


The repeatability of a process is not a constant parameter (© Engel)

How Repeatable Is Repeatability?

Working Properly with Machine Capability and Tolerance Limits

Repeatability means the ability to produce parts that have identical properties to one another. As with other manufacturing processes, this capability is very important in injection molding because it has a crucial influence on the efficiency. It is therefore often necessary to assess production systems or their components in advance according to whether they ensure a repeatable process. But how?

High repeatability over a relatively long period generally requires high robustness to sudden or gradually changing disturbances. Such disturbances may include fluctuating ambient conditions or the wear of machine and mold. Material properties, too, may be subject to fluctuations from batch to batch, representing disturbances for the process.

But, during the lifetime of a process, who knows what disturbances may emerge, what their extent will be, and, most important, how much they will affect the quality of the part? In practice, these future scenarios are usually neglected; processors restrict themselves to making an inventory of the current repeatability. But on closer examination, even this proves to be non-trivial.

Comparisons with Standard Deviations and Variation

For rapid assessment of the repeatability, the shot weights for a determined number of successive cycles are usually determined. These values serve as basis for calculating the standard deviation or variation (**Fig. 1**). Both parameters are often expressed as a percentage of the mean shot weight – as a result, they can be better compared using empirical values.

Variations are thus considered very satisfactory if they lie below 0.1% of the mean part weight. The disadvantage of this consideration is that the variation is calculated from only two values: the biggest and the smallest measured value. What takes place between them is not taken into consideration. This minor shortcoming can be pardoned however, since the short-term repeatability in which, e.g., 50 cycles are considered, actually conceals far more – but more about that later.

In the last decade, machine capability and process capability studies have become increasingly widespread. A determined number of parts are taken under defined conditions, and a property that is important for their subsequent function is measured. This property may be, for example, a critical dimension. Presupposing a normal distribution of samples, the aforementioned standard deviation is determined. From this standard deviation and from the permitted tolerance for the property under consideration, machine capability indexes are calculated.

The machine capability index c_m indicates how often six times the standard deviation fits into the given tolerance band. In one case example, the six times the standard deviation is illustrated with six vertically stacked double arrows in a yellow rectangle. As can be seen, the yellow rectangle fits about 2.3 times between the lower and upper tolerance limits. A value of $c_m > 1.67$ is usually required (**Fig. 2**).

The lower machine capability index $c_{m,l}$ indicates how often three times the standard deviation fits between the target value and lower tolerance limit; while the upper index $c_{m,u}$, on the other hand, states how often it fits between the target value and upper tolerance limit. In the case example, three times the stan- »

dard deviation is represented as three vertically stacked double arrows in an orange rectangle. As can be seen, the orange rectangle fits about 3 times between the lower tolerance limit and mean value, but only 1.59 times between the mean value and upper tolerance limit (**Fig. 2**).

$C_{m,l}$ and $c_{m,u}$ thus describe the position of the measurement values within the tolerances. The larger the index is, the further the measurement values are from the corresponding tolerance limit. Since a small value is consequently a problem, the smaller of the two values $c_{m,l}$ and $c_{m,u}$ is designated as a critical machine capability index $c_{m,c}$. In the example (**Fig. 2**), $c_{m,u}$ would thus be the critical value. A value > 1.67 is also usually required for this. While the scattering of the values with a c_m of 2.3 meets the requirements, $c_{m,u}$, at 1.59, is too low – the measurements lie close to the upper limit. One would then change the setting parameters in order to influence the shrinkage and so reduce the length somewhat. If this is not possible, the mold geometry would have to be changed.

The Pitfalls of Repeatability Measurement

If the injection molder has performed a repeatability test he thus obtains at least one of the above-described numerical

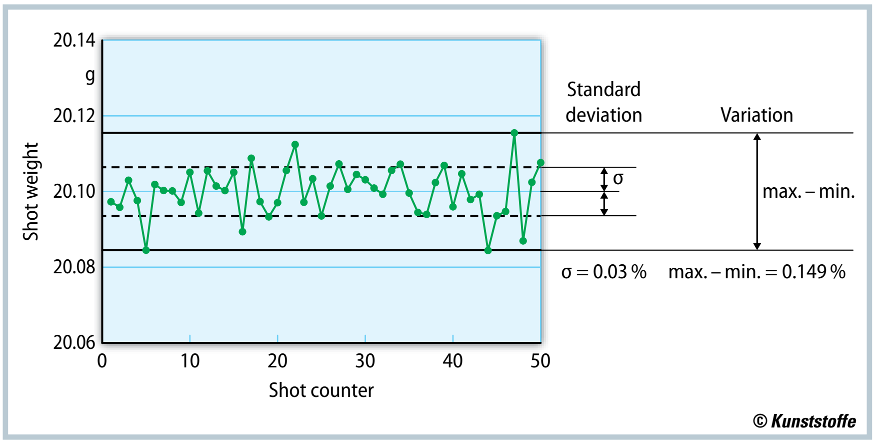

Fig. 1. The curve of the shot weights and the standard deviation and variation of 50 successive cycles are usually used for a rapid assessment of the repeatability (source: Engel)

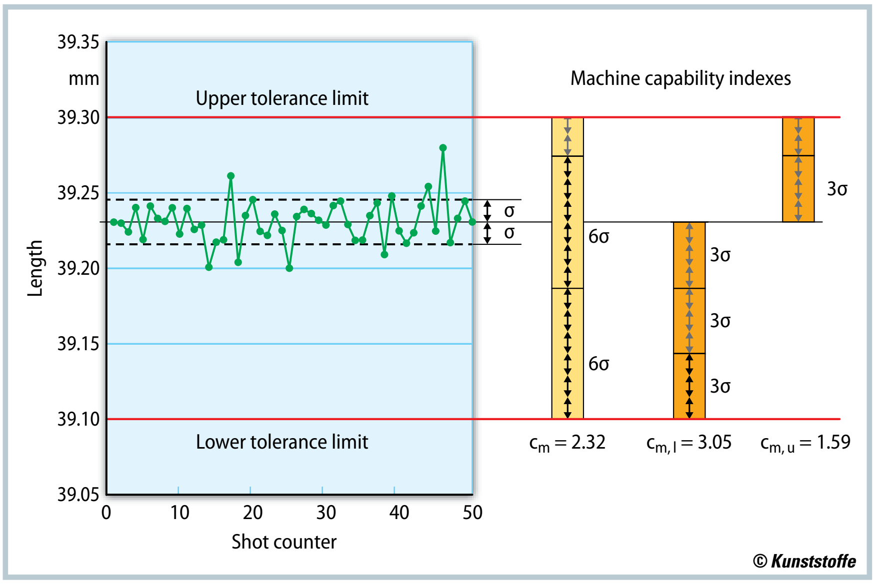

Fig. 2. From the profile of the length dimension of 50 successive cycles and the resulting standard deviation (shown as a double arrow), the machine capability indexes c_m, $c_{m,l}$ and $c_{m,u}$ are calculated (source: Engel)

values. This allows the process – or more accurately a snapshot of the process – to be assessed. It has been found in practice that the results of a repeatability measurement often do not stand up to closer scrutiny. There are a host of error sources, the most common of which are described below.

The first error occurs when at the end of a busy day there is not enough time to do measurements properly. If technicians decide to quickly take parts from 50 shots and place them on the scales, they often find out too late – namely when the shot weights are available – or in an extreme case never, that the process had not settled down (**Fig. 3**). Before the repeatability test, it should therefore always be tested whether the process is in a stable state (**see Practical Tip: Has the Process Settled Down?**).

Erroneous Measurements

The next pitfall comes during weighing. You could think that the ability to use a set of kitchen or bathroom scales would be adequate for determining the weight in the repeatability test. That is a mistake! Like any other measurement skill, weighing must be learned. The instrumentation proficiency must be ascertained, and air drafts must be avoided. It is advisable to weigh not in the production environment but in a lab, and the parts must not overhang the weighing pan.

It should also be observed that different storage times after removal can falsi-

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References & Digital Version

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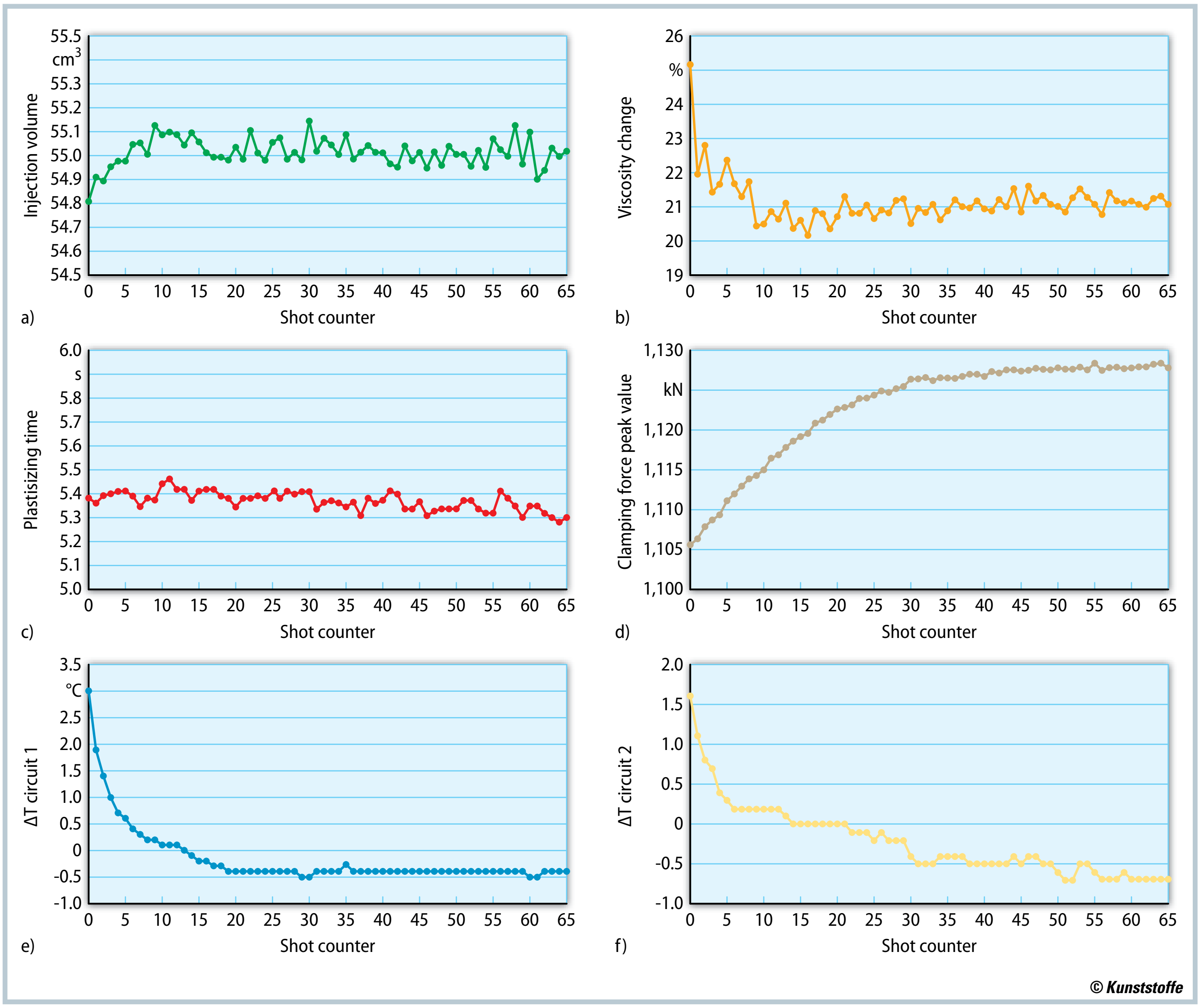

Fig. 3. To test whether a process has settled down, it is necessary to monitor several parameters shot by shot. The values can be graphically displayed in the injection molding machine control system (CC300) (source: Engel)

fy the result due to different moisture absorption – the same applies to electrostatic charging of the parts. The last point is not widely known. It is therefore advisable to discharge the parts with ionized air.

Suboptimum Settings

Anyone who has followed the tips so far will probably obtain a correct result – more precisely: a result that is correct under the given conditions. One of the key conditions is the operating point, i.e. the total of all the settings that the user has chosen. To make things a little more complicated: the repeatability is dependent on the settings. The mold temperature is reduced somewhat, the injection velocity increased and the repeatability can change – both in short-term tests and – probably even more – in the longer term.

In practice, it will be difficult to optimize both the robustness and repeatability during process optimization. Usually it is enough to perform at least one optimization according to the conventional rules of injection molding. Two key indicators for the quality of a setting are mentioned here as examples.

- First: can the injection drive follow the selected injection velocity profile? That would not be the case if the injection pressure limit chosen for protection of the mold is reached.
- Second: is the injection pressure curve the same from shot to shot in its principle form? This would not be the case, for example, if cold slugs in the nozzle caused fluctuations at the beginning of the injection process.

Modern machine controls like the CC300 from Engel Austria GmbH help engineers to find answers to these questions, and thereby fulfill important prerequisites for the robustness of the injection molding process (**see Practical Tip: Actual Value in the Target-Value Graph**).

Repeatability Tests with Process Data

Measurement is difficult and expensive. Why not, to a first approximation, use process data – i.e. actual values from the machine – instead of measurements on the part to judge the repeatability? Do not a uniform melt cushion and a stable metering time already say a lot about the quality of the machine? »

However convenient this procedure may seem, it is not possible to relate them to the part quality. It becomes particularly critical when a machine capability index is calculated from process data. As described above, this requires tolerance limits. For process data, however, they cannot be found in the part drawing. They must be freely invented, which takes us directly to the next point.

Relaxed Handling of Tolerance Limits

"The simplest way of increasing the process capability of a given process consists in relaxing the specification limits. The greater the difference between the upper specification limit and lower specification limit, the more the standard deviations can be accommodated between them." This declaration by Wikipedia [1] should not be used as a guide to self-deception. If the tolerance limits are freely invented, and the desired machine capability is not reached, it is tempting simply to determine the limits. We do not need to restate here that such a procedure is completely pointless.

Assistance Systems for Process Control

Anyone who is aware of the above-described pitfalls can sidestep them where possible and thereby obtain a value for the repeatability that is actually convincing – at least for the moment. Since, as mentioned above, it is not foreseeable how disturbances will change in future and how they will consequently influence the quality of the parts and the repeatability of the process.

A solution to this problem is offered by new intelligent assistance systems for process quality, such as "iQ weight control" from Engel. The module forms an automatic control loop that is superimposed on the familiar injection and holding pressure controllers. When the disturbances change, it adapts the injection, changeover and holding pressure parameters in real time, i.e. during the same cycle, so that the shot weight remains largely constant [2]. The software package is

Fig. 4. A quick graph can be generated from the process data log at any time (© Engel)

Practical Tip

Has the Process Settled Down?

In most cases, it is difficult to assess whether a process has settled down. To make an assessment of this kind, it is necessary to monitor multiple parameters shot by shot over a relatively long period. The latest CC300 machine control system from Engel offers the possibility of graphically displaying process parameters. This allows changes in the process or the state of the process to be assessed at a glance in up to six graphs on one screen page. Searching for changes in apparently infinite columns of figures is thus a thing of the past.

Machine-specific parameters or process-specific parameters give an indication of whether a process has settled down or not. On start-up of the machine, it (**Fig. 3**) can be seen that the process-specific parameters of injection volume (3a), the viscosity change (3b) and plastisizing time (3c) are stable after just a few cycles.

Given the temperature differences between the feed and return in the mold cooling circuit (3e and 3f), it should be observed that the two cooling circuits have not settled down at the same point in time. In this case, the difference can be explained by the fact that the two temperature circuits supply different regions of the mold. If the mass to be cooled is larger, it takes longer until a stable temperature difference is established.

In the case of toggle machines, the clamping force peak value (3d) changes as the mold is being brought to its service temperature because of thermal expansion. This parameter is therefore particularly suitable for assessing whether the mold is already heated throughout.

For the case in which six graphs are not enough, or where it is desired to investigate the profile of any other arbitrary parameter in the process data log and display it graphically, the operator only needs to tap into the column of the particular value. For example, the quick graph generated in this way can show that at least 25 cycles are necessary until the temperature of a cylinder zone has settled down (**Fig. 4**).

Practical Tip

Actual Value Display in the Target-Value Graph

One value per cycle is recorded in the process data log and in the associated graphs. However, these records do not give any information about the variation of values within a cycle. However, the user can display the actual value curves for injection velocity and injection pressure together with the target-value profile of the injection velocity (**Fig. 5**). This allows a simple check of whether and how the injection drive follows the set injection velocity. Moreover, the profile of the injection pressure can be observed and analyzed for irregularities (pressure spikes during injection, difference at the beginning of the pressure curve as a result of cold plugs etc.).

The so-called "actual value display" in the target-value graph, which is read from right to left, is subdivided into three regions (**Fig. 5**). Region a, on a dark gray background, marks the transition through the compression relief. Region b, on a light gray background, models the velocity-controlled phase of the injection process. The changeover point takes place at the transition from b to c. That in turn means that region c is part of the pressure-controlled phase of the injection molding process. The curves illustrated here show that the injection drive follows the preset profile and there are no abnormalities, such as pressure spikes, during the injection.

part of the "inject 4.0" program, with which Engel is paving the way to the smart factory for its customers.

For processes with poor repeatability in short-term tests, the software can provide an immediate improvement. If, on the other hand, the repeatability in short-term tests is very good, the software will not appear to offer any further improvement at first sight. Nevertheless, iQ weight control continually monitors the injection volume and intervenes reliably when something changes. The system is thus an insurance that the process will continue to run reliably in future. The good thing about this type of insurance is that it does not wait for a damage signal to be activated. It is already active before the rejects are produced. ■

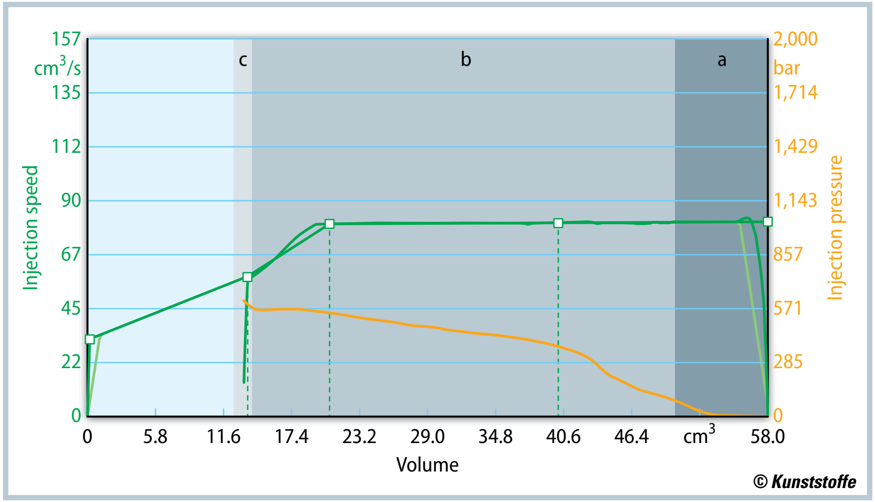

Fig. 5. The presentation of the actual value curves allows a simple check of whether and how the injection drive follows the set injection velocity. The graph should be read from right to left. Region a characterizes the compression relief stage, b the velocity-controlled injection and c a portion of the pressure-controlled phase of the injection molding process (source: Engel)