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HANSER

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The Time is Ripe

Hot-runner Control

Special reprint

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Ceramic bodies, made by CIM, for the latest generation of high intensity lamps
(photo: Priamus)

The Time is Ripe

Hot-runner Control. Systems for automatic balancing of hot-runner systems are now used extensively in a wide field of applications and have proven especially successful in medical technology. This experience has led to the development of control applications for specialty areas, such as ceramic injection molding and processing of liquid silicone (LSR). This necessitated modifying the control systems to widely differing requirements.

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Particularly in economically challenging times, it is necessary to take appropriate measures to stand out from the competition. While the overall order situation or the commodity prices are set by the market and are difficult, if not impossible, to influence, automated control methods afford a way of greatly boosting competitiveness with existing machinery.

Nothing Works if the Exact Position of the Melt Front is Unknown

Control and regulation of the injection molding process are predicated on automatic determination of the melt front [1]. After all, unless it is known, it cannot be influenced. Premature or delayed switch-over to holding pressure is just as deleterious to the quality of parts and the reject rate during production as different flow behavior in multiple molds [2]. The outcome is unfilled or overmolded parts, as well as variations in molded part weight and dimensions.

Complex predictive methods, such as process models based on a statistical experimental design, are no more able to influence the melt flow during production than the popular – but unauthoritative – view that accurate machine control will be enough. For example, neither a process model nor a machine control system can reliably detect clogging of a hot needle valve in the hot runner.

If the melt front is to be detected, then this must happen in real time [3]. Priamus System Technologies AG, Schaffhausen, Switzerland, has patented a proven solution which uses cavity temperature sensors to automatically detect the melt front when it reaches their positions. This principle is also the basis for Priamus Fill, a system which regulates the nozzles of a hot-runner system in such a way that variations in the process are automatically compensated [4].

To this end, the automatic melt-front detection is used to regulate processes according to individual criteria (Table 1). In this connection, a fundamental distinction is made between two operating modes: simple balancing of multiple

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Pressure and Temperature in the Cavity

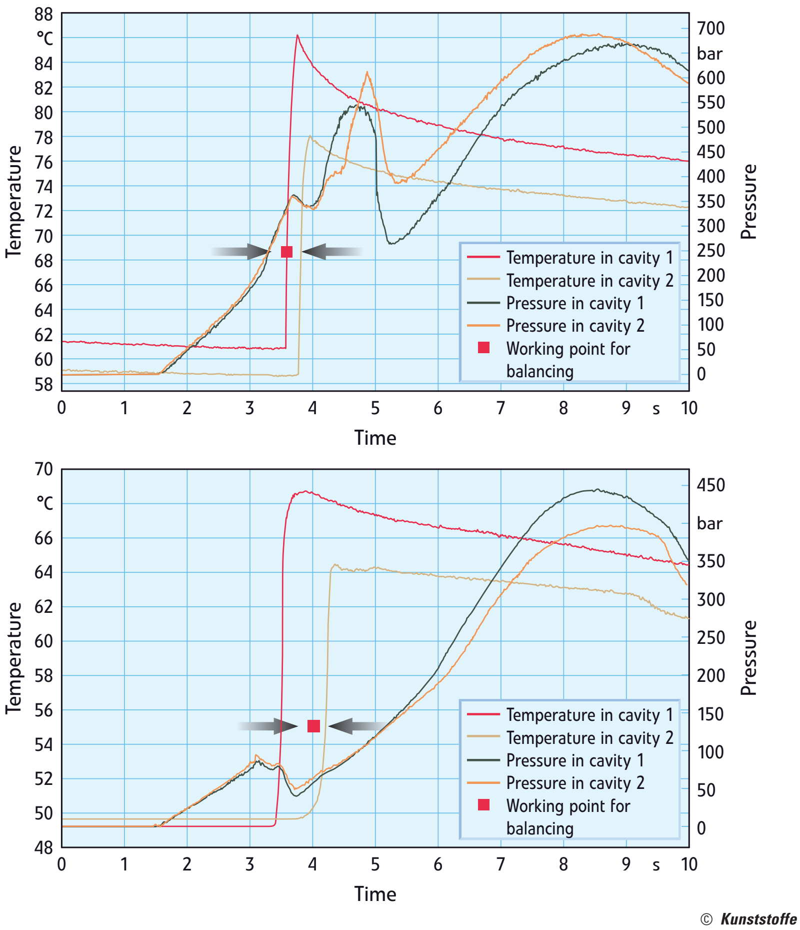

Fig. 1. Cavity pressure curves and cavity temperatures for a 2-cavity mold at different machine settings. The shape of the mold-wall temperature is always unambiguous and can therefore be detected automatically and used for controlling or balancing the hot runners (figure: Priamus)

Individual Process Monitoring		
Multi-cavity molds	Balancing the hot-runner nozzles	1 controller for all cavities
Multi-component molds	Controlling several plastics per part	1 controller per component
Cold-runner sub-manifold	Controlling several cavities per nozzle	1 controller for all sub-manifolds
Family molds	Controlling parts of different size	1 controller per injected part
Weld lines	Controlling a constant weld-line position	1 controller per weld line
Cascade method	Controlling of needle valves (filling times)	1 controller per needle valve (except first nozzle)
Mold-temperature control (thermoplastics)	Controlling the surface temperature	1 controller for all loops
Mold heating (thermosets, elastomers)	Controlling the surface temperature	1 controller for all heating elements
Needle valves (liquid silicone)	Controlling the delay times	1 controller for all cavities

Table 1. Overview of the various applications of hot-runner control and balancing with a freely configurable number of software controllers. Individual process monitoring allows bad parts in each cavity to be segregated

molds and actual regulation to an optimized reference state. In both cases, the temperatures of the hot-runner controller are automatically adjusted so that the viscosity of the melt changes accordingly.

Basically, the controller is designed for up to 128 cavities. To an extent depending on the application, one or more controllers in the software are activated and assigned to a specific task; the various control methods can be combined in principle. For example, a 16-cavity mold with two components can be installed on a rotary table and all parts and components can be individually regulated and monitored. In this case, a separate controller is assigned to each component in each cavity to ensure that all the cavities are always filled simultaneously. Regardless of the position of the rotary table, not only would each part, but also each component, be monitored 100 % of the time and could be separated individually. Should the mold have various heating loops, it would also be simultaneously possible to regulate the surface temperature of the individual cavities to ensure that the moldings shrink under the same conditions and that the dimensions of the molded parts remain stable.

Pressure Signal Changes

When the melt reaches the temperature sensor in the cavity, the temperature rise is automatically detected and can be used for controlling or balancing. Even when the machine settings are highly varied, the shape of the signal is unequivocal and can be interpreted automatically. In contrast, the shape of the cavity pressure signal changes as a function of part geometry and machine setting, so it is primarily used for optimizing the process and for monitoring compression (Fig. 1).

While the viscosity-dependent filling times in each cavity can be clearly identified from the temperature signals, this is difficult, if not impossible, to determine from the pressure curves in this example. For this reason, and to keep down the cost of such a system, Priamus usually recommends one cavity temperature sensor per cavity and one cavity pressure sensor per system.

Automatic Balancing of Ceramic Molded Parts

The example of a ceramic body from the Process Development department of

Philips Lighting BV, Uden, Netherlands, shows how sensitively the system responds to process variations, and the accuracy with which the use of temperature sensors to balance hot runners ensures constant molded part weights and dimensions. The ceramic body is produced in a 4-cavity ceramic injection mold (CIM) and used for the latest generation of high-intensity discharge lamps (HID). The sintered part is installed in the HID lamp to act as a reaction chamber for the plasma-discharge process (Fig. 2). To an extent depending on the type of lamp, the part is loaded with high thermal gradients. The growing diversity of geometric shapes means that powder injection molding, which offers great freedom of form, constitutes an attractive method for manufacturing various types of burners. This application requires absolute geometrical dimensional stability on the part of the ceramic part. The corresponding specifications can be achieved only through precise control over the injection molding process.

Fig. 2. Philips HID lamp with integrated ceramic bodies. The parts were made by ceramic injection molding and balanced with the aid of the Priamus Fill System (photo: Philips)

The purpose of balancing hot runners is to eradicate the differences in filling times in the various cavities (Fig. 3). Initially, all the nozzles of the hot runner are set to a constant value, but the process itself is in a permanent state of imbalance. The cavities are filled at different times, a fact which must inevitably yield to parts that have different properties. Figure 3 also shows the curves for the balanced state in which the nozzle temperatures – and thus the flow behavior of the ceramic melt – were changed automatically so that all cavities were practically filled at the same time.

While the differences in filling times in the unbalanced variant move continuously in the same order of magnitude throughout production, the Priamus Fill System balances the process after a few cycles, and more or less totally eradicates the differences in filling times. As the viscosity differences in the individual cavities have been balanced, the outcome is identical filling times in the various cavities.

Comparison of the process capabilities in the balanced and unbalanced state reveals a similar picture (Fig. 4). A distinction is made between the „potential process capability“, which pertains only to the properties of the molded part itself, and the overall process capability, which also factors in the influence of the machine over a prolonged period. This overall process capability, expressed in

Elimination of the Differences in Filling Times

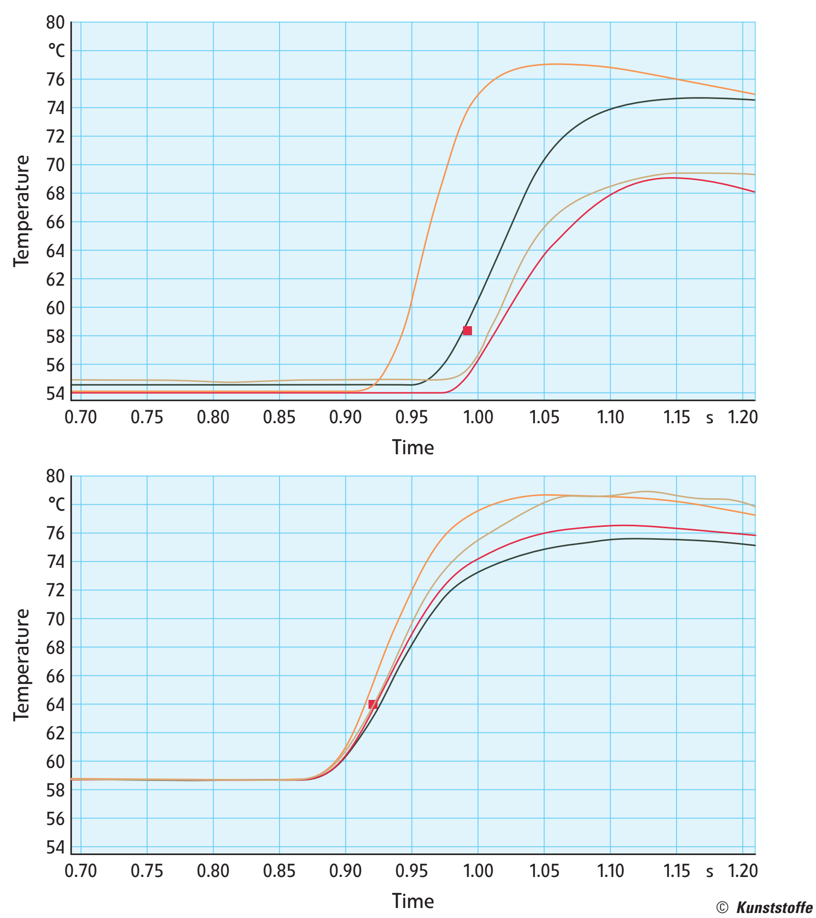

Fig. 3. Differences in filling times of the various cavities before and after balancing, as shown by curves of the cavity temperature. The nozzle temperatures of the hot-runner system are automatically changed such that each cavity is filled at the same time (figure: Priamus)

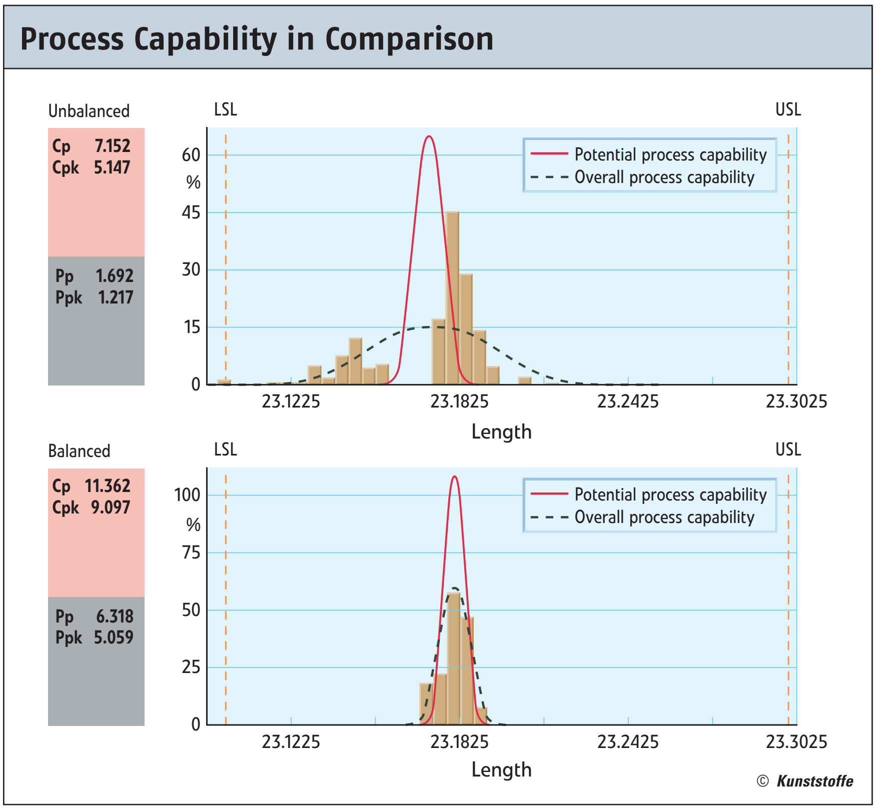

Fig. 4. Potential process capability and overall process capability, expressed in terms of the length of the sintered ceramic bodies. This overall process capability improves from the unbalanced to the balanced state by more than a factor of 4 (figure: Philips)

terms of the length of the sintered parts, improves by a factor greater than 4 on progression from the unbalanced to the balanced state.

The influence exerted by balancing on both the weight and the total length of each sintered part can be shown graphically (Fig. 5). A probability paper is used initially to check the distribution of the measuring values. In the ideal case of a normal distribution, the values lie on a straight line, as in the case of the balanced state. In the unbalanced state, one of the cavities does not follow this distribution, partly because it was not fully injected. Although the absolute measuring values in all scenarios move within a very narrow band only, it can be seen that even the smallest variations in the process can make the difference between good and bad parts. The statistical scenario reveals that a process involving unbalanced hot runners in this example can scarcely be used for the manufacture of ceramic bodies.

Automatic Control of Liquid Silicone Injection Molding

On account of the low viscosity of LSR, the differences in filling time have an even greater impact on the quality of the injection molded parts than is the case for standard thermoplastics. Then there is the problem that the LSR parts (Fig. 6) in the unbalanced state cross-link under different physical conditions, a fact which greatly impairs the quality of the parts made in a multi-cavity mold. Since hot runners are not used in the processing of liquid silicone materials, an alternative balancing method for the melt flow must be applied. The different filling times were compensated by modifying the Priamus Fill System such that it automatically calculates delay times for the needle valves.

Cavity temperature sensors report when the melt reaches the sensor position. If the filling times differ from cavity to cavity, the delay times until the nozzles are closed are automatically adjusted (Fig. 7). Since the mold in liquid silicone injection molding is at a higher temperature than the injected material, a tem-

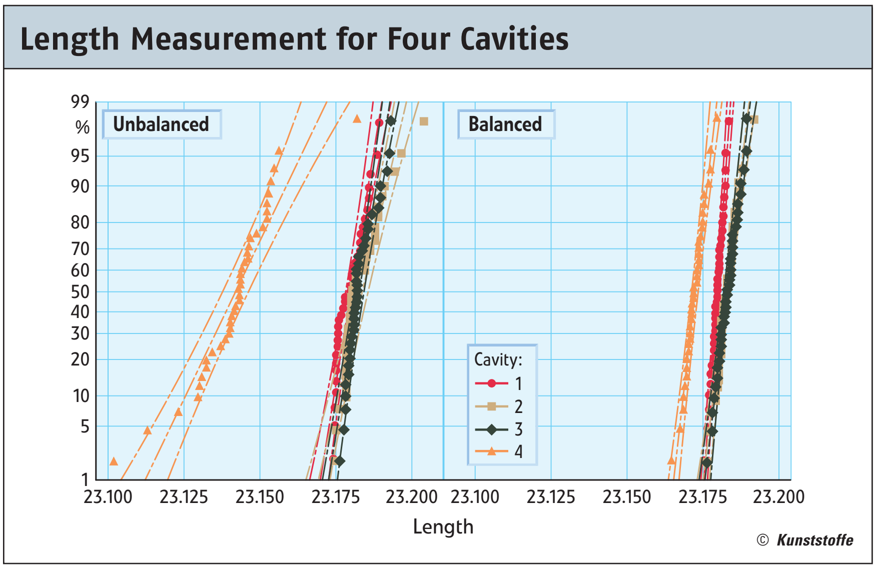

Fig. 5. Probability paper for the total length of the sintered parts in the balanced and unbalanced process. In the ideal case of a normal distribution, the values lie on a straight line. In the unbalanced state, one of the cavities does not follow this distribution, because it was not fully injected. A similar picture is presented by an analysis of the weight (not shown) (figure: Philips)

Fig. 6. LSR pacifier made by California-based firm Kipe Molds. On account of the low viscosity, differences in filling time in liquid silicone injection molding have a much greater impact on parts quality than is the case for standard thermoplastics (photo: Priamus)

Elimination of the Differences in Filling Times

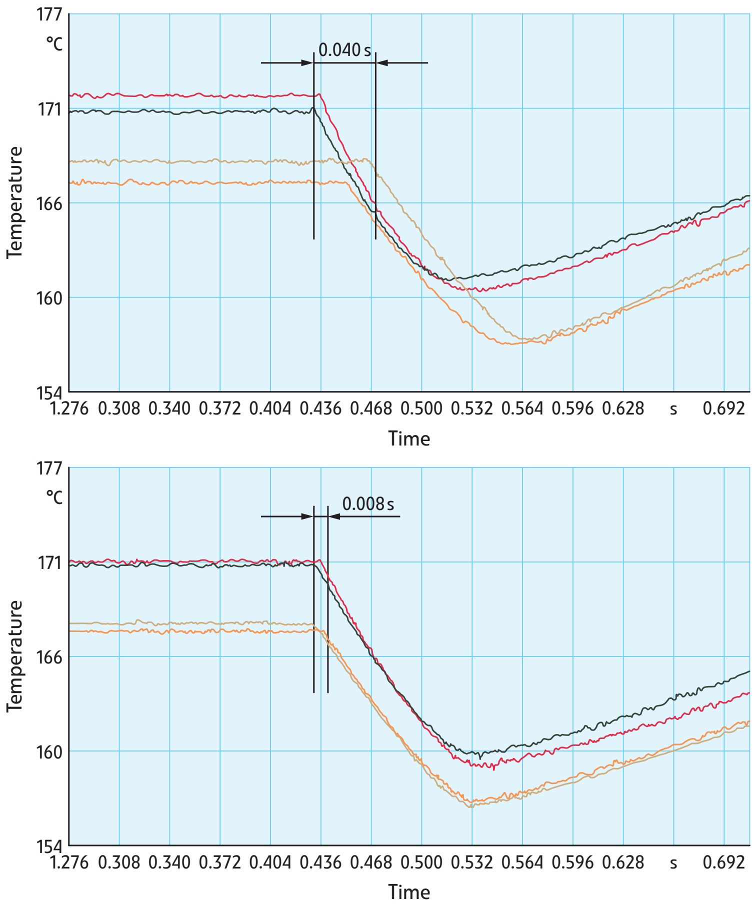

Fig. 7. Cavity temperature signals for a 4-cavity LSR injection mold in the balanced and unbalanced states. The Priamus Fill System compensated the different filling times with the aid of automatically calculated delay times at the needle valves (figure: Priamus)

perature drop is always measured, unlike the case for injection molding of thermoplastics. In this example, too, differences in filling times from cavity to cavity are eradicated, with the result that simultaneous filling and thus cross-linking under the same physical conditions are ensured.

Outlook

Anybody who in supposedly good times could afford to simply ignore scrap rates in the single-digit percentage range will no longer be able to do so in the foreseeable future. The economic climate is forcing more and more processors to wring the very last potential out of possible cost cuts. The examples show that this need not entail the acquisition of new machinery, but rather has more to do with enhanced process management. Especially in the field of hot-runner technology and melt-flow control, there are a number of ways in which costs may be further reduced, safer production ensured and product quality greatly enhanced. ■

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