The Switchover Problem and its Consequences

Phaseless Process Control Should Revolutionize the Switchover Process

The switchover process from the injection phase to the holding pressure phase is frequently the cause of reduced part quality in injection molding. An alternative process control concept aims to remedy this by completely eliminating the switchover process. For this purpose, the cavity pressure curve is predetermined and controlled for the entire filling process.

Typical injection molding defects, caused by incorrect switchover from injection to holding pressure phase (© IKV)

The application of the speed-controlled injection phase and the pressure-controlled holding pressure phase has already reached a high level. However, the hard switchover between two controlled variables is not optimal. As a result, the wrong switchover time between the two process phases leads to insufficient quality of the injection molded parts [1].

The ideal switchover time is when the melt front reaches the end of the flow path. The pressure curve in the transition between the two process phases should also be constant to achieve high part quality [2]. A premature switchover causes a pressure drop in the cavity, which may result in switchover marks or sink marks on the part surface. If the switchover process is executed too late, pressure peaks occur which can lead to high residual stresses and flash [3].

Because the injection molding process is also affected by external interferences, the ideal switchover time can change during production. This requires continuous adjustment of the machine settings to ensure consistent part quality. In addition, the threshold of the switchover signal (such as the screw position or a defined pressure value) has to be redetermined and thus adapted for each process-related change of machine, material or mold.

The resultant quality of the process setup is highly dependent on the machine operator's experience and knowledge. With the help of a filling study, he determines the switchover point experimentally, which enables the reaction times of machine control, injection unit and (if required) sensor technology to be taken into account [3]. Assistance systems from various machine manufacturers can provide additional support for the machine operator during process setup.

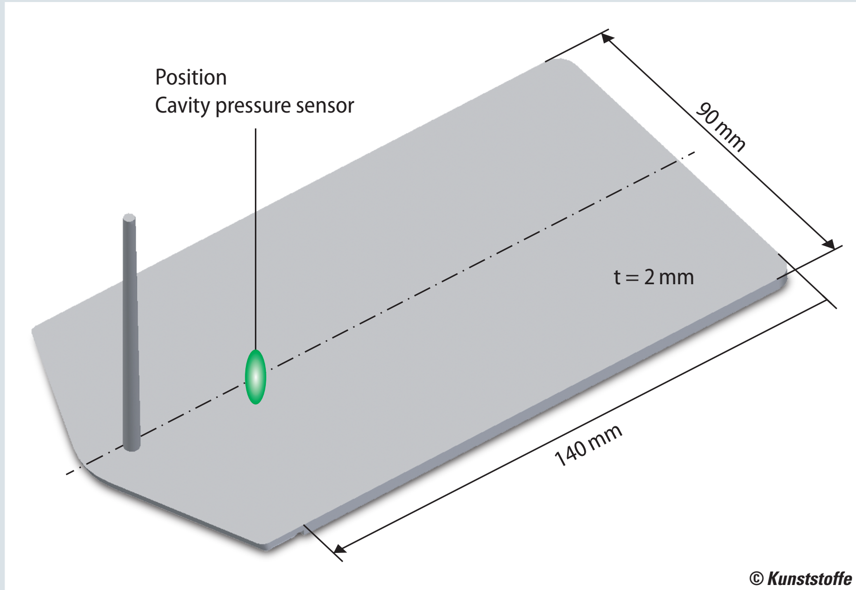

Fig. 1. The parts were manufactured on an injection molding machine (type: Allrounder 370 A, manufacturer: Arburg GmbH + Co KG, Lossburg) using a polypropylene (grade: PP579 S; manufacturer: Sabic Deutschland GmbH, Düsseldorf) (source: IKV)

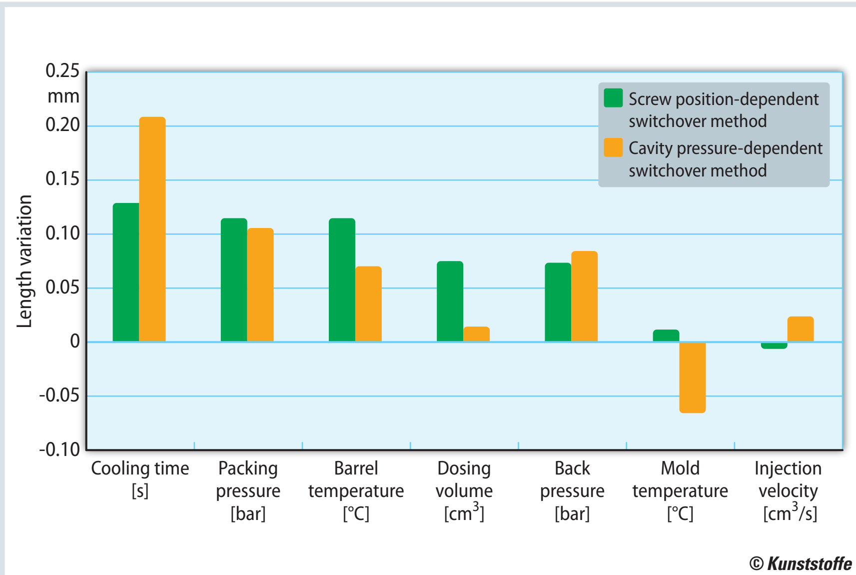

Fig. 2. The regression analysis describes the change in length of the part when the machine setting variable is varied by one unit (source: IKV)

Which Switchover Method Is Best?

There are a variety of switchover methods and assistance systems with several advantages and disadvantages. The user has to consider costs and benefits in order to select the right method for a particular process.

In practice, the screw position-dependent method and the cavity pressure-dependent method have become established – both with high reproducibility [2]. With the first method, a value is pre-determined for the screw position, whereas with the other, a defined cavity pressure has to be exceeded at the sensor. In comparison to hydraulic pressure, the process variable of cavity pressure has a strong correlation with part quality, which allows important conclusions to be made about part quality. For this reason, cavity pressure sensors are becoming increasingly popular for the production of high-precision parts.

In addition, other switchover methods exist, but these have not become established in practice. For example, temperature sensors installed in the mold can be used as thermocouples or infrared sensors. Temperature sensors react very slowly with a delay of a few milliseconds, which makes the temperature-dependent switchover method unreproducible [2]. Infrared sensors have a short response time and therefore enable a precise switchover [4], but are very sensitive and expensive, so they are mainly used for research work.

Part Quality Is Process-Dependent

During the setup process, an important aspect for the operator is the stability of the process. But how exactly does the part quality behave for the different switchover strategies when disturbances affect the injection molding process? In addition to changes in ambient conditions, batch fluctuations or increased wear of machine parts, for example, can shift the optimal operating point.

In order to evaluate the reproducibility of the part quality and thus obtain reliable information about the capability of the process, the process control working group at the Institute for Plastics Processing (IKV) in Aachen, Germany, carried out injection molding tests with specifically introduced disturbances. For this purpose, plate-shaped parts made of polypropylene (PP) with a weight of approx. 27 g were produced (**Fig. 1**) and seven machine setting variables were varied »

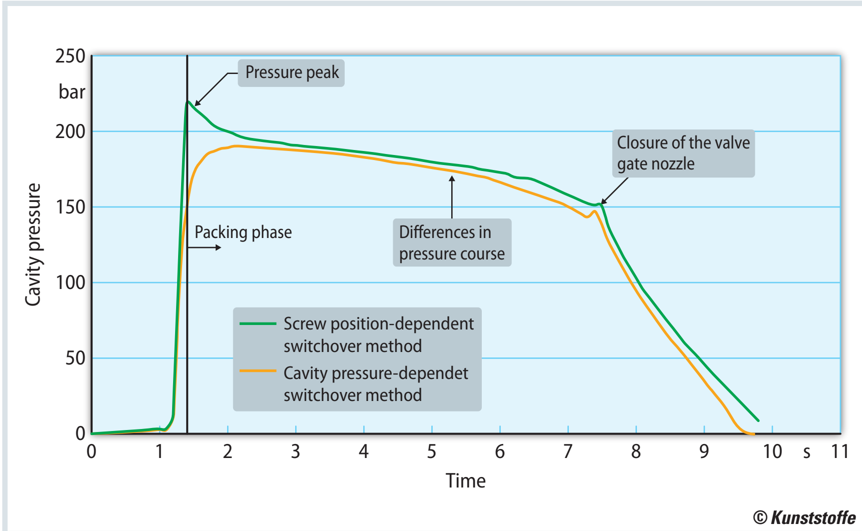

Fig. 3. A pressure peak can be identified in the cavity pressure curve for the screw position-dependent switchover method (source: IKV)

(**Table 1**) in order to simulate realistic disturbance influences. For each test setting, the quality characteristics of weight, length and width were determined for ten parts.

Both the switchover methods documented here are known for their ability to compensate different process fluctuations. While the screw position-dependent method is sensitive to metering deviations, the cavity pressure-dependent method is highly dependent on viscosity [5]. A sensor (type: 6157 BA; manufacturer: Kistler Instrumente GmbH, Sindelfingen, Germany) was used to measure the cavity pressure.

For an evaluation of process stability, the standard deviations of the quality characteristics are compared for both methods (**Table 2**). The calculation was performed under consideration of all test data sets. The deviations in part weight and length are of a comparable scale for both methods. However, differences can be seen in the part width, which has a standard deviation that is 0.067 mm lower for the cavity pressure-dependent switchover method. Thus the part quality is also process-dependent. The cavity pressure-dependent switchover method has the higher reproducibility.

How the Switchover Affects the Quality

In order to determine how precisely the switchover method influences the part quality, the length of the part is examined in more detail. For this quality characteristic, both switchover methods have comparable reproducibility. The regression analysis shows the extent to which the length deviates when the machine settings are varied (**Fig. 2**). It is noticeable that the influence of the machine parameters is different: when the cooling time is extended by 1 s, the part length is 0.129 mm longer for the screw position-dependent switchover method; with the cavity pressure-dependent switchover method, it is 0.209 mm longer.

Machine variable	Value	Variation (+/-)
Nozzle temperature [°C]	240	13
Mold temperature [°C]	40	6
Injection velocity [mm/s]	21	10
Packing pressure [bar]	250	25
Cooling time [s]	12	5
Dosing volume [cm³]	45	2
Back pressure [bar]	60	5

Table 1. Machine variables are varied in a fractional factorial 2^{7-3} experimental plan to simulate the effect of process disturbances (source: IKV)

Advantages at a Glance

The phaseless process control strategy has several advantages compared to a multi-phased process control:

- A switchover point does not have to be determined at great effort.
- There is a single reference variable for the injection, compression and holding pressure phase.
- The subjectiveness of the process setup is significantly lower since only a few intuitive variables have to be configured.
- Pressure peaks and pressure drops are eliminated by controlling the cavity pressure.
- A continuous cavity pressure profile for the entire filling process increases part quality.
- Disturbing influences can be compensated by automatic adjustment of the cavity pressure course.
- Process knowledge can be transferred to new processes with a minimum of experimental effort.

In contrast, a change of mold temperature has the opposite effect on part length. If the mold temperature is increased, the measured part length increases for the screw position-dependent switchover method, whereas it decreases for the cavity pressure-dependent switchover method. As a result, a standardized process setup and readjustment is not feasible even with the same combination of machine, material and mold.

The process dependency of the melt state at the switchover point can be seen when the injection pressure is observed (**Fig. 3**). Throughout the entire experiment, the screw pressure is lower for the screw position-dependent switchover method. At high injection speeds, low mold and barrel temperatures and high dosing volumes, however, the screw pressure is higher. The cavity pressure curve shows that the switchover point has to be adjusted for the screw position-dependent switchover method, whereas the cavity pressure curve for the cavity pressure-dependent switchover method is steady.

The injection molding trials demonstrate that a standardized process setup for different switchover methods is not feasible for consistent part quality. The parameter variation simulates process-related changes that affect the part quality (process-dependent). There are already systems available which adjust the switchover point and the holding pressure after each cycle to avoid the effects of an incorrect switchover time due to process changes [6, 7]. However, as long as a switchover point exists, it remains a weak point in the injection molding process. At »

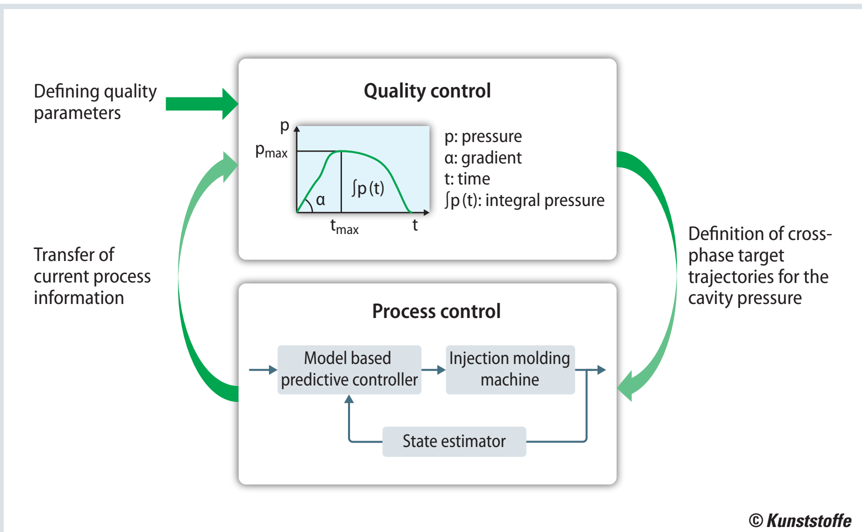

Fig. 4. The control loop consists of a superordinate quality control, which generates the target trajectories for a subordinate process control (source: IKV)

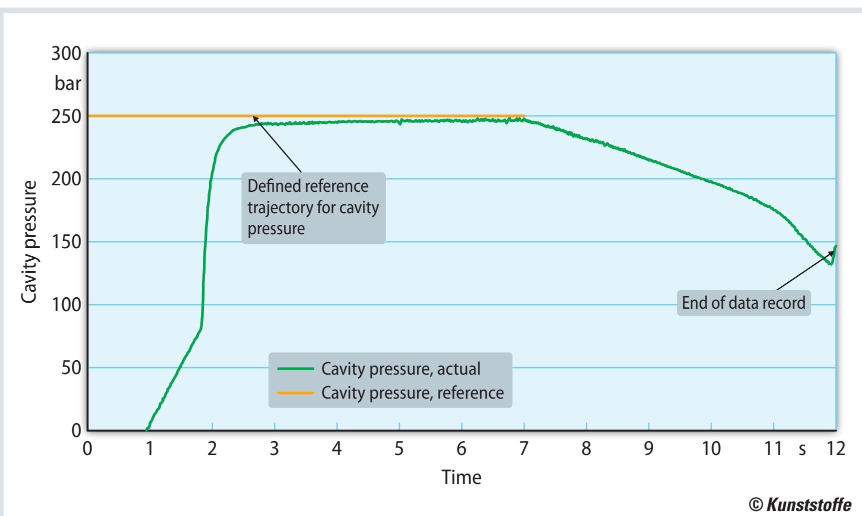

Fig. 5. The cavity pressure curve steadily converges to the reference trajectory of 250 bar (source: IKV)

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Acknowledgments

The research project HO4776/44–1 "Cross-phase process control concepts for injection molding using modern control strategies" is being carried out in cooperation with the Institute of Automatic Control (IRT) of RWTH Aachen University and is funded by the Deutsche Forschungsgemeinschaft DFG. We would like to extend our thanks to the DFG and also to Arburg GmbH + Co KG, Lossburg, Germany, and Sabic Deutschland GmbH & Co. KG, Düsseldorf, Germany, who supported this work by supplying plastics material and machinery.

Service

References & Digital Version

- You can find the list of references and a PDF file of the article at *www.kunststoffe-international.com/2020–2*

German Version

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Table 2. Standard deviations of the three quality characteristics are switchover method-dependent (source: IKV)

Switchover method	Weight [g]	Length [mm]	Width [mm]
Screw position	0.117	0.426	0.179
Cavity pressure	0.121	0.423	0.112

the switchover point, there is a change between the two controlled variables speed and pressure, so that the state at the switchover point is not clearly defined.

The Solution to Avoid the Break between the Controlled Variables

In a current research project, IKV has developed a process control strategy in cooperation with the Institute of Automatic Control at RWTH Aachen University that completely avoids the switchover process between different controlled variables. The phaseless process control is based on a cascaded control loop structure with a model-based predictive control approach (**Fig. 4**) and is intended to enable a reliable injection molding process with constant part quality [8].

This innovative approach uses any given cavity pressure curve for the entire filling process of the cavity, which is based on controlling the screw speed. This eliminates the necessity of switching between different controlled variables, so that only a single controller is used. To parameterize the controller, physically motivated gray-box models are implemented in the prediction model. This allows, for instance, the flow and cooling behavior of the polymer melt to be considered in process control. In addition, process knowledge as well as machine and tool data can be used. This reduces the amount of time and work involved in setting up new processes.

For successful practical application, it is important that a specified target pressure curve is reached quickly and without oscillations. For this purpose, the control loop architecture has already been tested in initial injection molding trials and a suitable parameterization of the controller has been implemented. The test results show a continuous cavity pressure curve at a selected reference pressure of 250 bar (**Fig. 5**).

At the beginning of the injection process, the difference between the set and actual value is large, so that the cavity is filled at the maximum injection speed. This speed can be set to any desired value. When the cavity is filled, the cavity pressure increases rapidly in the compression phase and the injection speed decreases so that the cavity pressure converges to the reference trajectory.

With the developed process control strategy, a constant cavity pressure curve can be ensured for the entire filling process. A high pressure level can be realized very quickly using the model-predictive approach, which leads to short cycle times. Since the cavity pressure correlates strongly with the part quality, the specification of the cavity pressure can improve the reproducibility of the injection molding process, preventing rejects. A cyclical adjustment of the specified cavity pressure curve can automatically compensate disturbing influences.

The optimization of the control parameters and the determination of the ideal cavity pressure curve are the subject of current research. In addition, the performance of the control method will be compared to the results of conventional process control.

Conclusion

The optimal switchover time during production is changed by disturbing influences, making continuous adjustment necessary. Studies show that the switchover point is a weak point in the process. Due to the switchover between different controlled variables, the state at the switchover point is not clearly defined.

An innovative process control concept developed by IKV and IRT Aachen avoids the switchover problem by controlling the cavity pressure course during the entire filling process. For this purpose, a model-based predictive control approach is used, in which process knowledge is taken into account by physically motivated models. The aim of cross-phase process control is to ensure consistent part quality while reducing rejects and setup time and thus the overall costs. ■

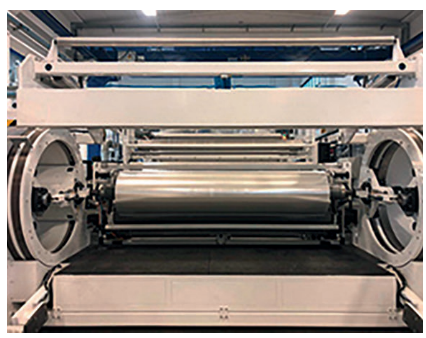
Cast Unit for Cast Film Extrusion

Thick and Thin

Colines spa, Novara, Italy, has developed a system for the production of high range thickness CPP, CPE and multilayer barrier film, from 15 to 500 micron, called "Thick&Thin". The system consists of a multi-roller cast unit with two separate cast zones, which allows getting the right set-up in order to cover a very wide thickness range, from flexible film to foil.

According to the company, the system introduces a number of technical developments in the CPP, CPE and multilayer barrier film world which are known in other sectors but had never been applied to cast film extrusion.

To the product presentation:
www.kunststoffe-international.com/10130053



The system consists of a multi-roller cast unit with two separate cast zones, which allows getting the right set-up in order to cover a very wide thickness range, from flexible film to foil (© Colines)