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The Discovery of the Melt Front

Sensor Technology


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Special reprint

Ventilation system component for automotive engineering. A mold wall temperature sensor monitors whether the part is completely filled at the end of the flow path (photo: Koyo Kasei)

The Discovery of the Melt Front

Sensor Technology. The injection molding process as such can be regarded as a temporal sequence of defined switching processes. Both the sequences in the machine controller and mold-related sequences such as the opening and closing of shut-off nozzles are based on such switching processes. High-speed switching systems banish instable processes and faulty molding from day-to-day production.

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The quality of a machine controller or a superordinate open-loop or closed-loop control system is ultimately determined by how quickly, how reliably and with what repetition accuracy a switching process is performed. The following examples illustrate the behavior of different switching processes and explain their influence on the flow property of the melt, on the molding characteristics and on the process control.

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Short and Long Reaction Times

The time lag of switching signals impacts the effective flow distance of the melt, in particular during the injection process. Depending on the switching method, there is a certain reaction time from the moment a switching signal is generated until it ultimately takes effect. For example, in order to open a shut-off nozzle during the injection process depending on the pressure, the switching threshold of a cavity pressure signal is programmed to, for example, 100 bar. With high time-lag, slow switching systems, a relatively long time passes before the signal takes effect, during which the melt continues to move. With high-speed, dynamic switching systems, on the other hand, there is only a comparatively short delay so that the melt barely moves any further in the cavity.

In order to be able to control a process, it is crucial to know the position of the melt at all times and under all conditions in order to be able to influence the posi-

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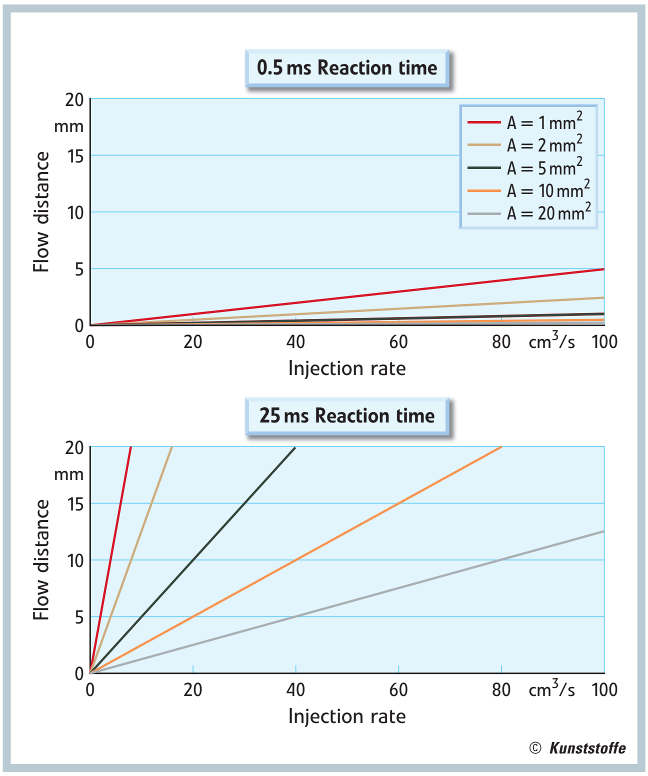
tion of the weld lines, the meeting of melt fronts and generally the filling of the part. For this reason it is well worth paying attention to ensuring that a switching process reacts quickly and with high repetition accuracy. With the switching systems generally on the market, both short and long reaction times are observed (**Fig. 1**). The influence on different part geometries is reflected in how the same volume of the injected melt affects different part cross-sections.


0.5 ms Reaction time

25 ms Reaction time

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Fig. 1. Flow distances for different reaction times during the injection process. The melt flows a different distance, depending on the cross-section of the cavity and the time delay of the switching system (Figs. 1 to 8: Priamus)

Whereas the flow distance with a high-speed system with 0.5 ms reaction time barely differs with differing injection rates, the melt flows far further with a slow system with a reaction time of 25 ms. Thus the slower a switching signal reacts, the less well known and controllable is the position of the melt. The two examples from practice show how important the reaction speed of a switching system is for reliable control of the melt front with high repetition accuracy.

Different Switching Methods

It is not only the time lag, but also the type of switching method that affects the flow distance and the process stability. For this reason, the switching thresholds to holding pressure have been displayed graphically on a large number of machine controllers for many years. And it is not unusual for the precise and stable switching thresholds of a screw position to be used as selling arguments for an injection molding machine. What is frequently forgotten here is that the filling of an injection molding can be subject to large fluctuations, even if the machine suggests a constant process. This can be seen plastically from the example of a motor vehicle ventilation system component (**Title photo**) from the Japanese company, Koyo Kasei, in which a mold wall temperature sensor detects the complete filling. If the melt reaches the sensor at the end of the flow path, the system automatically switches to holding pressure and a good part is signaled [1]. If the sensor position is not reached and the part is not completely molded, the bad part is automatically discarded.

The switching processes commonly used today,

- stroke-dependent switching as a function of the screw position,
- pressure-dependent switching as a function of a cavity pressure threshold [2],
- automatic switching on detection of an increase in cavity pressure (melt front detection),
- automatic switching on detection of an increase in temperature (melt front detection) [4]

have a widely differing influence on the process and its stability. The first two here differ fundamentally from the automatic switching processes, and that in a number of ways. Both a stroke-dependent and a pressure-dependent switching signal must always be optimized for a given working point and found by hand or by means of a filling study for a given machine setting and choice of material. If the machine settings or material properties change, the optimization process has to be repeated.

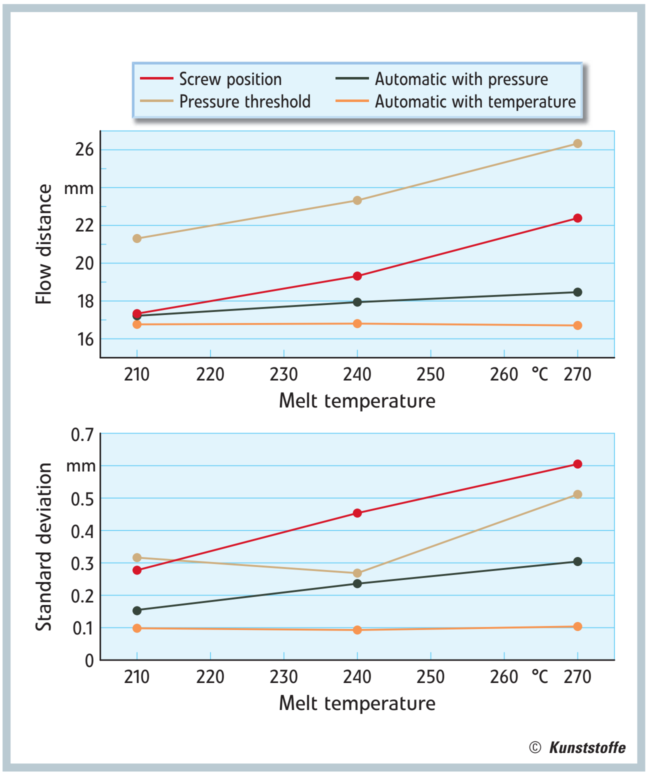

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Fig. 2. Flow distances for four switching processes with different melt temperatures. Only the automatic process with the mold wall temperature results in equal flow distances, as the values for the standard deviation also show

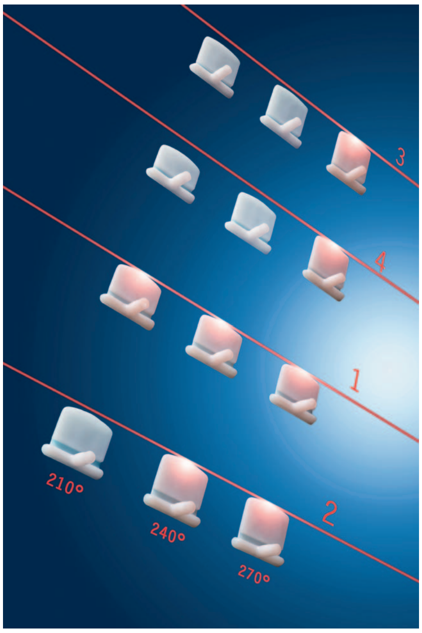

Fig. 3. The partly filled test rods with the four switching processes in comparison (least/ most fluctuations: Trial series 1/4). Only parts with the switching triggered automatically via the temperature signal exhibit the same flow distance. The largest differences are measured for the parts whose filling process was interrupted via the screw position

Automatic switching processes, on the other hand, adapt automatically to the process conditions and provide a precise switching signal, irrespective of the settings. Not only is the finding of a good basic setting eliminated, but also the laborious repeating during the process. Far more significant, however, are the consequences when the process conditions change, as tends to happen in reality.

In a comparison study (machine: 320A Alldrive 600-170, manufacturer: Arburg GmbH + Co KG; material: polystyrene Type 495F, manufacturer: BASF SE), the melt temperature was varied over the largest possible molding range. In view of the small injection volume of the only partially filled test rod and the comparatively stable behavior of the electric injection molding machine, only small differences in flow distance occur **(Fig. 2)** – this would be very much more pronounced with larger moldings and poorer machine properties. But even under these "homoeopathic" injection conditions it is clear that the two stroke-dependent and pressure-dependent switching processes cannot react to process fluctuations, and automatically result in different flow distances.

The two automatic switching processes, on the other hand, cause no change in the flow distance, corresponding to the ideal situation in production. The smaller standard deviation also favors the automatic switching processes. For this reason, plastics processors with a stroke-dependent switching signal and during switching with a pressure threshold generally have to anticipate a higher probability of unfilled parts. In the same series of trials with the partly filled test rods **(Fig. 3)**, only the switching signal generated automatically on detecting the increase in temperature caused no fluctuation in the flow distance (trial series 1). The largest fluctuation in the flow distance was observed with the screw position-dependent switching signal (trial series 4).

Automatic Determination of Viscosity Values

The automatic detection of the melt front using a pressure or temperature signal offers obvious advantages for the automatic switchover to holding pressure, when opening shut-off nozzles or when opening and closing venting cores. However, the process also offers far more possibilities for determining, monitoring and possibly controlling important process parameters such as the shear rate and shear stress – and from that the viscosity in the mold. The only precondition for the process (patent pending) is that in the course of the flow path, first a cavity pressure sensor and then in flow direction a cavity wall temperature sensor are installed **(Fig. 4)**.

As soon as the melt reaches the pressure sensor, a pressure increase p_1 occurs that is automatically detected. If the melt reaches the temperature sensor, the temperature increase T_1 is automatically detected **(Fig. 5)**. The respective shear rate is then determined at the end of each cycle from the time that the melt requires to cover the flow distance between the two sensors. The corresponding pressure value – and the difference to atmospheric pressure Δp required to calculate the shear stress – are determined exactly at the moment the melt reaches the temperature sensor. As these values are determined automatically, they are independent of the sensor position and thus make handling extremely simple, practically at the push of a button.

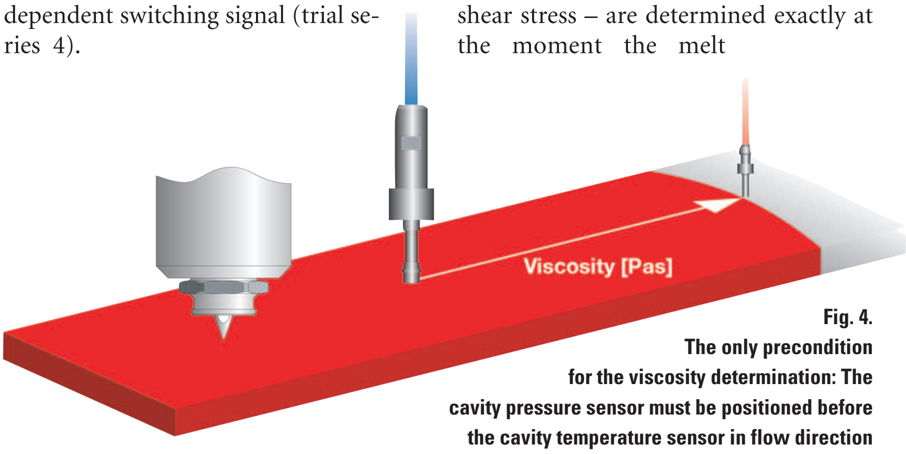

Fig. 4. The only precondition for the viscosity determination: The cavity pressure sensor must be positioned before the cavity temperature sensor in flow direction

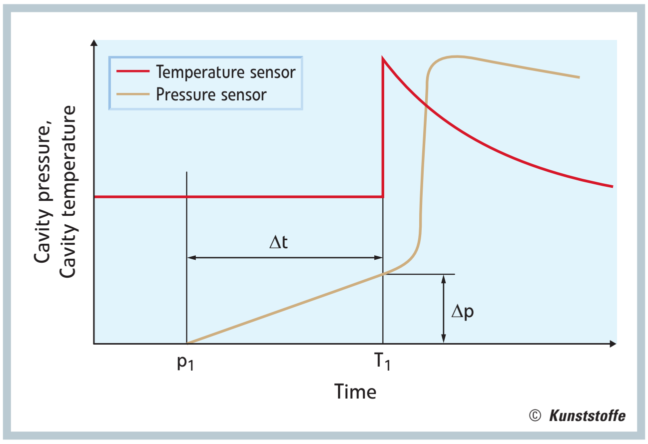

Fig. 5. The shear rate is calculated from the difference in time Δt that the melt takes to flow the distance between the pressure sensor and the temperature sensor. The pressure measured at time T_1 is used to determine the shear stress

The purpose of this strategy is not, for example, to replace laboratory rheometers with which viscosity functions are determined under isothermal conditions. It is also not the objective to replace injection molding machines converted into rheometers, since both methods do not reflect the actual influences on

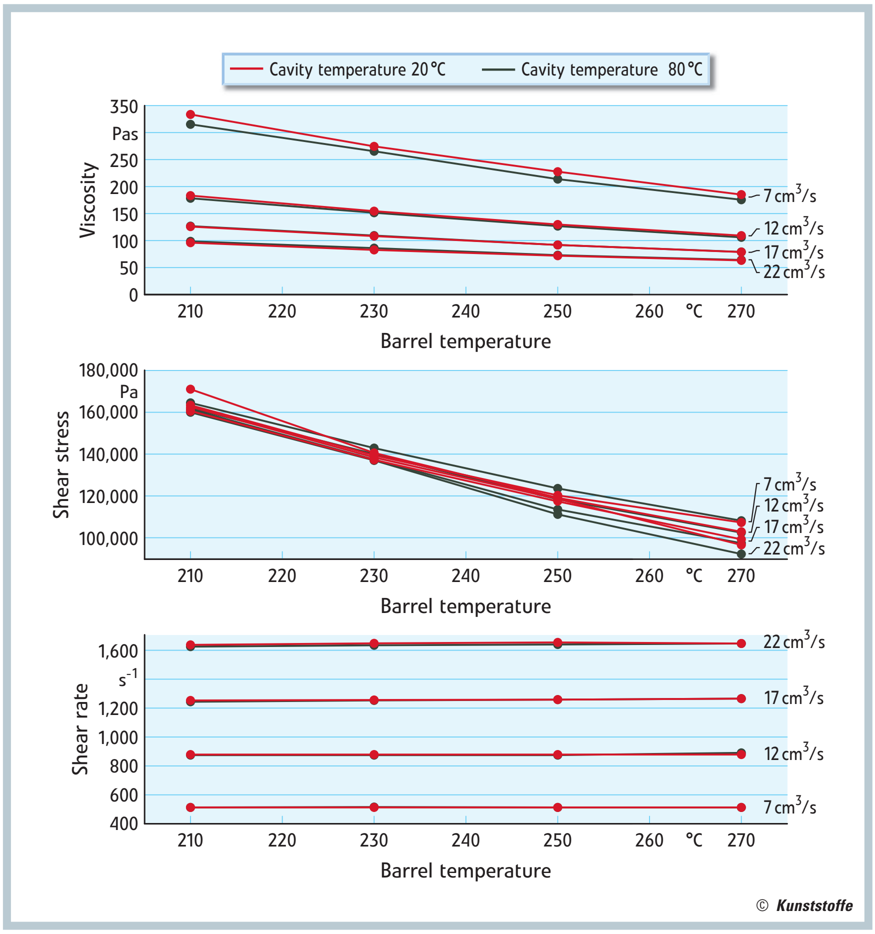

Fig. 6. The viscosities, shear stresses and shear rates determined in a test rod mold with different melt and mold temperatures. By contrast with the situation in the rheometer, the shear stresses measured in the hot and cold mold obviously differ significantly

the flow behavior in the cavity. Far more interesting for the permanent use in production is the question as to how the flow properties of a melt behave and can possibly be influenced under different process conditions. After all, what good is a viscosity function determined under ideal conditions if it is not comparable with the real conditions? It has to be assumed that every mold is used on machines that differ in size and design – and that the same machine settings do not result in the same flow conditions even on machines from the same series. Continuous measurement of the viscosity in the cavity is therefore highly expedient.

Whereas in one trial, different melt temperatures had practically no influence on the shear rate values, a noticeable influence of the mold temperatures on the shear stresses was observed **(Fig. 6)**. Automatic multi-channel determination of the viscosity directly in the injection mold is available today in all systems from Priamus System Technologies AG.

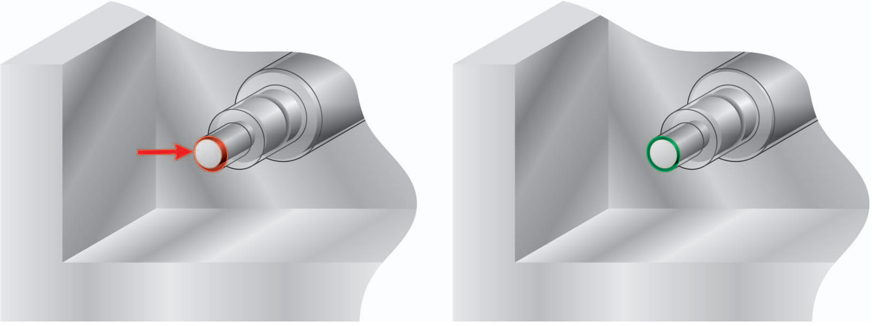

Fig. 7. Particularly very small cavity pressure sensors run the risk of touching the bore and losing sensitivity due to the close tolerances

Automatic Melt Front Detection for Process Control

The automatic detection of the melt front using temperature sensors has been successfully employed in several hundred applications for balancing hot-runner systems for almost ten years now [3]. Cold-runner systems are also controlled and balanced, for example during injection molding of liquid silicone by calculating the delay times for the opening of the shut-off nozzles automatically on the basis of the melt front detection cycle-by-cycle. What is new, however, is that these automatic control and balancing processes can now also be operated with cavity pressure sensors via the automatic detection of the increase in pressure. This is of significance insofar as open-loop and closed-loop processes based on a pressure threshold have a relatively unfavorable effect on the process for the reasons described above.

One of the reasons for this is that particularly very small pressure sensors tend to touch the bore wall, resulting in a force shunt, and hence in a loss of sensitivity **(Fig. 7)**. Particularly with multi-cavity molds in which a pressure sensor is installed in each mold cavity, large measurement errors in the form of pressure fluctuations have to be anticipated. Whenever pressure signals intersect, this indicates that the sensitivity of the sensors has changed since installation and that a measuring error has occurred.

One example **(Fig. 8)** shows the pressure curves in an obviously unbalanced 8-cavity mold – the first cavity is filled earlier than the other. The control and balancing of the hot-runner system with a pressure threshold proves to be difficult, because the distance between the curves due to the installation error is reduced with increasing pressure levels. The intersection of these curves even suggests that no flow differences exist in the cavities, but this is contradicted by the temporally different increases in pressure. The automatic detection of the pressure increase, on the other hand, reliably detects this situation and can be used to balance the process.

Conclusion

The simple trial series have shown that the simple choice of the switching process can have a major influence on both the flow distances of the melt and on the reliability and reproducibility of the pro-

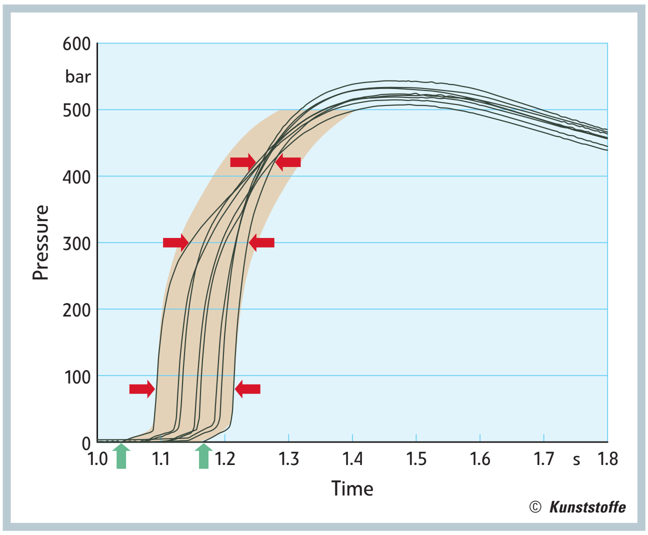

Fig. 8. The time difference between the pressure increases in the eight cavities shows that the process is unbalanced. As a result of installation errors and the change in the sensor sensitivities, this difference declines with increasing pressure so that balancing using a threshold value is not expedient. The increases in pressure determined automatically (green arrows) eliminate these installation errors

cess. Day-to-day problems such as sporadically unfilled injection molding can thus be prevented or at least reliably detected with the automatic detection of the melt front using pressure and temperature sensors.

Fixed pressure or stroke-dependent switching thresholds, on the other hand, have a rather more unfavorable influence on the process behavior and increase the risk of process fluctuations. The automatic determination of the viscosity directly in the mold offers an instrument for the first time that visualizes the effective fluctuations in the flow properties during the injection process. ■

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