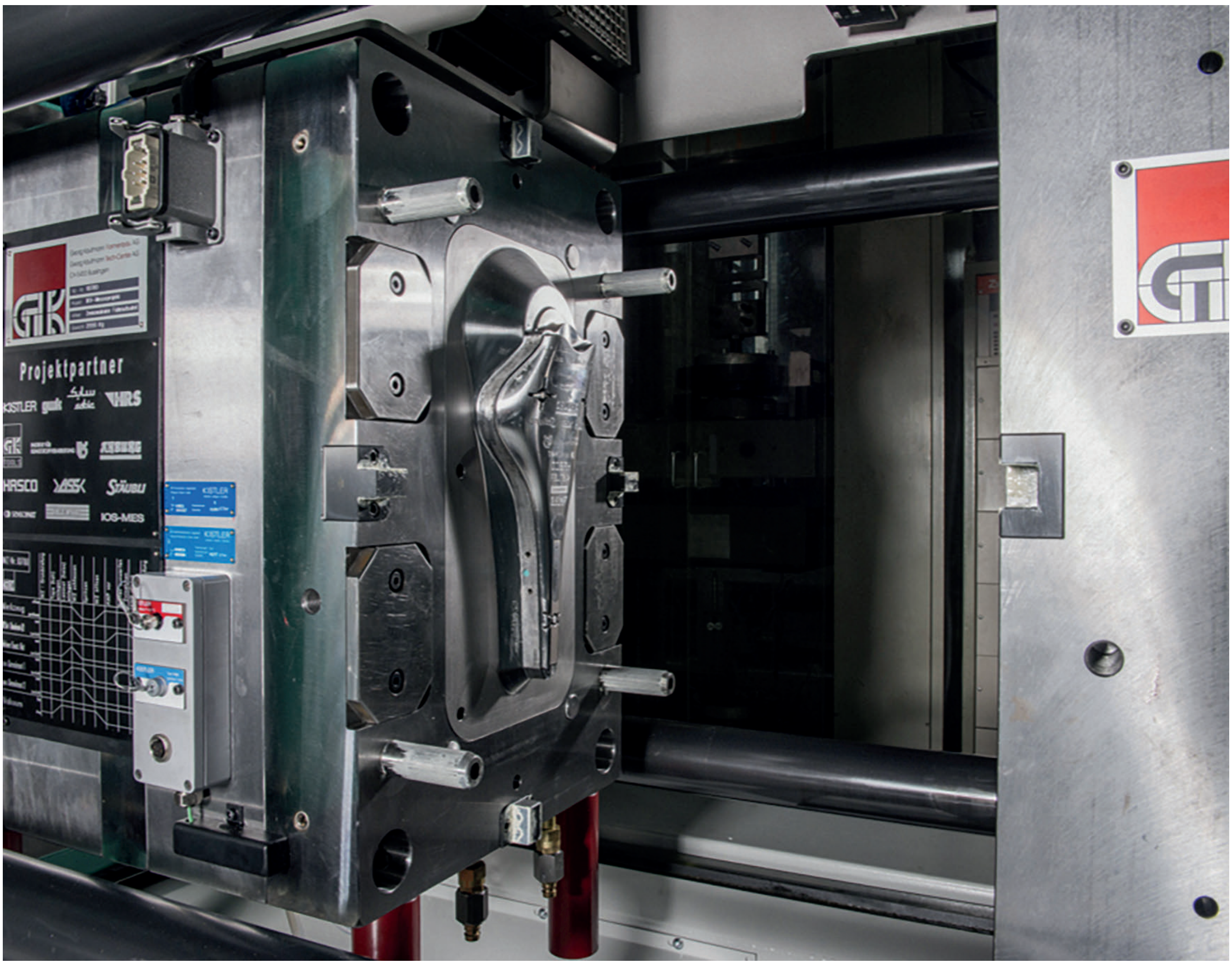
The Hot Runner Valve Pin as Actuating Variable

Cavity-Specific Pressure Control to Increase Process Consistency

The Institute for Plastics Processing (IKV) at RWTH Aachen University is investigating a new control approach for injection molding in which the cavity pressure is controlled by different positions of the hot runner valve pin. The influence on the cavity pressure of different strokes in the holding pressure phase is investigated.



The experimental mold with the cavity of a bicycle saddle has a servo-electrically driven hot runner © IKV

Product quality is an important competitive factor for plastics processing companies. Quality characteristics of a molded part, such as its dimensional accuracy, weight and surfaces, are determined by the thermodynamic melt state in the cavity during molding. The melt state is described by its pressure, specific volume and temperature. For high-precision molded parts, a reproducible pressure and temperature curve in the cavity is of decisive importance [1].

Despite constant machine setting parameters, unavoidable disturbances of the injection molding process, such as the processing of different material batches, fluctuating material conditioning or different closing behavior of the non-return valve, lead to fluctuations in the melt state and consequently also in the component quality [2]. Therefore, control systems that adapt the process to the prevailing conditions and thus demonstrably increase the process constancy are already state of the art [3–5].

Some systems detect fluctuations in viscosity throughout a change in injection pressure and adjust the switchover point and the holding pressure level [3, 4]. However, these concepts cannot detect disturbances caused inside the mold, such as fluctuations in mold temperature or disposals on the hot runner surface that change the flow properties. Another method regulates the cavity pressure directly via the screw movement in the plasticization unit [6]. Nevertheless, the system behavior and the material behavior depend on many factors and lead to a highly complex control system. These approaches require specialist knowledge when setting up the control system, which cannot usually be expected in production.

Control of Cavity Pressure Directly at the Gate

In addition, these concepts cannot regulate the melt flow into different cavities of a multi-cavity mold. This is particularly disadvantageous for family molds because of the different volume of the mold cavities. In order to be able to guarantee high part quality for each individual cavity, the gate system is elaborately balanced and optimized with regard to one process setting. Therefore, the balancing is dependent on the operating point, so that deviations in the process due to disturbances can lead to varied filling of the cavities.

Therefore, a system that can control the melt flow independently for each cavity using additional valves in the hot runner was developed [7]. Depending on the position of the valves, different amounts of material can be injected into the cavity. However, this system does not control the pressure directly in the cavity, but the gate system. The pressure at this point does not directly reflect the conditions inside the molded part.

At the IKV, a new control concept is developed that regulates the cavity pressure directly in the mold. In this process, the pressure transfer into the cavity is controlled using the movement of the hot runner pins. The pressure loss in the hot runner increases with a smaller opening stroke of the valve pin because the cross-section in the hot runner is reduced.

Component	Type	Manufacturer
Injection molding machine	Allrounder 520 A 1500 – 800 Alldrive	Arburg GmbH + Co KG, Lossburg, Germany
p/T sensor	6190CA	Kistler Instrumente AG, Winterthur, Switzerland
Hot runner	Flexflow	HRSflow/Inglass S.p.A., San Polo di Piave, Italy
Hot runner pin/control unit	Minas A5 / MBDHT2510	Panasonic Electric Works Europe AG, Ottobrunn, Germany
cRIO system	cRio-9074, including corresponding modules	National Instruments (NI), Austin, TX/USA
Polypropylene	579 S	Saudi Basic Industries Corporation (Sabic), Riad, Saudi Arabia

Table 1. Plant and system components as used in the experiments for cavity-specific pressure control Source: IKV

The Pressure Level in the Cavity Decreases with Smaller Opening Strokes

In preliminary tests (**Table 1**) for the development of the control concept the relationship between opening stroke and cavity pressure was quantified first. A mold operated on an electrical injection molding machine, whose cavity has the geometry of a bicycle saddle, was used during these experiments (**Title figure**).

Along the flow path, combined p/T sensors near the gate and at the end of fill (filling volume 22% and 98%) are installed (**Fig. 1**). The mold is equipped with a hot runner with servo-electrically driven valve gate nozzle. The hot runner pin, which is controlled by a cRIO system, opens completely before the injection phase (maximum opening stroke: 18 mm) and defines different opening strokes during the holding pressure phase.

In preliminary tests, the influence of constant opening strokes on the cavity pressure during the holding pressure phase was analyzed. With an opening stroke of the valve pin of 18 mm during the holding pressure phase, a pressure of about 115 bar is measured in the cavity (**Fig. 2**). By decreasing the opening stroke to 5 mm the pressure level decreases by 10 bar compared to the reference curve (opening stroke 18 mm). The comparison of the pressure curves of the different pin positions confirms that the smaller the opening stroke, the lower the pressure level inside the cavity. »

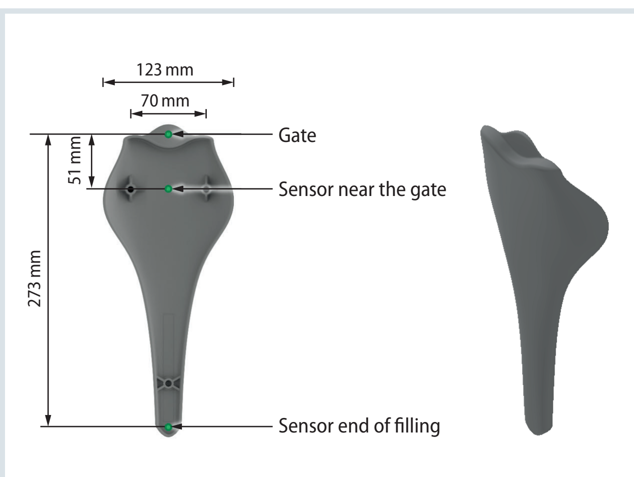


Fig. 1. Two combined p/T sensors for internal pressure measurement are installed in the mold along the flow path Source: IKV; graphic: © Hanser

Advances at a Glance

Since the pressure is controlled with a hot runner pin, a cavity pressure curve can be individually adapted for each cavity independently of other mold cavities. In this way, disturbances to the injection molding process can be compensated for on a cavity-specific basis. This is particularly advantageous for family molds since the cavities have different volumes.

The Authors

Prof. Dr.-Ing. Christian Hopmann is Head of the IKV – Institute for Plastics Processing in Industry and Craft at RWTH Aachen University and holds the Chair of Plastics Processing at the Faculty of Mechanical Engineering at RWTH Aachen University.
Hanna Dornebusch, M.Sc. RWTH, headed the working group for Process Control in Injection Molding at IKV from 2016 to 2020.
Matthias Schöll, M.Sc. RWTH, leads the working group for Process Control in Injection Molding at IKV since August 2020;
matthias.schoell@ikv.rwth-aachen.de

Acknowledgments
The research project 19966N of the Forschungsvereinigung Kunststoffverarbeitung was sponsored as part of „industrielle Gemeinschaftsforschung und -entwicklung (IGF)" by the German Bundesministerium für Wirtschaft und Energie (BMWi) due to an enactment of the German Bundestag through the AiF. We would like to extend our thanks to all organizations mentioned.

Service

References & Digital Version

- You can find the list of references and a PDF file of the article at ***www.kunststoffe-international.com/archive***

German Version

- Read the German version of the article in our magazine ***Kunststoffe*** or at ***www.kunststoffe.de***

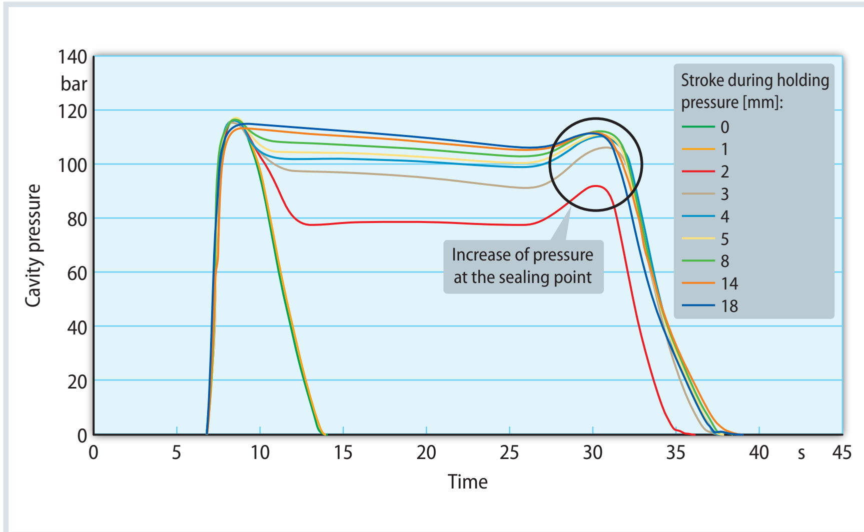


Fig. 2. Different opening strokes in the holding pressure phase influence the cavity pressure Source: IKV; graphic: © Hanser

The lower pressure level results from the decreased cross-sectional area throughout smaller opening strokes. The influence of the opening stroke on the cavity pressure increases with lower strokes. For example, the cavity pressure curve is with each millimeter of smaller opening stroke during the holding pressure about another 0.5 bar less in contrast to reference (opening stroke 18 mm). However, as soon as the hot runner is opened by less than 4 mm, the pressure loss increases noticeably, resulting in a pressure decrease inside the cavity [8]. At opening strokes between 0 mm and 4mm, the cross-section is varied as the pin tip dips into the reduction of the cross section to close the hot runner. The pressure resistance in the hot runner is therefore at its greatest (**Fig. 3**). With larger opening strokes of the pin, the pressure resistance in the hot runner is varied by the length of the ring flow in the hot runner. However, the influence of the flow length on the pressure resistance is less than a change in the cross-section in the hot runner.

Furthermore, an increase in pressure at the sealing point is noticeable in the pressure curves measured near the gate. This can be traced back to the fact that the components shrink onto the pressure sensor, which sticks out of the cavity surface.

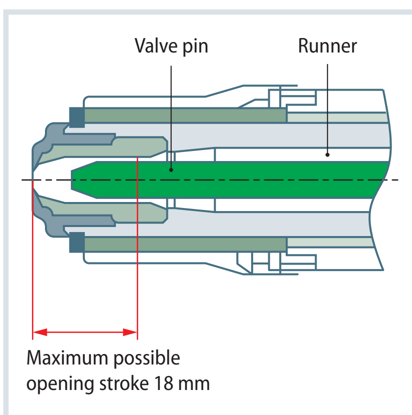


Fig. 3. The narrowest cross-section in the hot runner is only affected in the last quarter before the pin closes completely Source: IKV; graphic: © Hanser

Closing the Pin: Small Pressure Increase with Each Positioning Step

In further tests, the hot runner pin not only maintained a defined opening stroke during the holding pressure phase, but also moved according to predefined position profiles. For this purpose, the influence of a gradual closing of the hot runner on the cavity pressure was investigated (**Fig. 4**). The opening stroke is reduced in six 3 mm steps from 18 to 0 mm. Each individual step is held for 5 s.

The resulting cavity pressure is only slightly below the level of the reference curve (18 mm). The deviation results from the longer ring flow in the hot runner compared to the unchanged pin position and the associated higher pressure resistance in the hot runner. However, the pressure increases at the start of the pin movement. A possible reason for this may be the additional compression of the melt and the additional melt injected into the cavity due to the closing movement of the pin.

Opening the Pin: Slight Pressure Decrease with Each Travel Step

Finally, the reverse movement of the pin in the holding pressure phase was analyzed. During the stepwise opening of the hot runner, the pin initially closes completely after an opening stroke of 18 mm during the injection phase and opens in six 3 mm steps from 0 to 18 mm. Here again, the individual steps are held for 5 s each. Shortly after the switchover point, a maximum cavity pressure of over 115 bar is measured – a higher value compared to the other tests (**Fig. 5**).

Analogous to the slight pressure peaks during the stepwise closing of the pin, this is caused by the additional compression of the melt because of the traversing movement of the pin. Closing the hot runner completely interrupts the pressure transfer from the plasticizing into the cavity. Due to the shrinkage during cooling of the melt, which cannot be compensated because of the closed cavity, the cavity pressure decreases by about 50 bar. With the subsequent opening of the hot runner, the pressure measured in the cavity rises again to almost the same level as when the runner system was fully opened during the entire holding pressure phase, since the melt flow can compensate the shrinkage.

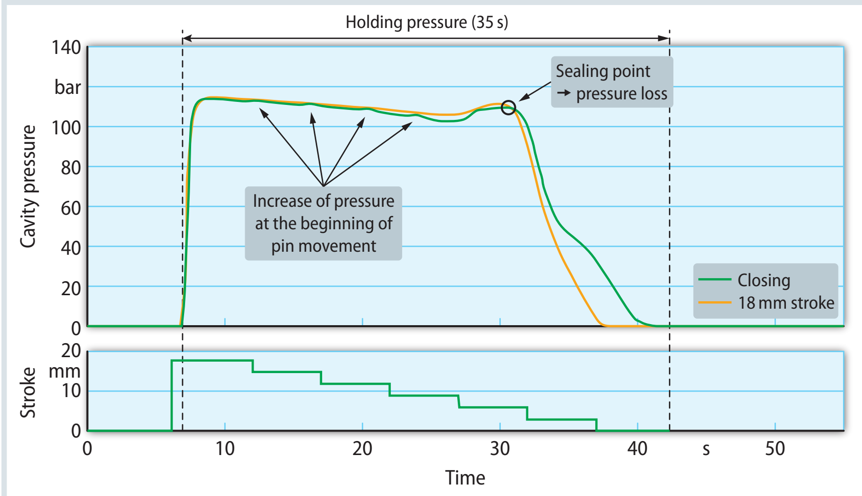


Fig. 4. Gradual closing of the hot runner only slightly influences the pressure curve
Source: IKV; graphic: © Hanser

In contrast to the previously discussed experiment, at the beginning of the pin's movement a small pressure decrease occur briefly at each of the individual stages. In contrast to the previous test point, the melt is depressurized because of the opening movement of the valve.

The sensor at the end of filling can also detect the influence of the pin movement on the measured pressure curve. Here, the pressure curve also shows a decrease when the hot runner closes after switching from the injection to the holding pressure phase, which is also almost compensated for by the subsequent opening. However, the pressure decreases far from sprue are not as significant at the start of the pin movements. The reason for this is the lower melt temperature, which causes the plastic to solidify sooner and reduces the pressure transfer in the melt. In addition, the distance between the sensor position and the gate is larger, so that the effect is even smaller.

Based on these results of the different studies, a control strategy was developed in further investigations which specifically controls the cavity pressure using the hot runner pin as a manipulated variable. The results obtained with this control system can be found in the final report of the project [9]. In the future, the control of cavity pressure with the aid of the hot runner valve pin is to be transferred to a family mold, because this enables cavity-specific influencing of the process conditions.

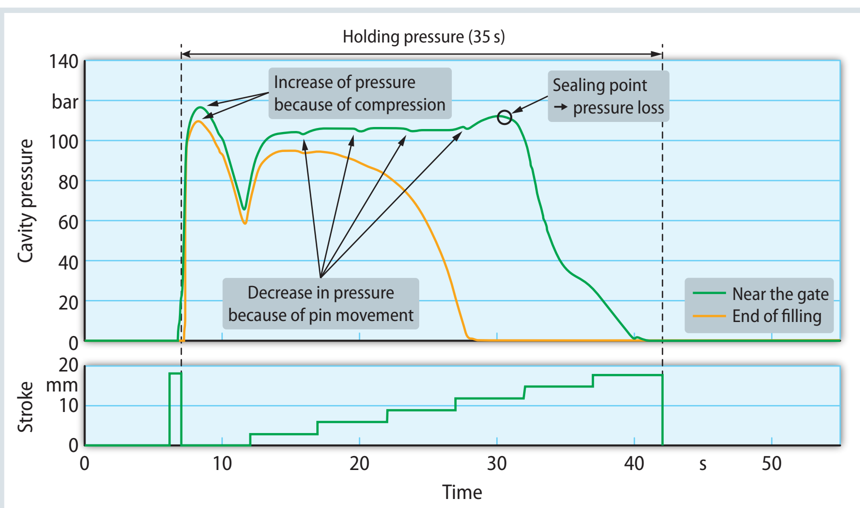


Fig. 5. When the hot runner is gradually opened during the holding pressure phase, a sink mark can be seen in the cavity pressure curve Source: IKV; graphic: © Hanser

Conclusion

The tests have shown that different mold cavity pressures can be realized by moving the hot runner valve pin during the holding pressure phase, both near the gate and end of filling. The hot runner pin can therefore be used as a manipulated variable for controlling the injection molding process. The pressure level in the cavity correlates with the opening stroke of the pin, but the pressure loss can only be significantly influenced by varying the flow cross-section of the hot runner at the nozzle. Varying the length of the ring flow, on the other hand, has only a minor influence on the pressure transfer into the cavity. ■