Reject parts are not separated</td><td rowspan="6">Uncontrolled process
Shipment of reject parts
Viscosity change
Part quality change
Metering changes
Unbalanced flow</td><td>Short shots</td><td rowspan="7">Rejects are detected
Reject parts are separated
Examples:
■ Monitoring of the maximum pressure
■ Viscosity monitoring in the cavity
■ Monitoring of the switchover time in the cavity
■ Monitoring of the fill time in the cavity
■ Monitoring of the mold surface temperature
■ Monitoring of the integral values (cooling performance)</td><td rowspan="7">Process is automatically readjusted
Guaranteed full parts
Examples:
■ Automatic switchover to hold
■ Automatic hotrunner balancing
■ Automatic hotrunner control
■ Automatic viscosity control in the cavity
■ Automatic compression control
■ Automatic shrinkage control
■ Automatic valve gate control</td></tr>
<tr><td>Batch to batch variations</td></tr>
<tr><td>Wear on the barrel</td></tr>
<tr><td>Wear on the mold</td></tr>
<tr><td>Wear on the hotrunner</td></tr>
<tr><td>Machine change</td></tr>
<tr><td>Temperature drift cannot be compensated</td><td>Temperature variations</td></tr>
<tr><td>Balance of the process cannot be determined</td><td>Balance is only reached slowly</td><td>Start-up cycles</td><td>Rejects are reduced to a minimum</td><td>Process is automatically readjusted, balance is reached faster</td></tr>
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Table 1. Overview of possible defects and their consequences when sensor-based process monitoring and process control systems are not used

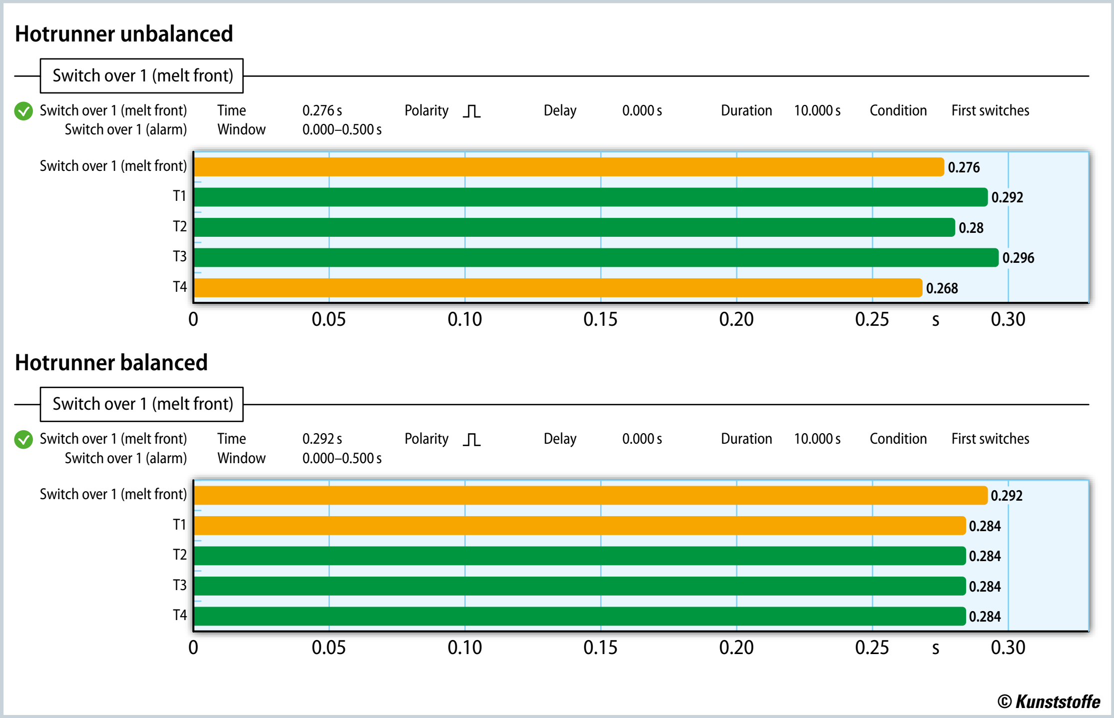

Fig. 2. The melt front is automatically recognized in each cavity when it reaches the temperature sensor. Preferably the first recognized signal is used for automatic holding pressure switchover; all four signals are used for balancing the hotrunner. Filling of the four cavities only takes place simultaneously in the balanced state

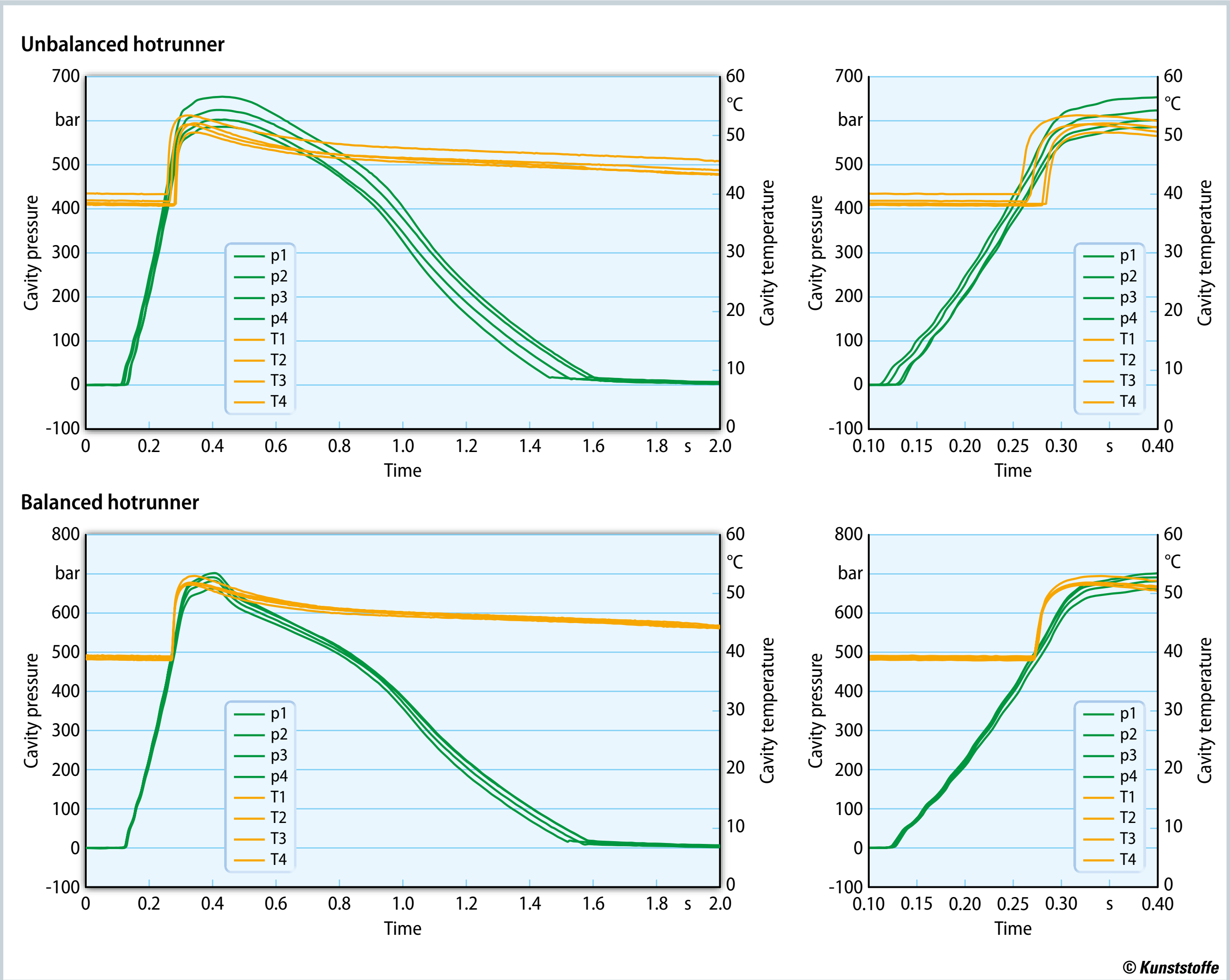

Fig. 3. In the balanced state, too, the cavity pressure curves in the four cavities are different from one another. In the enlarged view (right), it can be seen that the filling time difference from the temperature curves does not correspond to that from the pressure curves »

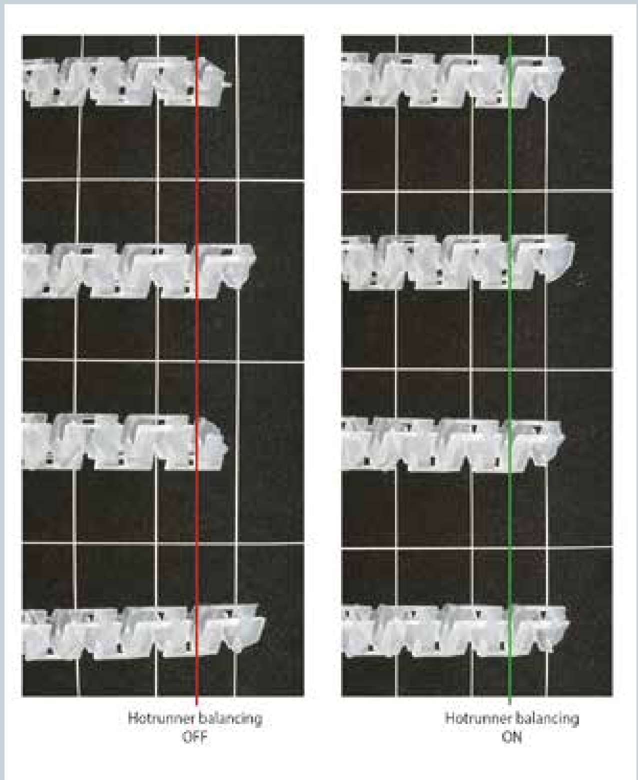

Fig. 4. The different flow-path lengths in the unbalanced state (left) clearly differ from the approximately identical flow-path lengths in the balanced state (right)

not automatically readjusted, every change means that different amounts of melt are injected, which inevitably leads to quality fluctuations.

However, Priamus systems automatically recognize when the melt encounters the position of the temperature sensor. This can compensate for different flow velocities in the cavity and the switchover to holding pressure is automatically adjusted. Without the recognition of the melt front and automatic adjustment of the switchover, automatic process control is virtually impossible to realize.

Automatic Hotrunner Balancing

Particularly with multicavity molds, it is advisable to first balance the hotrunner to ensure that all the cavities are filled simultaneously. Due to the recognition of the melt front, the different filling times are determined in each individual cavity and analyzed by the Priamus control system (type: 7080A Fillcontrol Control H). In the unbalanced state, the particular hotrunner nozzles are automatically adapted until identical filling times have been reached in all cavities (**Fig. 2**).

As mentioned above, the pressure profiles do not behave in a linear relationship with the temperature profiles (**Fig. 3**). This is first and foremost because the temperature signals rise precisely at the moment at which the plastic melt encounters the sensors. The pressure differences from cavity to cavity in the range of the pressure rise, on the other hand, are not constant, but change with increasing pressure.

To illustrate the behavior of the hotrunner balancing, the hotrunner nozzle temperatures were deliberately strongly altered and then automatically controlled in a balanced state. At the same time, a basic setting was chosen in which the molded parts are not com-

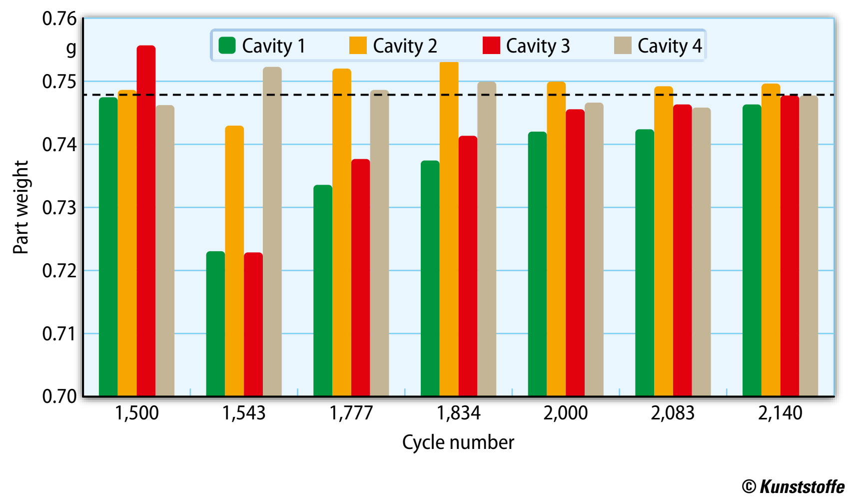

Fig. 5. The hotrunner balancing has a direct effect on the part weight. In cycle 1,543, the weight of the four injection molded parts differs considerably because of the unbalanced state, while after the balancing (cycle 2,140) virtually the same part weight is produced

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References & Digital Version

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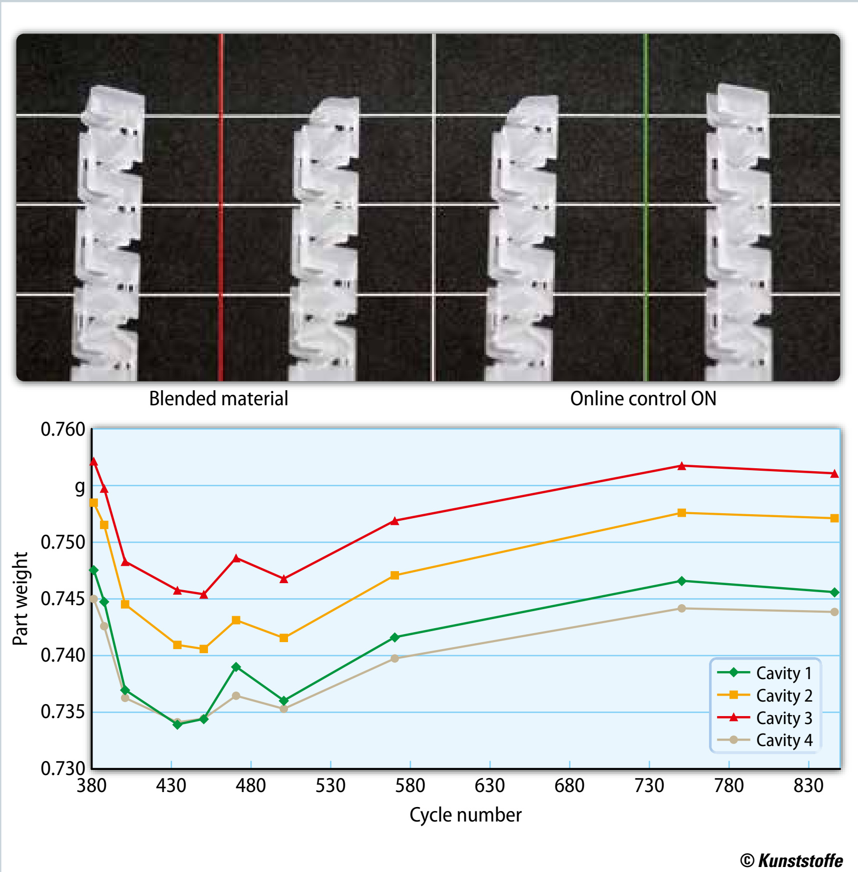

Fig. 6. Batch fluctuations were simulated by mixing two different polypropylene grades. Because of the different viscosity, both the weight and the degree of filling of the molded parts changes immediately after the addition of the second material. After activation of the viscosity control, the original values are automatically reached again

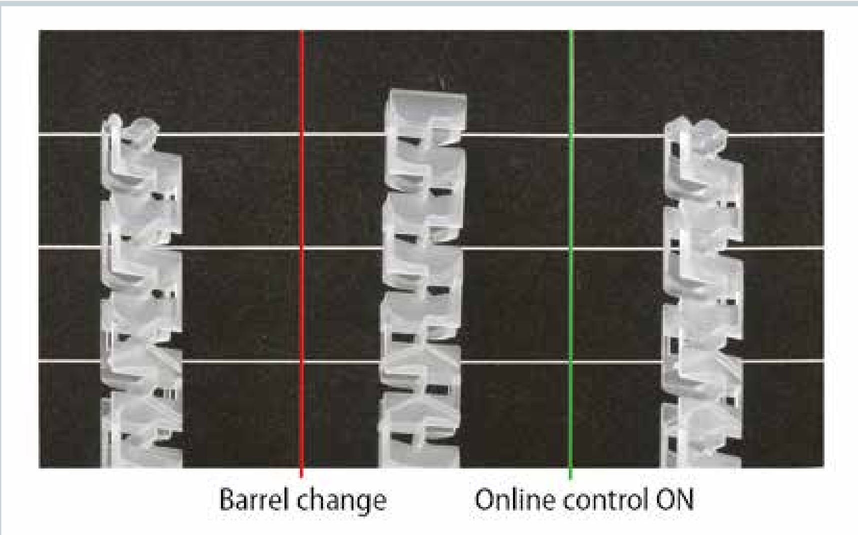

Fig. 7. After the barrel exchange, the injection molded parts were completely filled; later, the original state was reached again with the aid of the automatic viscosity control. The setting with incompletely filled parts was chosen in order to allow the flow paths to be optically assessed

pletely filled in order to optically recognize the different flow-path lengths (unbalanced and balanced) (**Fig. 4**). Depending on the part geometry, a few milliseconds of flow difference from cavity to cavity are enough to achieve an unbalanced state. The results show how the weight of the molded parts from the four cavities are changed and then gradually rebalanced by the control system (**Fig. 5**).

Material and Batch Fluctuations – Everyday Routine

Every batch of a plastic material is subject to greater or lesser fluctuations, which, when the processes are unregulated, have an effect on the part quality due to the differences in viscosity. With a constant machine setting, this generally leads to incompletely filled parts (short shots) or to flash. To simulate this behavior, two polypropylene grades with different flow properties were mixed in the ratio 4:1.

The machine was first started up with the unmixed polypropylene without control by Priamus, and the corresponding reference viscosity values were stored. Then the mixed material was processed and the viscosity control was activated. The Priamus control system (type: 7080A Fillcontrol Control P) controls the viscosity of the melt cycle for cycle by automatically adapting the injection velocity (= shear rate) and the melt temperatures (= shear stress) [3].

In the tests, a basic setting was again chosen at which the molded parts are not completely filled in order to allow even the most minor changes to the process to be optically tracked. The evaluation shows how the flow front and the weight of the injection molded parts are changed immediately after the mixing of the material (**Fig. 6**). By controlling the viscosity, the original weight is reached again in all four cavities.

Sulzer Mixpac AG has over 120 injection molding machines at its Haag site, and hardly any mold is always used on the same machine. Due to manufacturing tolerances, wear and different configurations, this inevitably frequently leads to quality differences in the parts.

To simulate the use of the molds on different injection molding machines, the barrel of the test machine was exchanged and controlled back to the original quality parameters of the part using the Priamus system (**Fig. 7**). This was achieved by adjusting the viscosity, the holding pressure profile and the mold temperature at a specific pressure via the host computer interface of the machine. »

Cost Optimization on Start-Up of the Process

A cost-free and very-effective side effect is achieved here by recording and monitoring the cavity temperature. Depending on the complexity of the part, the thermal equilibrium is achieved after 5 to 30 min, a state that is very difficult to determine in a conventional way using critical masses on the part. During start-up of the machine or after a production interruption, the thermal equilibrium can be very easily and precisely determined using the cavity temperature (**Fig. 8**), which results in a significant cost reduction.

Summary

The trials have shown that monitoring and automatic control of the hotrunner and machine using sensors in the mold not only increase process reliability but also improve the controlled quality of the injection molded parts (**Table 1**). A constant setting of the machine and hotrunner, on the other hand, often results in rejects, simply because it cannot respond to fluctuations in the process and the material.

With the use, principally, of automatic control systems, it is now possible to use an injection mold on different machines and at different sites and to obtain the same quality independently of the operating staff. ■

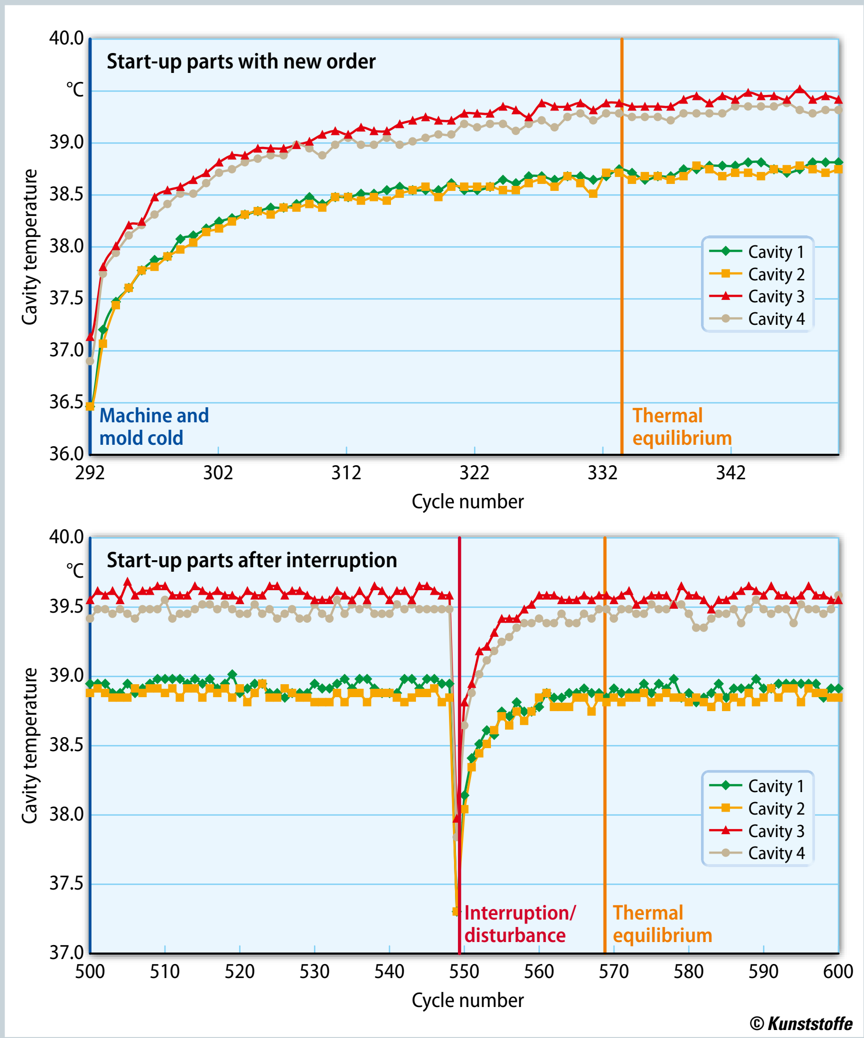

Fig. 8. By monitoring the cavity temperature, the thermal equilibrium can be very easily and precisely determined after machine start-up or after a production interruption

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