

Numbers that Count

With its iQ Weight Monitor, Engel Shifts Process Monitoring One Step up

Cyclically measured process parameters are used for monitoring and optimizing injection molding processes. In the past, attention was focused on axis movements and the associated necessary forces and times. Now, the software package iQ weight monitor goes a large step further. It generates process parameters that are relevant for component quality: injected volume, melt viscosity variation, and pressure deviations during injection.

One decisive success factor for the efficiency of injection molding processes is a low reject rate. In spite of repeatable machine movements, the quality of the produced components can be subject to certain variations, caused e.g. by changes in ambient conditions or the material properties. If such variations

are detected and compensated early enough during ongoing production, process efficiency can be improved. Provided, of course, that the associated outlay and costs are limited to a minimum. Hereby, it is most effective to use signals that are provided anyway by the sensors in the machine. For example, the signals

from sensors used for the control and sequencing of machine movements, also permit conclusions about component quality to be drawn. However, it must be noted that these sensors are located further away from the actual processing location than sensors in the mold.

Taking these factors into account, the injection molding machine manufacturer Engel Austria, headquartered in Schwertberg, Austria, develops intelligent assistant systems aimed at helping plastics processors to increase production efficiency and quality. When integrated into the machine control system CC300, some of these systems even enable manufacturing processes to continuously optimize themselves – a feature that will be standard in the factory of the future.

The software package iQ weight monitor prepares the way for the smart factory, and provides plastics processors with data informing them for which processes the investment in additional assistant systems is worthwhile. The package is now a standard component of all Engel injection molding machines.

Focus on Filling Procedure

While developing the software, Engel paid particular attention to cavity filling. The machine operator enters setpoints for starting position, speed profile, and a switchover point for the screw move-

The CC300 machine control system enables the injection molding process to be monitored effectively by means of quality-relevant process parameters (© Engel)

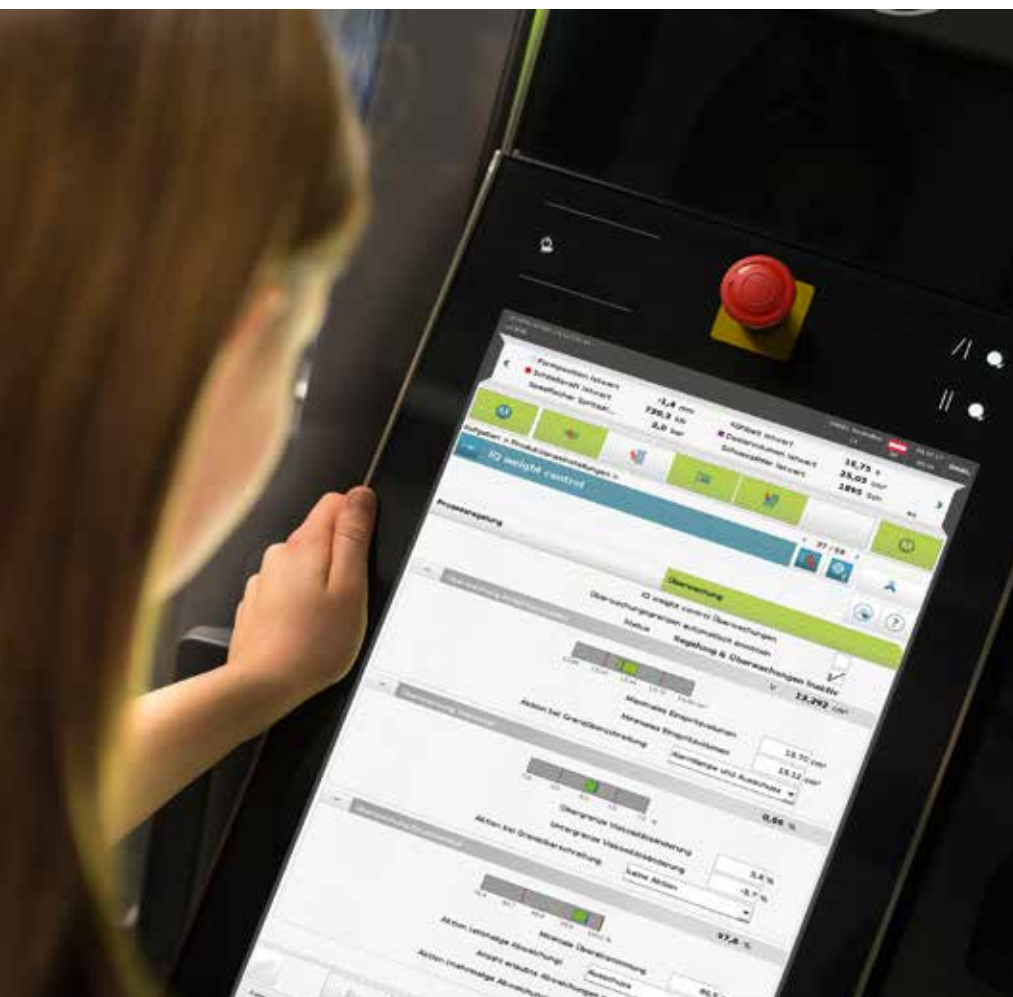
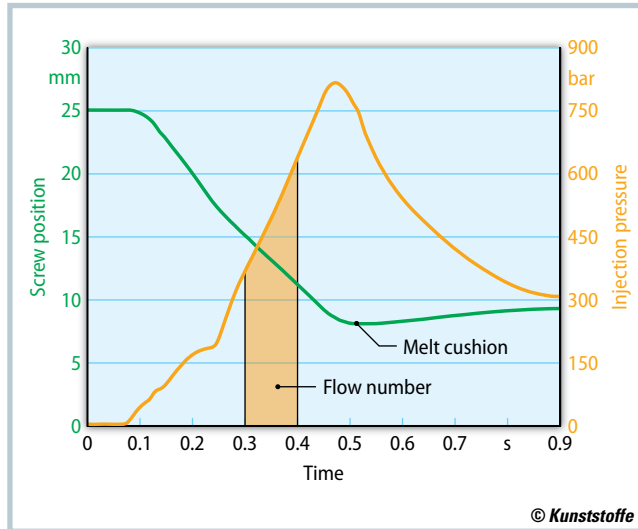


Fig. 1. In spite of their limited significance, melt cushion and flow number were frequently used in the past for process monitoring (source: Engel)



ment in the speed-controlled filling phase. From this data, the machine control system calculates setpoint preset values, which the injection controller fulfills as closely as possible.

Apart from injection speed, the resulting pressure curve depends on the amount of melt in the injection chamber, the material's flowability, and the flow resistance through nozzle, hot runner, and cavity. Due to the numerous influencing factors, the injection pressure curve is characteristic for the respective application – and therefore unique. For variations occurring in practice, one or several influencing factors not only have an effect on the molding's quality, but also change the pressure curve. Consequently, this curve is basically suitable for indirect quality monitoring.

Already several generations of injection molding machine control systems offer the possibility of determining process parameters cycle by cycle from sensor signals such as injection pressure or screw displacement, and monitoring them during the entire production process. So far, the analysis methods are comparatively simple. Process values are determined at specific points in time, together with minimum, maximum, and mean values or integrals.

As an example, two usual process parameters for the filling procedure will be examined more closely: Melt cushion and flow number (Fig. 1). It can be expected that the melt cushion provides data about shot weight, and the flow number about the material's flowability and the filling resistance.

Classics under Scrutiny

In order to determine the informative values of these two parameters, thin-walled test samples of polypropylene (type: HG 385 MO; manufacturer: Borealis) with 0.8 mm wall thickness and about 8.5 g shot weight were produced in a test series using a single-cavity cold runner mold. For this, a hydraulic injection molding machine (type: Engel victory 330/120 tech) was used, which was fitted with an inline precision weighing system for automatic determination of the molding weight.

The question was: How do the process parameters react to variations in viscosity, density, temperature, material quantity or flow resistance? In order to simulate such effects, deliberate changes were introduced in the process. The analysis of the resulting effects and influences on melt cushion, flow number, and component weight showed that the process parameters did not always change in the expected direction (Table 1). For example, it was expected that the melt cushion would change inversely to molding weight – larger screw displacement leads to a smaller cushion. In the case of flow number, it was assumed that it would mirror the material's flowability. The figures show the amount of change. If no value is specified, this means that the change was less than the fluctuation range of the number.

That the process parameters reacted differently in practice, can be explained e.g. by the fact that the flow number is an integral value. The area below the »

		Measured component weight [g]	Expected melt cushion	Measured melt cushion [cm ³]	Expected flow number	Measured flow number [bar]
Change	Effect	5.453		8.10		480
Addition of 3 % wax	Lower viscosity	▽ -0.054	△	▽ -0.41	▽	▽ -156
Increased mold temperature	Reduced filling resistance	○	○	●	▽	●
Reduced holding time	Lower material quantity	▽ -0.069	△	●	○	●
Reduced back pressure	Lower material quantity, lower melt temperature	▽ -0.053	△	▽ -0.13	△	▽ -54
Start-up after down time	Lower melt temperature	▽ -0.550	△	▽ -0.32	△	▽ -130

Table 1. Intentional manipulations of the process and their influence on component weight and also on the two process parameters melt cushion and flow number. The colors indicate the significance of the process parameters. Green: The process parameter has changed in the expected direction. Red: The process parameter has changed contrary to the expectation (source: Engel)

pressure curve not only responds to changes in pressure demand, but also to a shift of the curve along the time axis. Therefore, the flow number not only changes due to variations in melt flowability, but also as a function of the time when the backflow valve closes, as well as the actual amount of material. When interpreting the melt cushion, the problem is that the value only describes how far the screw has moved forwards, but not which melt quantity it has transported.

In most cases, melt cushion and flow number are able to indicate changes in the process, but neither process parameter permits conclusions about the cause

of the change or its influence on component quality.

Process Parameters with Significance

With its iQ weight monitor, Engel therefore focuses on other parameters. During every cycle, the software compares the injection pressure curve with a previously defined reference curve, and simultaneously calculates viscosity change as well as injection volume by means of a mathematical model that will not be described in more detail here, which separates the deviation between actual pressure curve and reference pressure curve, as shown in

Figure 2.

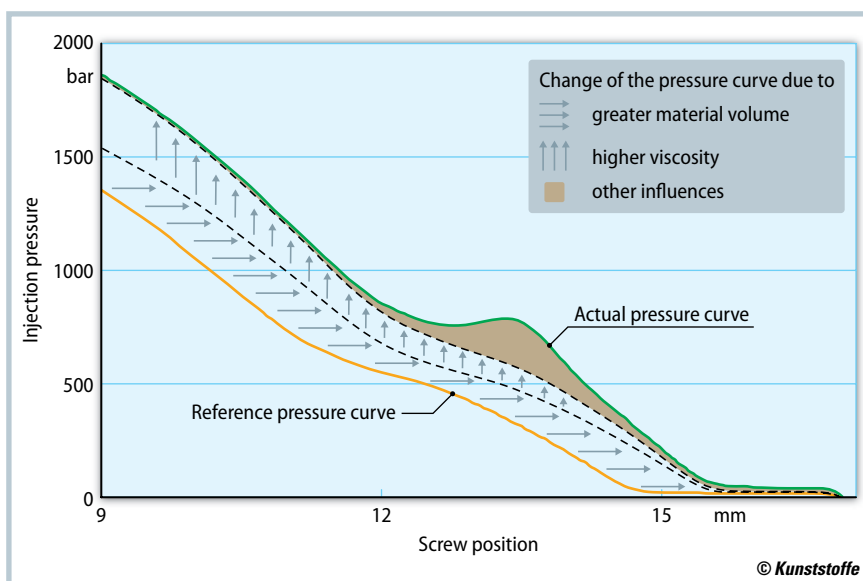


Fig. 2. Changes of injection volume, viscosity, and the pressure curve can influence component quality. In the worst case, as shown here, various interference factors occur together. For better understanding, very large deviations from the reference curve have been selected here (source: Engel)

Engel)

Hereby, injection volume is the primary process parameter. Even if the screw always moves in exactly the same manner, i.e. from its starting position to the frontmost position, namely the melt cushion, this does not mean that the same melt volume is also always transported. The reason for this is the backflow valve. Before injection starts, the valve is open, so that due to the different pressure conditions, the material is able to flow from the screw flights into the injection chamber. When injection starts, the pressure conditions are reversed. This means that the material flows back from the injection chamber into the screw flights until the valve closes. The iQ software takes these phenomena into account, and supplies a value for injection volume that corresponds to the actual shot weight.

The second parameter – viscosity change – is significant because viscosity determines melt flowability, which in turn determines the injection volume. Viscosity changes can result from variations in the material batches, the amount of recycle, the humidity content, or temperature changes.

Thirdly, the degree of conformity between the pressure curve and the reference curve provides valuable clues for additional interference factors during injection. For example, a strongly varying value could mean that the process setup is not ideal or a cold plug has formed in the nozzle.

One example illustrates how several factors can influence the injection process simultaneously (**Fig. 2**). Contrary to the reference, the injection chamber con-

		Measured component weight [g]	Expected injection volume [cm ³]	Measured injection volume [cm ³]	Expected viscosity change	Measured viscosity change	Conformity of pressure curve [%]
Change	Effect	5.453		13.49		0	100
Addition of 3 % wax	Lower viscosity	▽ -0.054	▽	▼ -0.32	▽	▼ -3.5	▽ -6
Increased mold temperature	Reduced filling resistance	○	○	●	▽	▼ -0.5	○
Reduced holding time	Lower material quantity	▽ -0.069	▽	▼ -0.17	○	●	○
Reduced back pressure	Lower material quantity, lower melt temperature	▽ -0.053	▽	▼ -0.18	△	▲ 1.5	○
Start-up after down time	Lower melt temperature	▽ -0.550	▽	▼ -1.12	△	▲ 6.0	▽ -30

Table 2. Intentionally introduced process changes and their influences on component weight: The process parameters injection volume and viscosity change in the respective expected directions. The changes of injection volume are greater than for component weight, as the sprue was not taken into account in the latter (source: Engel)

tains 1cm³ more melt. This increased melt quantity leads to an earlier pressure increase. With the same viscosity, the pressure curve would correspond to the dashed line. But in this case, material viscosity is some 20% higher. As if that were not enough, a cold plug has formed in the nozzle, which requires additional force at the start of the injection phase. Even in such a complex case, the algorithm of the iQ weight monitor can detect the respective magnitudes of the three individual effects.

Reduced Outlay, Large Benefits

Use of the assistant system is quite simple. First, the user optimizes the process as usual to the required component quality. Next, he starts the reference measurement with the push of a button,

thereby establishing that he wishes to save the current state as target value. During the 20-cycle referencing procedure, the software automatically recognizes whether the process has actually lined out.

If this is not the case, the iQ weight monitor automatically repeats the referencing procedure. Hereby, the assistant system evaluates the injection volume, the material's viscosity, and the shape of the injection pressure curve, and views these values as benchmarks for subsequent production. Based on the observed scatter, the software automatically suggests limits for permitted variations, which the operator can either accept and apply, or adapt as required.

At this time, the operator also defines what is to happen if the specified limits are exceeded. For example, the system

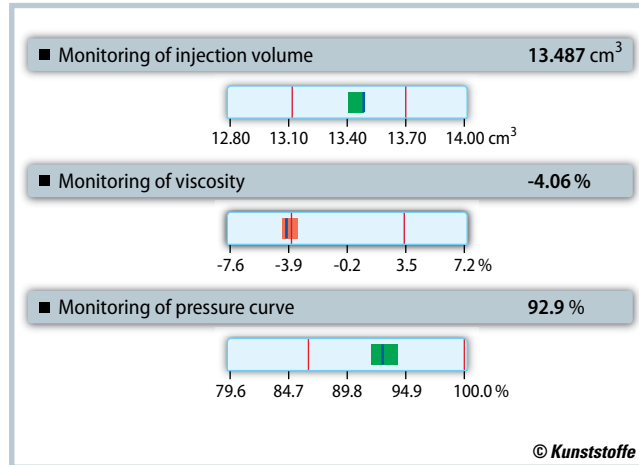
can generate an alarm, stop the process automatically, or divert the parts as rejects.

The reference state remains valid until setup parameters for the injection phase are changed. Also the reference curve is saved with the setup data, so that it is immediately available as soon as the mold is installed again. In order to understand the process status at a single glance, the process parameters – which are updated with every cycle – are shown in the system's display in traffic light colors (Fig. 3).

Process Monitoring with Control Possibilities

In the final step, the process parameters injection volume, viscosity change, and conformity of the pressure curves »

Fig. 3. The respective actual process parameters are shown clearly on the display of the machine control system. The traffic light colors indicate which values are within or outside the tolerance range (source: Engel)



Process parameters	Significance
Melt cushion Flow number Conformity of the pressure curve (iQ weight monitor)	Detects changes in the process, but does not permit a direct conclusion about cause or effect.
Viscosity change (iQ weight monitor)	Is a measure for a certain input or interference value. The effects of detected changes are predictable for the plastics processor.
Injection volume (iQ weight monitor)	Is a measure for a certain output value, which in turn is related to a quality feature of the molded parts.

Table 3. The iQ weight monitor provides highly significant process parameters (source: Engel)

were also examined during the test series mentioned above. The results mirror the changes of the measured molding weight with the calculated injection volume, although this also includes the sprue (Table 2). Contrary to melt cushion and flow number, the calculated viscosity change reacts exactly as can be assumed on the basis of the associated interventions in the process.

The same as modern assistant systems in automobiles, the iQ assistant systems in injection molding machines are also subject to the laws of physics. During injection, the iQ weight monitor analyzes the pressure signal as a function of screw position, and derives additional information that is not available simply by viewing the curves. A prerequisite for this is that the interference effects are represented clearly enough by the injection pressure signal. If this is not the case, it is possible to use a sensor near the sprue to measure internal mold pressure, or a melt pressure sensor located in the injection chamber as signal source.

Because the monitoring system calculates the parameters already during injection, i.e. before the moldings can be weighed, it is possible to react to deviations from the setpoints during the

same cycle, thereby preventing rejects. Engel has also developed a solution for this inline control system [1]. During every cycle, the iQ weight control adapts the switchover point to the actual state, thereby maintaining a constant injection volume. By shifting the switchover point, also the opening and closing times of the shut-off nozzles in the mold are adapted. If the software detects a change of viscosity, the system adjusts the holding pressure to ensure constant shrinkage compensation in the cavities – even after the volumetric filling phase has been completed.

To what extent repeatability can be improved by the software, depends on several factors. Naturally, processes whose operation is already very stable can only be further optimized to a limited extent, if at all. In order to assess which additional effect the application can provide, the iQ weight monitor offers a useful function for plastics processors: The program calculates the possible improvement potential achievable with iQ weight control. Hereby, two values are indicated: Firstly, the improvement that can be expected by correcting the switchover point, and secondly, the improvement resulting from a correction of back pressure.

Summary

During injection molding, numerous process parameters are generated, whose usefulness for monitoring and optimizing the process can vary. For example, although the frequently determined values for melt cushion and flow number are able to indicate changes in the process, they do not provide data about the nature of the change or its influence. In contrast, the iQ weight monitor provides parameters with a higher informative value (Table 3). By means of the CC300 machine control system, and also by means of a MES, the process parameters permit highly effective monitoring of the injection molding process. Moreover, the software package makes optimizing potentials evident, which can be exploited e.g. with the iQ weight control system. ■

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