No More Incomplete Parts

Process Technology.

A new process–specific changeover parameter allows the familiar faults during injection molding to be reliably detected even in sophisticated technical parts, and hence the process to be corrected accordingly. Thanks to the improved process stability, scrap rates can now be signifi–cantly reduced.

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Particularly for moldings with close tolerances, it is essential to immediately correct any type of process fault (photo: Sumitomo (SHI) Demag)

I njection molding technology is today able to produce complex technical parts with close tolerances even with large numbers of cavities. The basis for this are high-quality molds with balanced hot runners and the sophisticated control and drive technology of modern injection molding machines. With optimized system components it is thus possible to reduce fluctuations in the molding weight to less than 0.05 %.

Unfortunately these are often only snapshots during the course of an optimization for product approval. What is far more demanding is to ensure the close

tolerances over a prolonged period of time under the tough production conditions with medium-term faults. There are various reasons for these faults. Machine wear, particularly at the non-return valve or cylinder, can be one possible cause. Batch fluctuations can also change the flow, compression and shear conditions of the melt during the process. Materials with high filler contents, flame retardant or very low viscosity materials are particularly critical here. This results in fluctuations in the screw end position and in the closing behavior of the non-return valve. Last but not least, the ambient conditions play a role, for example when the humidity or shop temperature change due to the weather.

The consequences are frequently varying filling levels of the moldings. This is reflected either – particularly with thin-walled technical parts where the holding pressure has little chance of compensating the deviations – in the form of incomplete parts, or by pressure peaks which have a

significant impact on the intrinsic properties, either in the form of stresses, deviating dimensions and distortion or, in extreme cases, in the form of overfilled moldings. In addition to the faulty parts, this can also lead to extensive mold damage. Although a well-organized process monitoring system is able to at least identify these deviations, this is too seldom in place.

Adequate Reactions to Changes in the Process

This situation often necessitates the intervention of the machine setter and continuous correction measures to the process settings, resulting in frequent scrap parts. The wish is therefore for the use of a system for molding with close tolerances which can analyze this type of process fault even during the process and ideally make the necessary corrections directly from the process value.

The most influential setting parameter for correcting different filling levels in the →
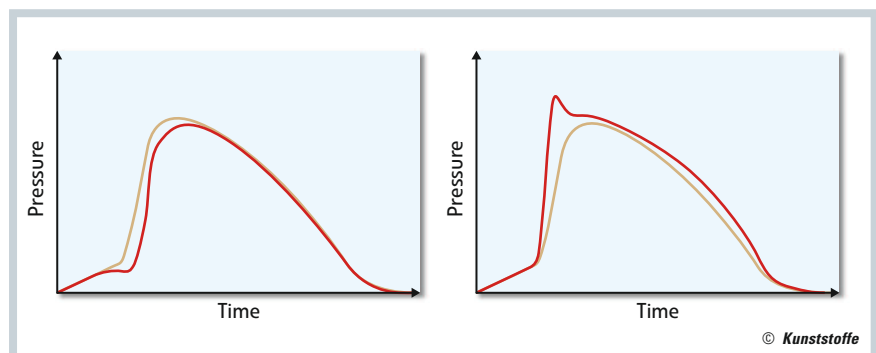

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Fig. 1. The curve of the mold cavity pressure deviates with too early (left) and too late (right) changeover from the right (beige) changeover point [5]
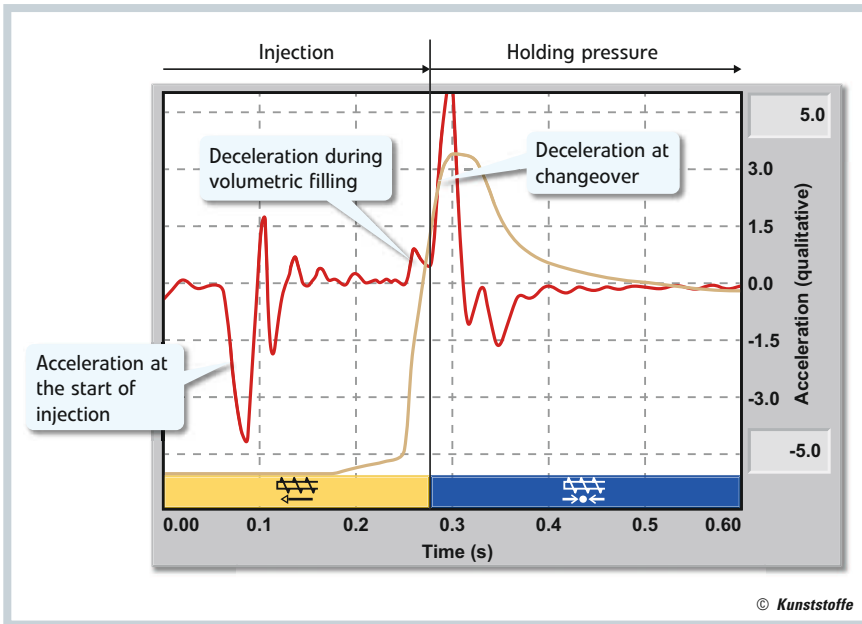
Fig. 2. The inverted signal of the screw acceleration (qualitative) and the mold cavity pressure over time from an Arburg process diagram shows the behavior in chase of injection with changeover too late [3]

These changes in the process have a direct effect on the cavity filling level and on the internal properties of the finished product [1, 2].

As a result of this, the changeover on the basis of the mold cavity pressure established itself many years ago. The mold cavity pressure curve indicates clearly when the volumetric filling level has been reached, and can therefore ensure a changeover with the same filling level and as late as possible in the process [1]. The changeover takes place at a threshold value during the phase of the rapid rise in pressure (compression phase). This enables constant molding internal properties and dimensions to be achieved. The installation of mold cavity pressure sensors has established itself today in some branches, although the signals are used far too seldom for the changeover. On the other hand there are some plastics processors who still have reservations about the installation of sensors in the mold be-

mold is the changeover point. This is physically the changeover point from the speed-controlled injection phase to the pressure-controlled holding phase **(Fig. 1)**. The injection phase should ideally continue until the cavity is completely filled and take place as quickly as possible [1]. The aim should be to ensure that the heat generated by the shear forces during injection and the cooling should compensate one another to such an extent that the molding has the same temperature at every point at the start of the holding pressure phase. Only with very fast injection molding is it also still possible to suf-
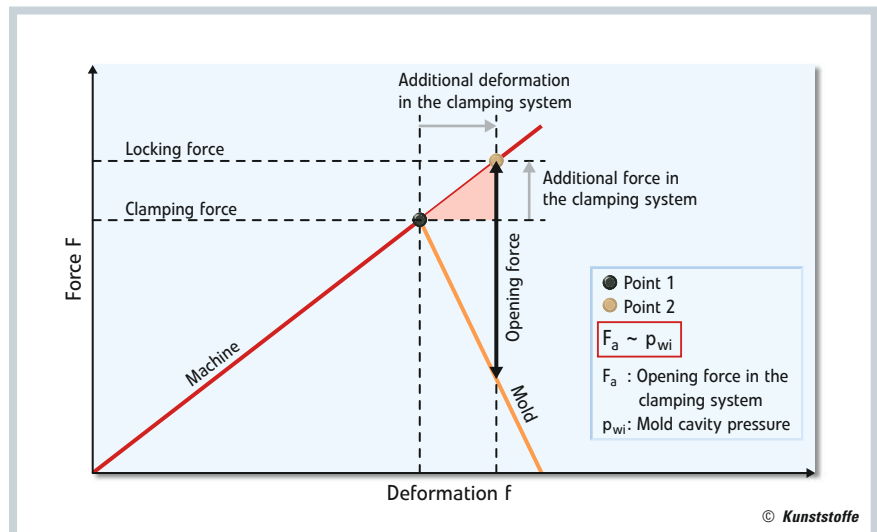

Fig. 3. Force-deformation diagram of a mechanical clamping system (point 1: locked; point 2: additional deformation caused by opening force/mold cavity pressure). The deformation of the machine increases proportionally with the clamping force.

ficiently pressurize the whole molding over the complete flow path during the holding pressure phase. Furthermore, the orientations induced in the molding may be lost after the end of the injection phase as a result, and hence the mechanical properties in the molding may be isotropically distributed.

The changeover is effected today for the most part by a stroke or volume signal from the screw (stroke-dependent changeover). This changeover method is quite sufficient for many injection moldings, but for complex technical parts this variant is not suitable as it is unable to react adequately to changes in the process.

cause they fear, for example, damage during maintenance, high investment costs or marks on the moldings. Ultimately we have to say, however, that the mold cavity pressure, often in conjunction with an integrated temperature sensor, can provide the most meaningful information on the process.

Alternative Changeover

A working group at the University of Applied Sciences in Würzburg, Germany, therefore started a project to develop alternative methods for the process-dependent changeover. This method was to

Fig. 4. The transducer is simply fastened to the fixed platen (figures: FHWS)

Fig. 5. The additional deformation of the fixed platen (orange line) under the mold cavity pressure is very small, but can be reliably measured
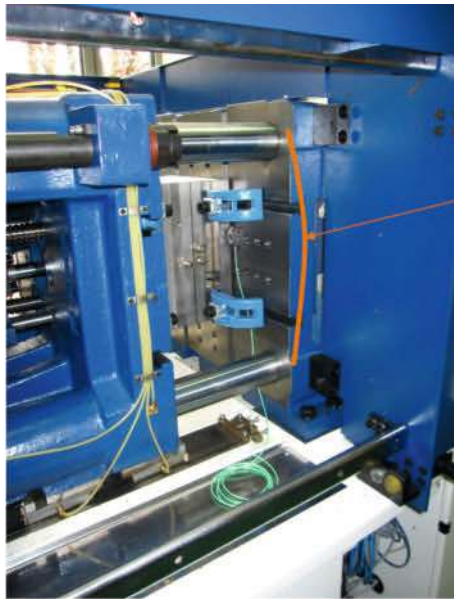
do without measuring technology in the mold, while retaining the benefits of the process dependence, i. e. continuing to use the signal to clearly monitor the volumetric filling and making it evaluable for the changeover. Two variants are most suitable for this:

■ Acceleration-dependent changeover. In the case of volumetric, speed-controlled filling the screw acceleration during the injection phase is zero. At the moment of volumetric filling there is a negative deflection, as the screw is momentarily braked by the spontaneous back-pressure from the mold. Initial trials **(Fig. 2)** show the fundamental behavior in an inverted representation [3].

■ Deformation-dependent changeover. With mechanical clamping systems, an additional deformation of the clamping unit beyond that of the clamping force occurs during injection. This deformation is directly proportional to the prevailing mold cavity pressure and can therefore be used in the same way as this pressure for a changeover.

The deformation-dependent changeover was investigated in an initial project and is described in greater detail below.

If we consider the mold clamping system as a spring and plot the behavior in a force-deformation diagram, we see that the deformation of the machine increases proportionally to the clamping force of the clamping unit. The injection mold is upset at the parting line as the clamping force is built up, reflected in the negative gradient (**Fig. 3**, point 1). The particular feature of the mechanical clamping systems is that the deformation of the machine during injection, i.e. as the mold cavity pressure increases, continues to in-

crease because the spring stiffness of the system does not change (**Fig. 3**, point 2). This is paired with a decrease of the upsetting of the mold at the parting line. The difference between point 1 and point 2 now expresses the additional locking force of a toggle lever and at the same time the additional deformation of the machine. This additional deformation is

recorded here and evaluated for the process control.

The machine deformation affects the whole system of tie rods, platens and connecting rods of the toggle lever, even though the deformation of the tie rods certainly accounts for the greatest proportion. This situation enables other measuring points on the clamping unit to be used that lie in the force flow of the clamping system and which are easier to reach. Due to the simple installation situation, the deformation sensor (type: 9232A; manufacturer: Kistler Instrumente GmbH) was bolted here to the machined surface of the platen **(Fig. 4)**. The platen bends minimally under the clamping force and mold cavity pressure and thus, through the spring law, correlates proportionally with the mold cavity pressure. These deformations are very small, but can be reliably measured using corresponding sensors **(Fig. 5)**.

Validation of the Measurement Principle

In this case a piezoelectric sensor measures the elongation and upsetting of the clamping unit monoaxially. The measure- →

ment signal is transmitted via a charge amplifier directly to the machine controller where the signal can be visualized and evaluated. As with the mold cavity pressure measurement, the volumetric filling and the start of the compression phase are clearly recognizable here.

Under the effect of the mold cavity pressure, an additional bending of the platen takes place and hence the measurement points move closer together. Despite the relatively small changes, the deformation during the injection and holding pressure phases (from right to left) can be clearly read off **(Fig. 6)**. As was to be expected, the curve is identical with the curve of the mold cavity pressure. The mold employed here is a two-cavity mold for a thick-walled lens (3 mm) of polystyrene (type: 168 N; manufacturer: BASF SE) with cavity pressures of max. 160 bar.

Comparative trials were now performed to make the process comparable for the stroke-dependent and deformation-dependent changeover. At first the short production run over 50 cycles showed no significant differences. This confirmed the experience that with current machines – here the trials were carried out on an all-electric 900 kN model (type: Venus VE900; manufacturer: Zhafir Plastics Machinery GmbH) – no deviations are to be expected over short periods. The stroke-depend-

ent changeover also produced good results here. The standard deviations in the molding weight of 2.7 mg (stroke) and 2.3 mg (deformation) with a shot weight of 17.3 g were on a comparable level.

In order to simulate a medium-term fault, such as a charge fluctuation, the melt temperature of the PS was changed. With amorphous materials, the viscosity changes as a function of the melt temperature, corresponding very closely to changes in the material. The increase in deformation at the changeover point

(stroke-dependent) of almost 150 % shows that the changeover takes place too late **(Fig. 7)**. Despite otherwise identical process settings, the part takes on completely different properties and dimensions, or would even have been overfilled.

In the case of the deformation-dependent changeover, on the other hand, the process curve remains unchanged, as the changeover takes place at the same threshold value in the deformation curve, and hence at the same filling level.
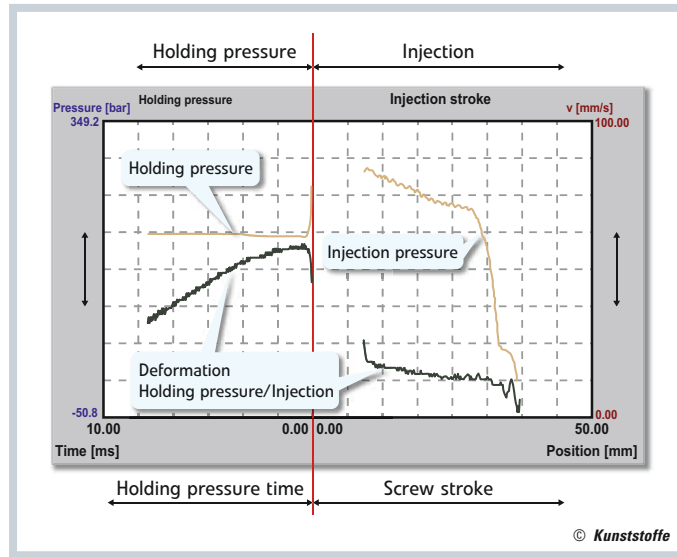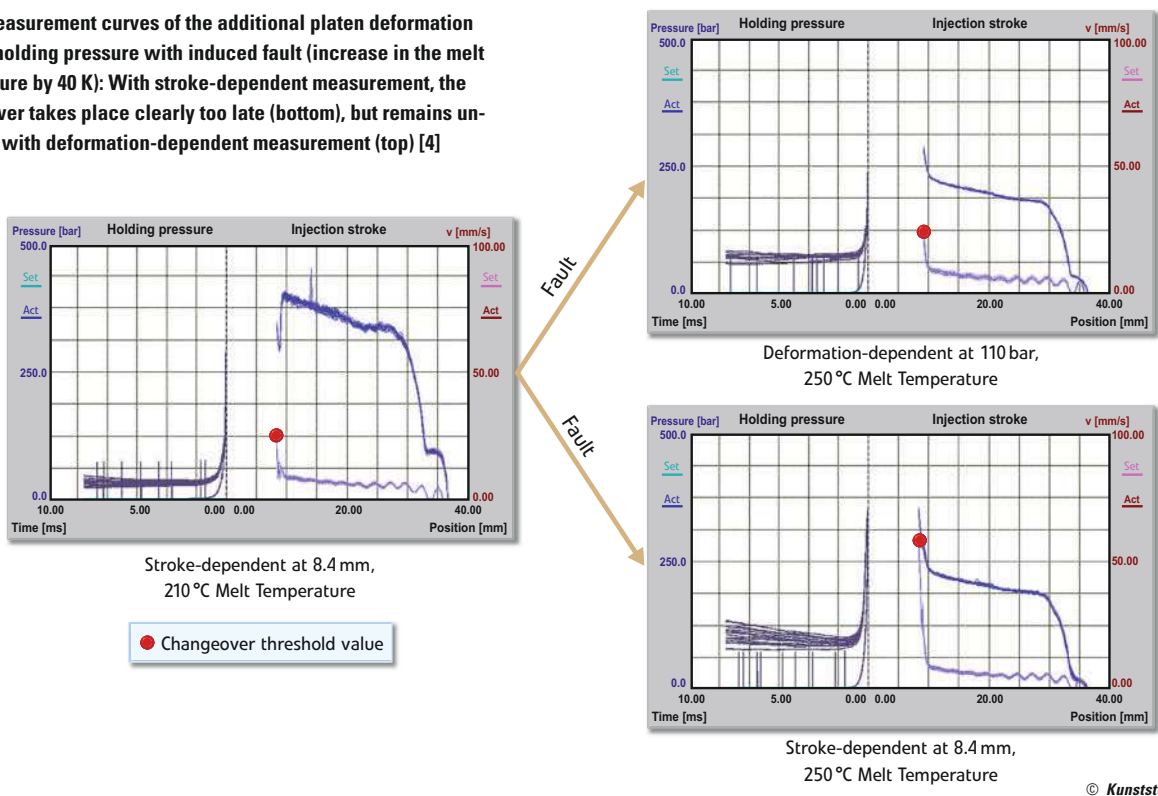

Fig. 6. The measurement curve of the additional platen deformation (injection pressure and deformation plotted from right to left) is identical with the curve of the mold cavity pressure [4]

Fig. 7. Measurement curves of the additional platen deformation without holding pressure with induced fault (increase in the melt temperature by 40 K): With stroke-dependent measurement, the changeover takes place clearly too late (bottom), but remains unchanged with deformation-dependent measurement (top) [4]

Stroke-dependent at 8.4 mm,
210 °C Melt Temperature

● Changeover threshold value

Deformation-dependent at 110 bar,
250 °C Melt Temperature

Stroke-dependent at 8.4 mm,
250 °C Melt Temperature

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Conclusion

The measurement of the machine deformation provides an identical signal curve to that of the mold cavity pressure. The moment of the volumetric filling can be reliably recognized. A process-dependent changeover practiced in this way allows changes in the process caused by external faults to be detected and corrected. The method is thus suitable also for quality monitoring of the process, even if it does not allow monitoring of the individual cavities in multi-cavity molds.

The method cannot be used for hydraulic clamping systems, as the significant deformation of the clamping unit does not occur with these systems. In this case the deceleration of the screw can be used as changeover parameter. The method has been essentially validated and is being further investigated with regard to the optimum measurement point and the measurement principle. ■

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