Twin-cavity hot-runner mold of a cylinder housing for clutch slave cylinders. A pressure sensor and a temperature sensor are incorporated into both cavities (figures: Priamus)

Quality from the Depth of the Mold

Process Control. To reproduce an injection molded part in the same quality, it is not enough to use the machine settings as basis, since even an optimized process changes continually. However, different part properties can be modified and controlled as desired directly from the cavity. This means that processors no longer need to elaborately test these features after the injection molding process.

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All self-respecting injection molders have full confidence in their machine, just continuing to produce while ignoring the high reject rates that make downstream testing of the final moldings necessary in the first place. The typical injection molding shop, therefore, still has a department that laboriously separates the acceptable parts from the unacceptable.

Cavity pressure sensors have therefore been used directly in the mold cavity for many years to give feedback about part quality indirectly, for example from the maximum pressure. That is a step in the right direction, but it is by no means adequate to describe all the quality features. For some time, cavity temperature sensors have been gaining in importance. They automatically detect the melt front and use it for balancing hot-runner molds or for automatic opening and closing the nozzles [1].

It is therefore all the more surprising that, in 2013, there are still machine suppliers who insist they can manage all quality problems solely via the machine settings. Even with two cavities, this raises the question of how the machine can compensate flow differences between one cavity and the next. And who can explain why the standards for determining the capability indexes recommend testing during dry running – i.e. without a mold?

A New Dimension

It is not enough just to use one sensor to determine the flow of the melt in the mold – and therefore its viscosity. The melt must flow for a defined path in order for the measurement instruments to detect its shear rate and shear stress. Today, a process developed by Priamus System Technologies AG, Schaffhausen, Switzerland, can be used to automatically determine the flow properties of polymer melts during production, monitor them and control them to a desired target value [2]. The cavity pressure sensor and cavity temperature sensor are positioned in the flow direction and the increases in the signals are evaluated as required.

Priamus goes one step further, additionally controlling the strength and dimensional accuracy of the molded parts by adjusting the melt and mold temperatures, in addition to the injection and holding pressure profiles in each production cycle, depending on the process [3]. What appears very laborious and complicated in theory is in practice quite easy to implement with the Fillcontrol system from Priamus. But what actually motivat-

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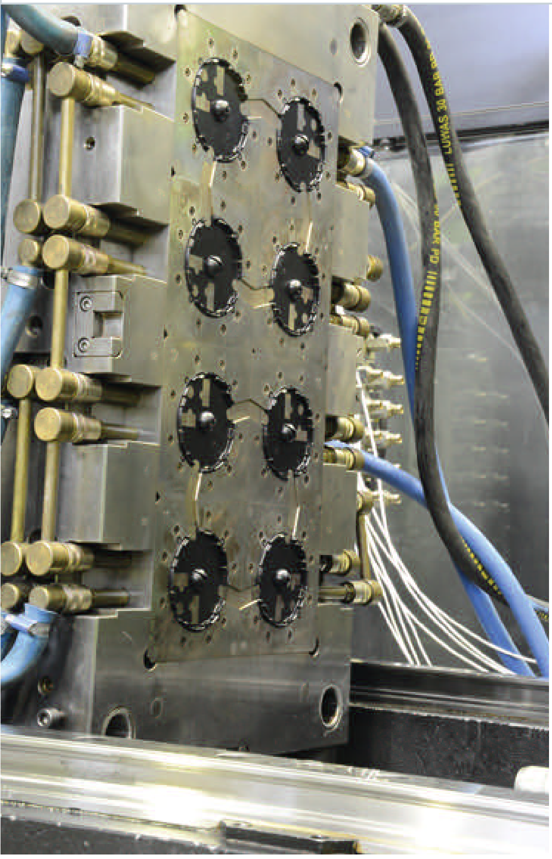

Fig. 1. Eight-cavity hot-runner mold for manufacturing base plates for adjustment motors of side mirrors. For automatic hot-runner balancing a temperature sensor is incorporated into each cavity, and a pressure sensor is additionally incorporated into one cavity for quality control

ed processors not only to monitor the process directly at the part, but also to specifically control particular quality parameters? There is no simple answer, and it will differ depending on the industry and application.

For manufacturers of medical products, the complicated and somewhat dubious process validation procedures, particularly in the USA, are an expensive and not always effective quality assurance method. Characteristics and properties that have little to do with product quality are often validated. Those concerned are aware of this; however there are no alternatives and it is difficult to break with the ingrained traditions of Total Quality Management and Six Sigma. A system that allows processors to simplify the validation process appropriately at the touch of a button, however, changes this situation fundamentally.

In other sectors, such as the automotive supply industry, there are genuine quality criteria that have to be satisfied. Manufacturers must eliminate, for example, the risk of an airbag failing to open at the critical moment. In this case, the practical benefit of a control system lies quite simply in controlling and reproducing the quality feature reliably to the desired point.

Another aspect that concerns many companies in an age of globalization is the question of how product quality can be ensured at different production sites. Since what use is a process that has been optimized in Stuttgart, Germany, but cannot be so efficiently reproduced in Romania, Spain or Malaysia?

Confidence Is Good, Control Is Better

Whereas process monitoring and hot-runner balancing systems have been in successful use for many years, the quality controllers of the Fillcontrol system can be explained in detail with reference to two examples. The Austrian automotive supplier Magna Auteca from Krottendorf/Weiz produces over 275 million plastic parts per year, mainly adjustment motors for side mirrors, on over 30 injection molding machines. It has been using Priamus systems since 2005 for automatically balancing hot-runner systems, ensur- →

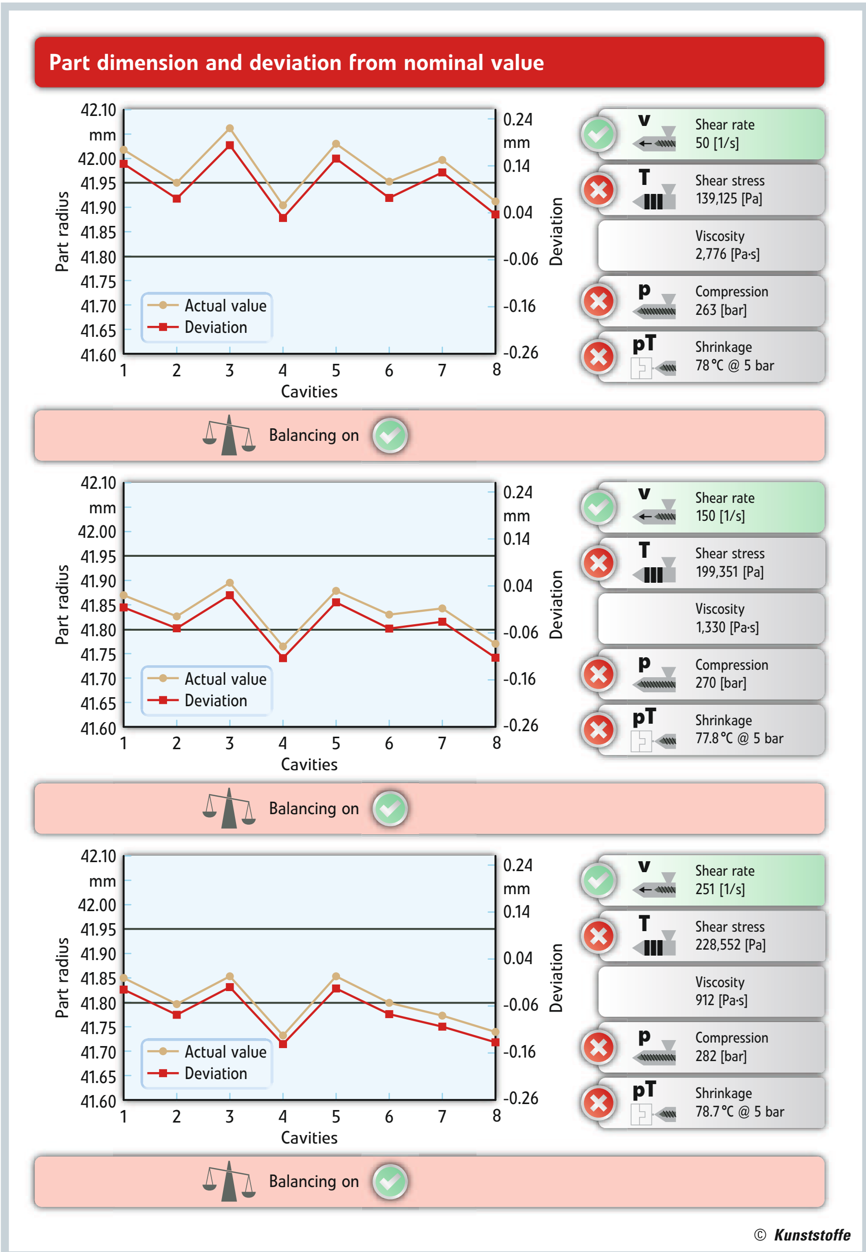

Fig. 2. The diameters of the eight base plates dependent on different shear rates, measured directly in the cavity. The shear rates are deliberately changed via the injection profiles. In this case, the process was already balanced before the shear rate was controlled

Fig. 3. The production of this cylinder housing of a PPA-GF50 makes strict requirements on the burst strength, surface roughness, dimensional constancy and absence of flash

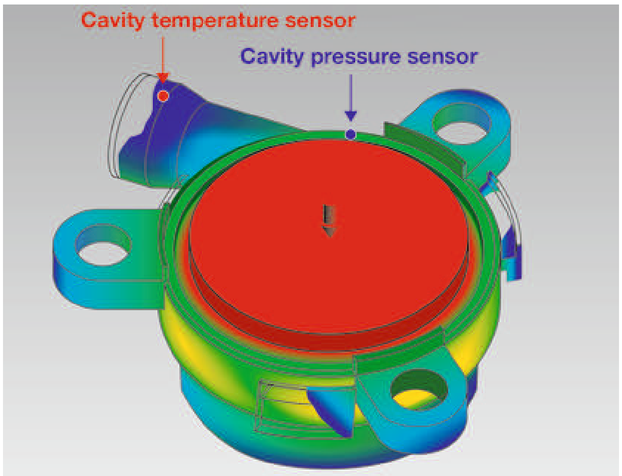

Fig. 4. The positions of the cavity pressure and cavity temperature sensor in the cylinder housing. The prerequisite for automatic process control is that the pressure sensor is always positioned before the temperature sensor in the melt flow

ing that all the parts are always filled simultaneously. In the production of the base plate of these adjustment motors in a typical eight-cavity hot-runner mold **(Fig. 1)**, the diameter of the injection moldings is a critical quality parameter. This dimension is currently carefully controlled in a downstream operation after the parts have been demolded, which is to be eliminated for cost reasons.

What is required, therefore, is not a constant machine setting but a constant process. A lengthy series of experiments was therefore carried out to investigate the quality controllers of the Fillcontrol system and characterize this parameter's dependency on the different machine settings. After the cavities have been bal-

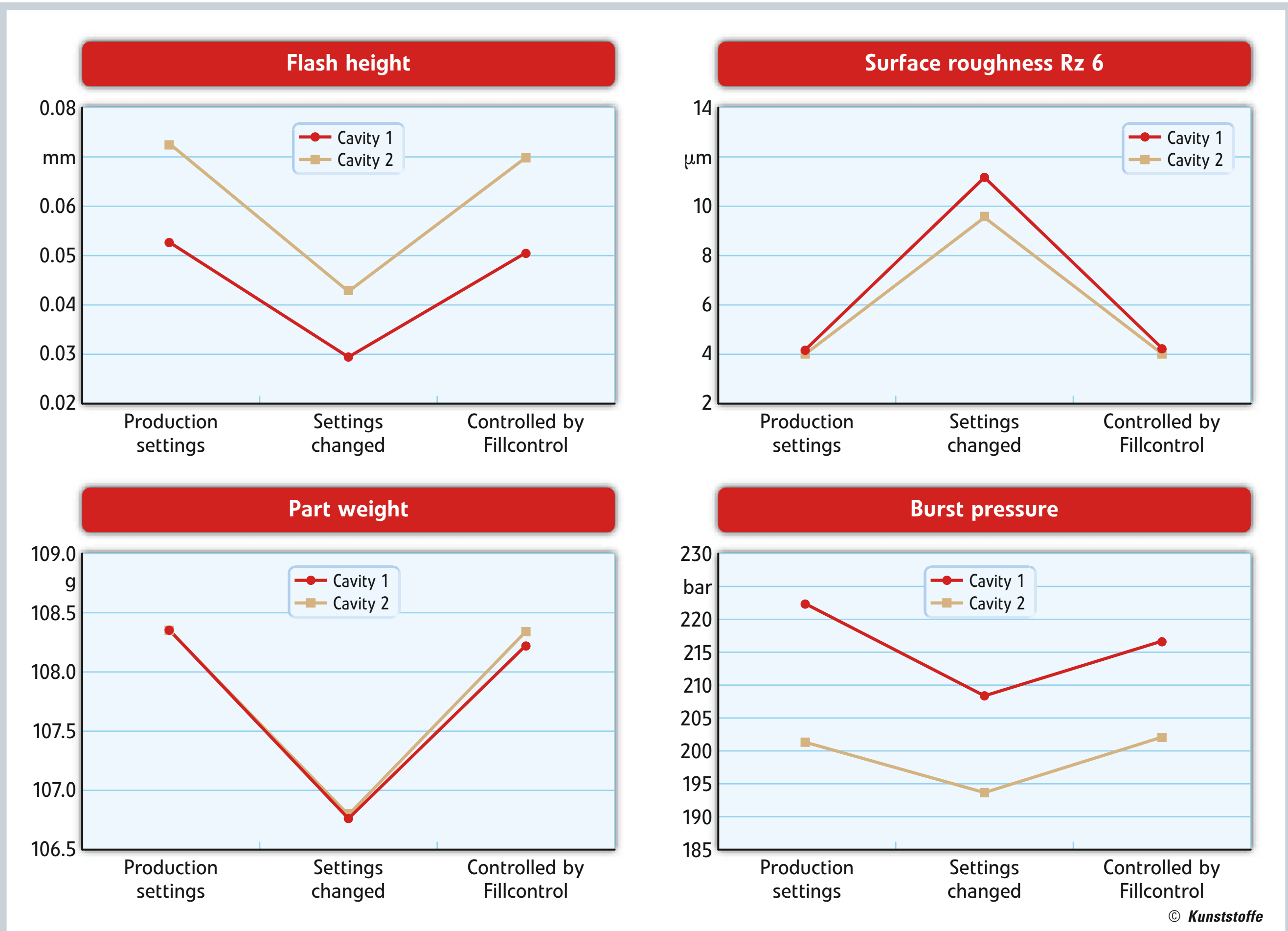

Fig. 5. Effect of the four controller parameters (injection profile, holding pressure profile, melt temperature and mold temperature in dependence on the cavity pressure) on the various quality parameters. They were first determined under optimized process conditions and then deliberately changed. The system eventually automatically corrected the parameters back to the optimized values

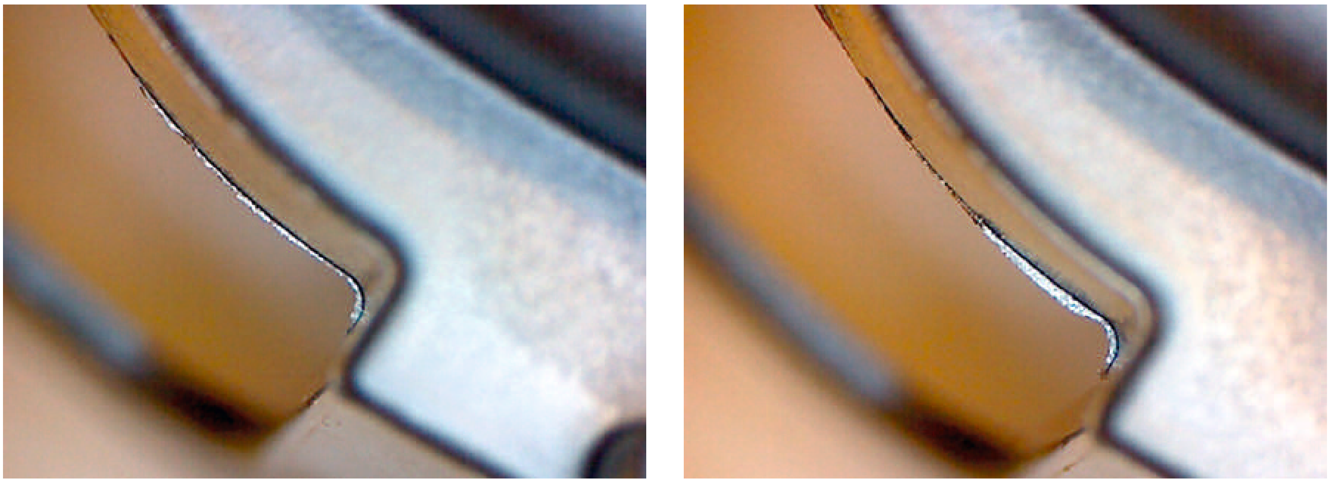

Fig. 6. The flash height of the injection molded parts depends directly on the flow behavior of the melt, and therefore on its viscosity. The Fillcontrol system determines and regulates, e.g., the viscosity of the melt in the form of shear rate and shear stress, resulting in the flash height of the parts. In the figure at the right-hand side, significantly higher flash can be seen because of a lower melt viscosity

anced in each individual cycle, the diameters of the eight base plates can be selectively changed solely with the aid of the shear rate controller **(Fig. 2)**. This is done by changing the injection profile of the machine proportionally until the set target value of the shear rate in the cavity has been reached. Automatic control of this diameter within the required tolerances is thus possible and subsequent measurement is not required.

The System Finds the Right Way Itself

A similar series of tests was performed at Ensinger GmbH in Rottenburg am Neckar, Germany. The tests were performed on a cylindrical housing for clutch slave cylinders **(Fig. 3)** produced from a HAT-PPA filled with 50 % glass fibers (grade: Grivory HTV-5H1 black 9205; manufacturer: EMS-Chemie AG, Domat/Ems, Switzerland). To consistently meet the high requirements on the burst strength, surface roughness, dimensional constancy and absence of flash, the quality fluctuations of the plastic melt must be compensated. A cavity pressure sensor and cavity temperature sensor were therefore incorporated into both cavities of the hot-runner mold in order to determine the melt flow in the form of shear rate and shear stress, cycle for cycle directly in the mold **(Fig. 4)**. The viscosity is determined automatically from the data at the point when the melt reaches the respective sensor position. The pressure sensor is additionally used to control the compression, the temperature sensor to control the shrinkage and for automatic switchover to holding pressure.

To determine the influence of the four controllers on the different quality parameters, parts were first injection molded and evaluated under the optimized process conditions. Then the control parameters (injection profile, holding pressure profile, melt temperature and mold temperature in dependence on the cavity pressure) were deliberately altered to create unacceptable parts outside the quality tolerances. The Fillcontrol system eventually corrected the injection molding machine settings, based solely on measurements in the mold, until the originally optimized parameters were reached again **(Fig. 5)**. The effects of the controllers can be recognized by means of the flash height **(Fig. 6)**, with the change explained by the different flow properties or viscosities of the plastic melt.

Summary

A constant machine setting is by no means sufficient for constant part quality. The studies have demonstrated that different quality parameters of the molded part can be automatically regulated to a desired target value, avoiding the need for expensive downstream controls. The prerequisite for this is a cavity pressure sensor and a cavity temperature sensor, with a host computer interface for communication with the injection molding machine.

The future will show to what extent validation processes, too, can be simplified and made more meaningful with this process. It is already foreseeable that it will be possible to transfer processes optimized in this way from one machine to another and from one production site to another. ■

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