Using Breathing Signals for Process Optimization

Comparative Methods for Determining Mold Breathing

Mold breathing provides useful information about the processes that occur in the mold and the cavity. Mold-maker Schneider Form and injection molding machine-maker Engel have recognized the potential which this process variable offers and have worked intensively on it for several years, albeit by adopting different approaches. They recently carried out joint tests on bumper molds using a two-platen injection molding machine with a clamping force of 40,000 kN and then swapped experiences.

Bumper molds were the focus of mold-breathing studies aimed at process optimization. The photo shows an example from the bumper portfolio of Schneider Form (© Julia Lav/Shutterstock.com)

Plastics converters are increasingly gathering and analyzing machine and process data so that they can optimize their processes. As a result of the constant growth in computing power and ever-increasing networking of systems, it is easy to gain the impression that any injection molding problem can be simply resolved by properly linking together the available data and subjecting it to analysis. Yet, a ready availability of process variables for the molding process and molded-part quality that are high in information value cannot be taken for granted. If relevant variables are to be obtained, either intelligent software capable of processing the signals present in the machine or additional sensor technology is required. One process variable that offers high information value is mold breathing [1].

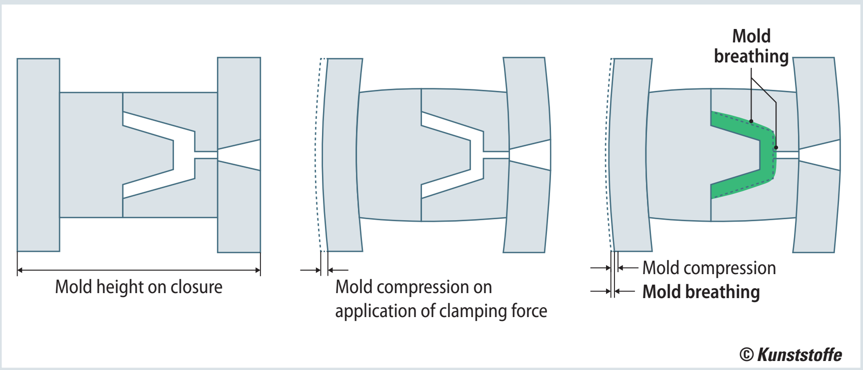

Fig. 1. Mold breathing in brief (exaggerated drawings): when the mold closes without force, there is no compression of any significance initially. As the clamping force builds up, the mold height and the volume of the cavity (center) are reduced. Some of this compression is compensated by the opening pressure of the melt during injection (right). The resulting change in cavity volume and mold height is known as mold breathing (© Schneider Form)

Part quality is determined by the interplay of physical variables: pressure, temperature and volume in the cavity. The volume does not remain constant over the cycle. It initially decreases as the clamping force is applied and then increases due to the opening pressure exerted by the melt (**Fig.1**). This compensation in mold compression as a result of the opening pressure ranges from a few thousandths to several hundredths of a millimeter and is called mold breathing.

Used for Large Parts, such as Bumpers

The cumulative effect of local breathing in the mold changes the force on the mold platens. This change can be detected by sensors integrated into the machine. At Fakuma 2015, Engel presented its "iQ clamp control", the first assistance system to use the clamping force signal from the clamping unit to calculate mold breathing across the entire projected surface and to optimize the clamping force fully automatically [2].

Schneider Form GmbH, Dettingen unter Teck, Germany, a mold-maker that specializes in large outer skin parts for automobiles – especially bumpers (**Title figure**) – presented its proprietary "OptiCheck" system at Moulding Expo 2017. This system uses sensors to measure mold breathing directly at the parting line [3] and thus to determine local mold breathing (**Fig.2**). To ensure that all the essential effects are recorded, a number of sensors are placed at critical positions in the mold. These positions are determined by means of FEA analyses and filling simulations.

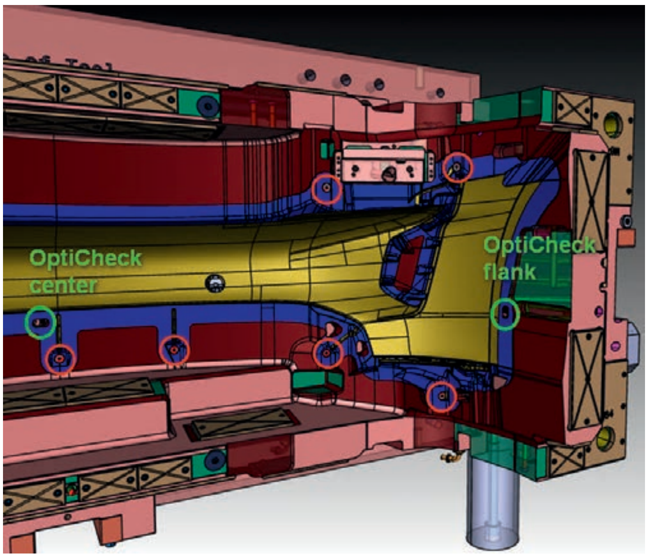

Fig. 2. For the OptiCheck measurements – shown here on mold 2 – sensors were placed at various points in the cavity (green circles). The red circles mark the injection points (© Schneider Form)

Intelligent Assistance

Intelligent assistance is a key feature of the Smart Factory, which is the goal of Industry 4.0. Engel was quick to embrace the trend towards digitalization and networking of production processes and today offers a range of mature and proven products for this purpose. The modularity of Engel's "inject 4.0" approach makes it particularly easy for plastics converters to take advantage of the new possibilities. Even individual solutions such as iQ clamp control prove highly beneficial.

➘ www.engelglobal.com/inject-4–0

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References & Digital Version

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Fig. 3. The tests were carried out in the Schneider Form pilot plant on an Engel duo 23050/4000 injection molding machine (© Schneider Form)

Significant local differences in breathing can be expected in the case of large molds, especially. Bumpers are filled in cascade via several injection points, a process which can lead to significant differences in cavity pressure along the long flow path and thus in the resulting local opening force. Breathing on the large-area flanks of the bumper running virtually parallel with the machine's longitudinal axis is often different from breathing on the surfaces perpendicular to the same axis.

On one hand, this makes the observation of locally measured information particularly interesting and, on the other, puts the machine's integrated breathing signal to the test. Schneider Form and Engel jointly carried out tests on two bumper molds using an Engel duo two-platen machine with a clamping force of 40,000 kN (**Fig. 3**) in the Schneider Form pilot plant and compared the results of their two systems. Mold 1 processed ABS with a shot weight of 4440 g and mold 2 (**Fig. 2**), PP with a shot weight of 2950 g.

Signals on the Test Bench

How do the signals compare? **Figure 4** shows the hydraulic injection pressure as well as the breathing signals determined by OptiCheck at three positions (center top, center bottom, flanks) and the breathing calculated by iQ clamp control for an injection process on mold 1. The pressure-drops in the curve of injection pressure indicate when the shut-off needles open. These are highlighted in the chart by vertical dotted lines.

Clearly, the signals returned by the OptiCheck sensors vary with their position in the mold. While the "center top" sensor responds markedly to the opening of the various shut-off needles, the "center bottom" sensor further away from the needles barely registers at all. This illustrates the importance of proper sensor positioning. For example, if the "center top" sensor had been omitted, the pressure peak upon opening of the needles would not have been revealed. The sensor on the flanks of the bumper responds mainly to the second and third needle opening. Even in the holding pressure phase, the breathing values are locally very different.

In the duo series, the breathing signal determined by iQ clamp control is based on the pressure signals produced by the pressure cushions of the four tie-bars. The user is presented with the mean breathing value across the entire projected area. This signal is emitted in response to all three needle openings. Since this is an integrated signal, the only way to resolve the local effects is to perform temporal assignment to specific events, such as needle opening. A

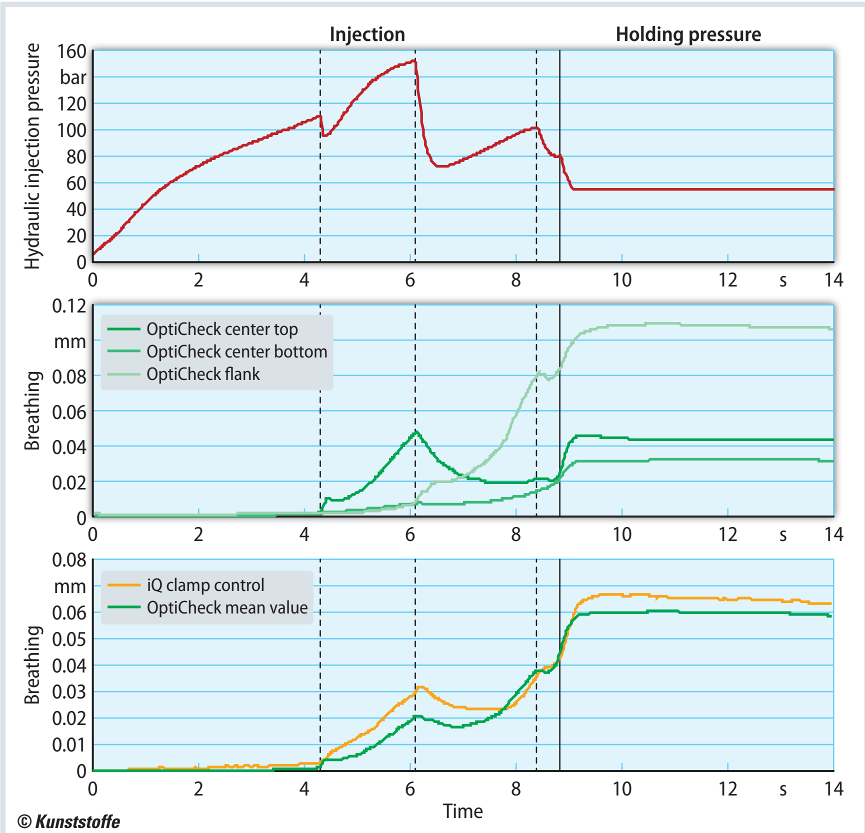

Fig. 4. Comparison of the mold breathing signals from OptiCheck and iQ clamp control during an injection cycle in mold 1 (ABS). The hydraulic injection pressure is provided for reference. The opening of shut-off needles is indicated by dashed lines, and the switchover point, by a solid line (source: Engel)

single signal is incapable of distinguishing between the breathing values occurring on the flank and in the center. The breathing curve calculated by the iQ clamp control agrees very well, both qualitatively and quantitatively, with the mean value of the three OptiCheck signals.

For an optimal process, the injection parameters, the distribution of forces in the mold and the set clamping force must be coordinated. If any of these factors is disregarded, whether intentionally or unintentionally, then compromises will have to be accepted in the quality of the molded part, the service life of the machine and mold components, or energy efficiency. The various interactions require an iterative approach that takes sufficient account of all the factors. Mold-breathing signals, whether emanating from the mold or the machine, can be helpful in all stages of process and mold optimization.

Avoiding Additional Costs of Tens of Thousands of Euros per Year

The bumper molds are filled via a cascade of injection points. In this regard, mold breathing provides valuable information about local deformation and the pressure conditions prevailing in the cavity. The example in **Figure 5** shows the hydraulic injection pressure, the breathing curves for "OptiCheck center" and "OptiCheck flank", and the overall breathing curve determined by iQ clamp control for two different shut-off needle settings on mold 2.

The orange curve indicates an unfavorable shut-off needle setting. Here the needles are opened in a cascade and remain open until the end of the holding pressure phase. Before the switchover point, breathing increases markedly because the injection pressure required for filling via the needles generates an additional opening force in the center of the molded part. After switchover to holding pressure, the pressure equalizes in the molded part and mold breathing decreases in its center, but increases at the flanks.

The fact that mold breathing is not completely dissipated at the end of the holding pressure phase suggests that the cavity is overpacked. The resulting increase in wall thickness of a few hundredths of a millimeter can translate to additional costs in the tens of thousands of euros per year for large outer skin parts. This unnecessary use of raw material can be avoided effectively by optimizing the settings on the injection side to take mold breathing into account.

Optimized Breathing Curves Reduce the Required Clamping Force

The green curve shows an optimized production setting. Here, the needles located in the center of the mold are closed »

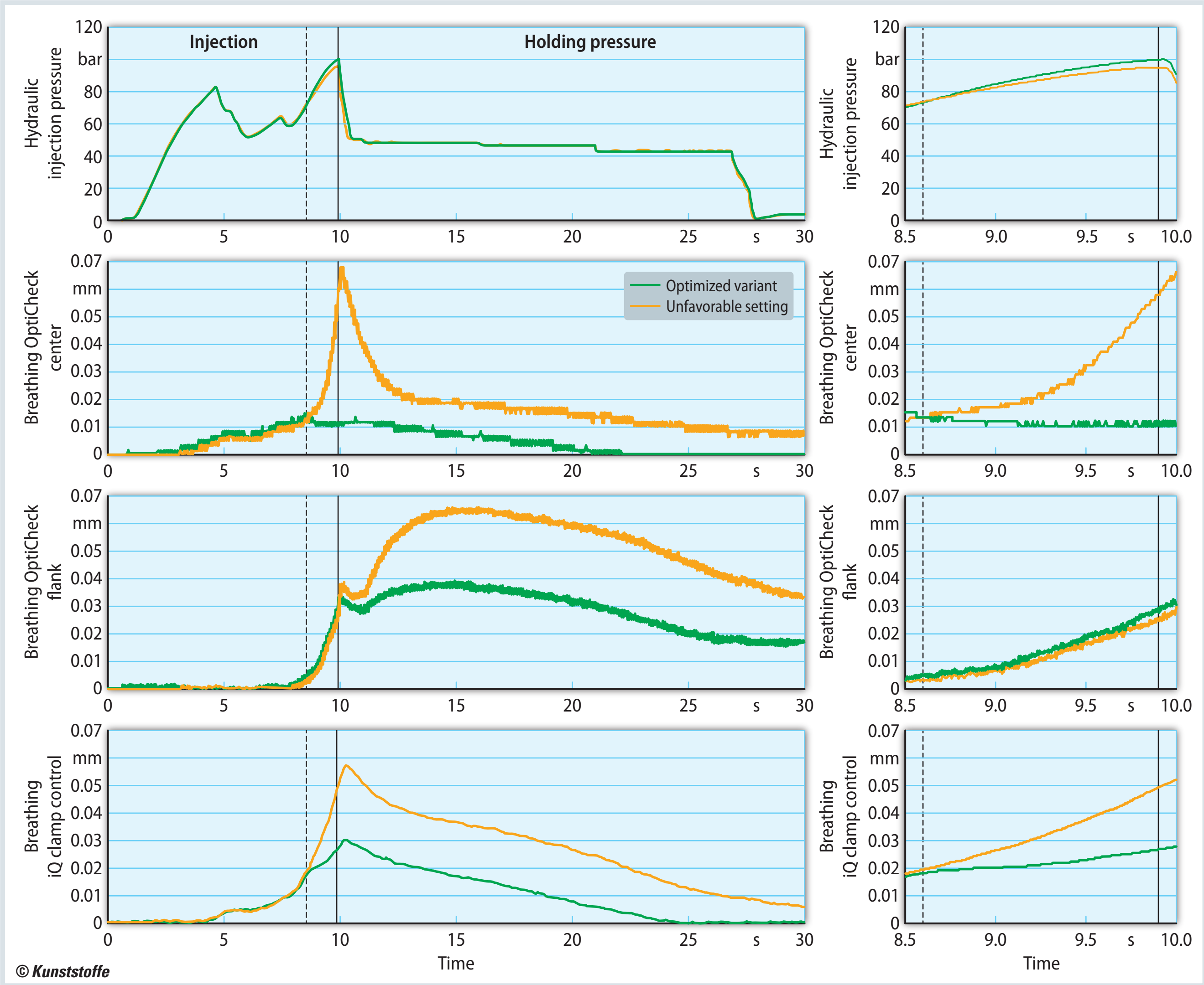

Fig. 5. Influence of the shut-off needle setting on the profiles of hydraulic injection pressure and various breathing signals for mold 2 (PP). The orange curve shows an unfavorable setting, while the green curve shows the variant optimized for low opening pressure. The magnifications on the right show the time range before the switchover poin (source: Engel)

after the needles located further out are opened. This affords a way of preventing the sharp increase in mold breathing in the center of the part and ensuring that much less breathing occurs during the holding pressure phase.

Closer examination of the injection pressure curve reveals that the injection pressure even decreases in the region before the switchover point for the unfavorable setting. This only appears at first glance to contradict the pressure conditions observed in the mold. Since all hot runner nozzles remain open, the pressure loss in the hot runner is lower during the filling phase. This effects better pressure transfer into the mold, and so the injection pressure is reduced.

In this case, the injection pressure signal is obviously not the right signal for evaluating pressure conditions in the mold. The mold-breathing signals, on the other hand, respond very sensitively to changes in the opening pressure and so can be used effectively to optimize the injection process by minimizing the opening pressure. The positive effects can be seen both in the OptiCheck signals and in the mold breathing calculated by iQ clamp control. The optimized breathing processes reduce the mold load and also the required clamping force.

More Efficient Blueing

In the bumper mold, pressure platens are used to adjust the surface pressure along the parting line and so prevent plastic deformation, especially of the sealing edge. In more than 80 test series, Schneider Form used mold breathing to develop a method that has markedly shortened the times needed for blueing and scraping. The measurements show how the different breathing signals respond to removal of some pressure plates in the bumper's flank areas (**Fig. 6**).

In those areas in which the pressure plates have been removed, the outcome is reduced mold rigidity, leading to greater compression, both locally and overall, for the same clamping force. Local breathing increases only in the areas of reduced rigidity, i.e. on the flank surfaces, while it remains unchanged in the center area. This can be clearly seen from the OptiCheck signals. The iQ clamp control assistance system detects the reduced rigidity of the overall structure and also detects increased mean breathing, but does not provide any information about local differences.

Clamping Force Optimization Made Easy

Another possible application for the mold-breathing signal is clamping force optimization. If the clamping force is gradually reduced, the peak value for mold breathing increases exponentially due to stress removal in the steel in the parting line area. If the clamping force setpoint is changed over several cycles and the machine operator observes how the breathing changes, he can draw on empirical experience or follow user-specific specifications to optimize the clamping force with the aid of OptiCheck.

Engel's assistance system goes one step further and provides a function that uses objective criteria to determine the minimum clamping force under the instantaneous process conditions for a given mold, without the need for additional user specifications. After activation, the machine automatically changes the clamping force setpoint value over several cycles, and determines the optimum clamping force from the change in peak breathing value. Experience with iQ clamp control in production shows that mold maintenance intervals can be extended substantially as a result of adjusting clamping force.

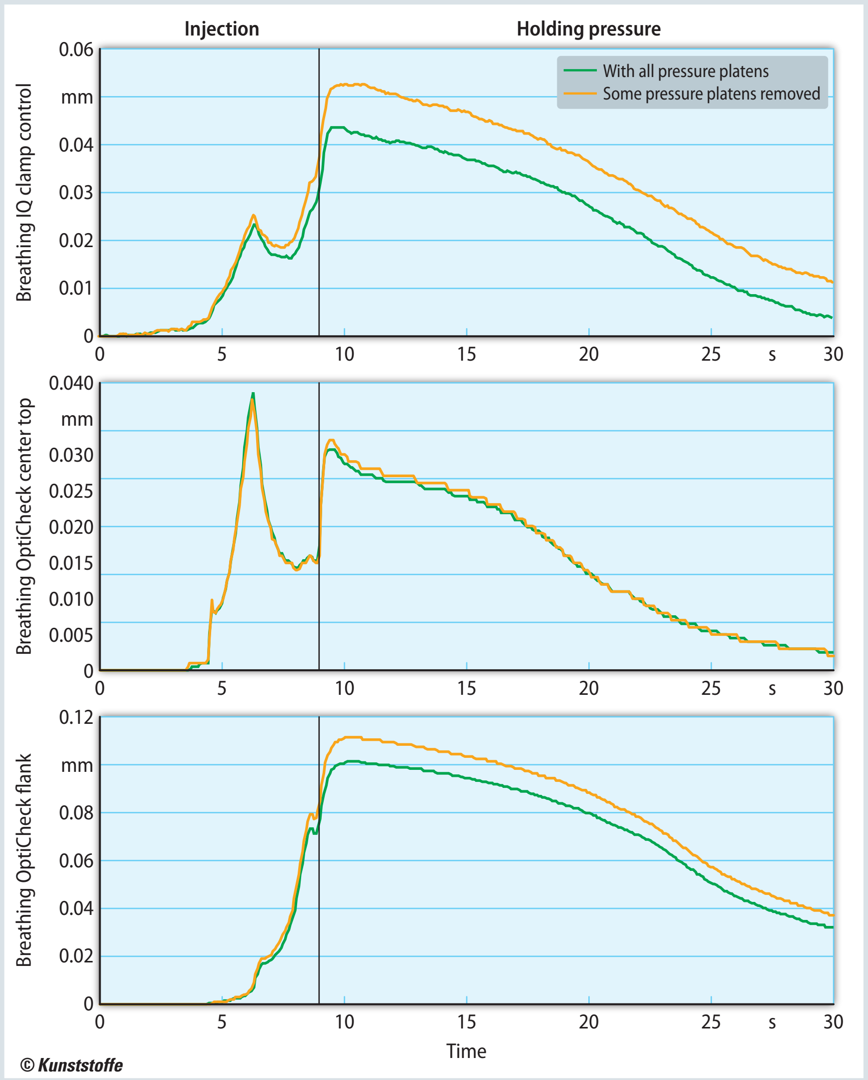

Fig. 6. Comparison of the profile of various breathing signals on mold 1 (ABS) with all pressure platens (green) and with some pressure platens removed (orange) in the area of the flanks (source: Engel)

Conclusion

OptiCheck determines mold breathing at defined positions in the mold, while iQ clamp control provides an average "picture" for the mold. Investment costs naturally differ because the iQ clamp control assistance system uses existing sensors on the machine. However, the additional investment in OptiCheck may be worthwhile, especially for large molds having very large differences in local effects.

The process optimizations described in this article with reference to bumper molds can be applied to all kinds and sizes of molds. At K2019, for instance, Engel presented the iQ clamp control for its all-hydraulic victory series of small and medium-sized machines. The software is now available for all types of injection molding machines obtainable from this manufacturer.

It is clear from the examples that the information content of mold breathing can be of great benefit throughout all phases of iterative optimization of the injection mold and the injection molding process. Added to which, the different approaches taken by the mold-maker and the machine-maker are heightening understanding and providing new insights. Initially, it is of secondary importance as to whether the beneficial signal comes from the mold or from the injection molding machine. ■