Injection vs. Holding pressure

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At the operation level, one could mix injection stages with holding pressure stages. At the conceptual, theoretical, optimization and communication levels, they had better be separate. This article discusses the theory behind injection and holding pressure, and advises on the importance of distinguishing between the two for machine operators.

Theory and practice

Theories are generalized from the experience gained in practice. The same is true in injection molding.

In the 1950's when injection molding machines started being used, injection pressure was used to fill cavities. Subsequently, two-stage injection was developed. The second stage is what we call holding pressure stage nowadays.

Distinguishing between injection and holding pressure is needed because they have different purposes. Furthermore, there is a difference between speed control and pressure control. Especially when it comes to quality injection molding, thin-wall molding, and using T-mould, it is a must to separate the two.

The purpose of injection

The purpose of injection is to fill the cavities and to pack the melt so that the most minute details of the mold are transferred (written) to the melt.

Speed controlled

Before the cavities are completely filled, injection pressure is quite low, as read at the system pressure gauge. This is because a low injection pressure is sufficient to overcome the resistance to the viscous melt flow due to the nozzle, flow channels and cavities. Low pressure is maintained until the cavities are 100% filled.

Please be reminded that the pressure setting in an injection stage is an upper limit. If an injection pressure of 90 bars is set, it means the injection pressure at this stage cannot exceed 90 bars, but at which pressure below 90 bars depends on how much resistance the melt presents to the screw. This pressure could be read at the system pressure gauge during injection.

As a result, before the cavities are completely filled, injection pressure cannot be controlled, only injection speed could be controlled. Pressure is the result of resistance and resistance cannot be controlled at the pump.

The stability of the parts is highly dependent on the repeatability of injection speed. In closed-loop injection, the injection speed of each stage is kept at its set value.

Please set the pressure of each injection stage at system pressure which is usually at 140 bar or 160 bar. Having sufficient pressure upper limit ensures that there is sufficient pressure to attain the set speed on the face of varying resistance. As the cavities are not completely filled, the high injection pressures will not cause flashing.

After all the cavities are completely filled, it does not mean the end of injection. There is also a packing stage.

Packing

The difference between injection and other processes on plastics is the extraordinarily high injection pressure that could be created. The injection pressure on the melt could be anywhere between 1000 and 2000 bars. To know that the pressure in the deepest abyss on earth has not even reached 2000 bars, you would know how high this pressure is. Only at this high pressure could the minute pits of a CD be transferred from its mold to the melt. So it is for a polished (mirror-like) cover.

Packing pressure is created by the compressibility of the melt and the continued forward motion of the screw after all the cavities are completely filled. This could be considered as overfilling in which a certain % of cavity volume is overfilled with melt, creating a rapid rise in pressure. Packing is the last stage during injection, which is the only pressure-controlled stage so its pressure has to be set carefully to avoid flashing. After the packing stage, the process switches to holding pressure. The position of the screw at the transition is called the transition point. It is a setting on the controller screen.

The purpose of holding pressure

The purpose of holding pressure is to maintain a pressure at the screw tip to continue filling material into the cavities as the melt in the mold cools and contracts. The space created by the contraction is taken up by more melt to reduce or avoid sink marks in the solidified parts.

The holding pressure setting should not exceed the packing stage pressure setting. For otherwise, flashing could be created at the holding pressure stage.

In multiple-stage holding pressure, sequential stages should have reducing pressure settings. However, the ideal pressure setting is not stepwise pressure reduction but linear pressure reduction to match with the continuous contraction due to cooling.

As contraction is a slow process, the screw speed forward is also low. For example, it would be sufficient if speed is set at 2%. Energy saving in injection molding machine comes mainly from a low flow rate set during holding pressure. A variable displacement pump is needed. Compared to a fixed displacement pump that always pumps out 100% of the flow, 97% of the energy used up during this stage could be saved. The longer is the holding pressure duration (the thicker is the part), the more saving is possible.

From this discussion, we know holding pressure stages are pressure controlled and not speed controlled as contraction is not controllable by the pump. This is the opposite control used during injection.

Concerning the durations of the holding pressure stages, they could be determined when the part weight stops increasing or when sink marks are acceptable. Then holding pressure could stop. The next stage is plasticizing which starts at the same time as cooling.

Judging when the cavities are completely filled

The transition point separates injection (including packing) from holding pressure. To set the transition point, the operator has to find out when are the cavities completely filled. There are three methods.

1. Theoretical calculation

   If d = screw diameter, mm

   s = screw stroke, mm

   w = parts shot weight (including cold runner), g

   ρ = plastic density at room temperature, g/cc

   w could be expressed as

   $$w = (\pi d^2) / (400) \times s / 10 \times 0.85 \times \rho$$

   in which 0.85 is a fudge factor.

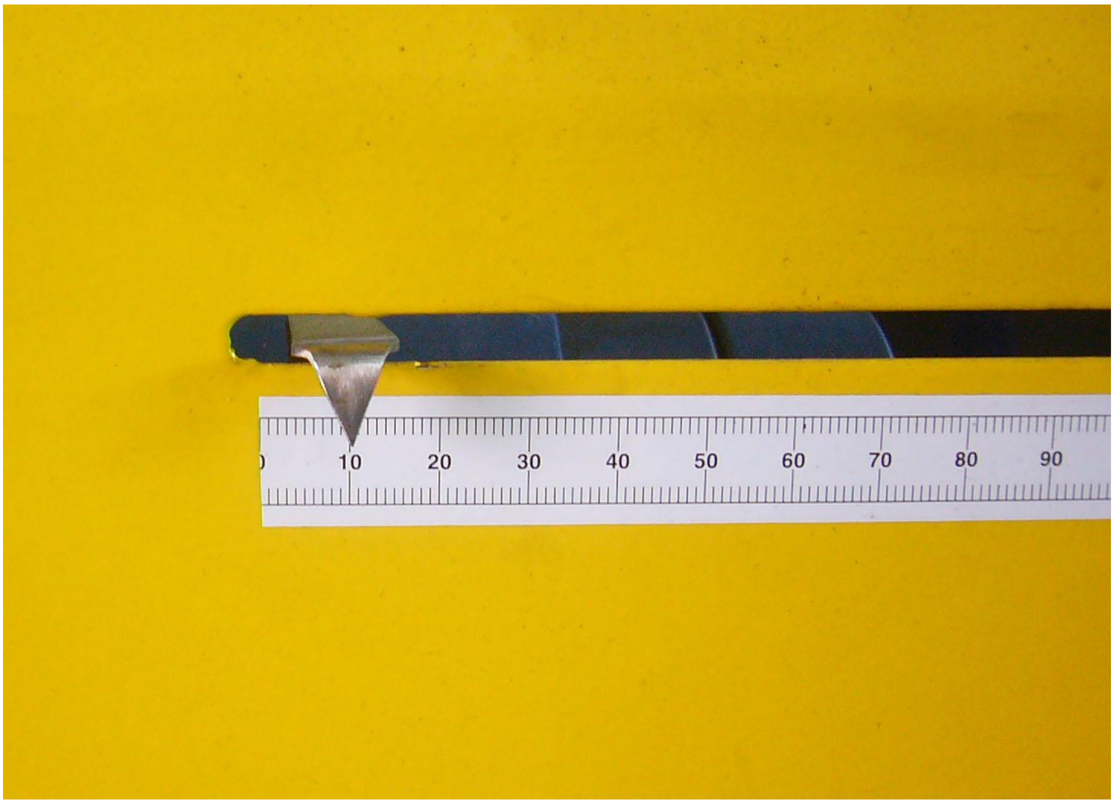
   So

   $$s = (4000w) / (0.85 \rho \pi d^2) = (1497.9w) / (\rho d^2)$$

   and the transition point is, in mm

   $$h = p - s$$

   p = position of the screw after plasticizing, mm
2. When the cavities are completely filled, the forward speed of the screw is suddenly reduced. This could be read at the mechanical pointer of the screw during injection and holding pressure stages. Transfer this reading to the transition point on the injection screen.
3. During injection and holding pressure stages, observe the system pressure gauge. When all the cavities are completely filled, the hydraulic pressure suddenly rises. The observer would call this out while another observer reads the screw position display at the controller or the mechanical pointer. Transfer this reading to the transition point on the injection screen. This method is only suitable for slow injection speed in thick-wall molding.



Pressure controlled or speed controlled?

We summarize the few points above about injection, packing and holding pressure in a table below. It is most common to delineate injection stages by screw position. Holding pressure stages are delineated by time.

		Screw position	Pressure control	Speed control	Remarks
Injection	Injection stages			√	Fill all cavities 100%。 Pressure setting at system pressure
	Packing		√		Overfill. Pressure setting is upper limit, avoid flashing
	Transition point	Value from the previous section			
Holding pressure	Stage 1		√		Pressure setting < packing pressure
	Stage 2		√		

	Stage 3		√		Reducing pressure settings with stages Set low speed to save energy

Operating an injection molding machine

From an operation point of view, injection and holding pressure have the following in common.

1. Unless an injection servovalve is used, the injection direction valve is open during injection and holding pressure stages. The valve does not close during the transition nor is there a reversal in direction.
2. In most controller screens, both pressure and speed could be set in injection and holding pressure stages.
3. The injection stages, although it is better to delineate them using screw position, could also be delineated by time if time injection is selected. In this case, it is the same as the delineation in holding pressure stages.

As a result, some operators do not use the holding pressure stages but use the last injection stages to do holding pressure. In simple injection in which there are two injection stages and two holding pressure stages, there is little difference. In high-end application, optimization and conceptually, not making a distinction creates problems.

<table>
<tr><th></th><th>Screw position</th><th>Pressure control</th><th>Speed control</th><th>Remarks</th></tr>
<tr><td>Injection stage 1</td><td></td><td></td><td>√</td><td>Filling</td></tr>
<tr><td>Injection stage 2</td><td></td><td>√</td><td></td><td>Packing</td></tr>
<tr><td>Injection stage 3</td><td></td><td>√</td><td></td><td rowspan="2">Injection stages used for holding pressure. Time injection used.</td></tr>
<tr><td>Injection stage 4</td><td></td><td>√</td><td></td></tr>
<tr><td>Transition point</td><td>Value</td><td colspan="3"></td></tr>
<tr><td>Hold press. stage 1</td><td rowspan="2"></td><td></td><td></td><td rowspan="2">Hold pressure stages not used</td></tr>
<tr><td>Hold press. stage 2</td><td></td><td></td></tr>
</table>

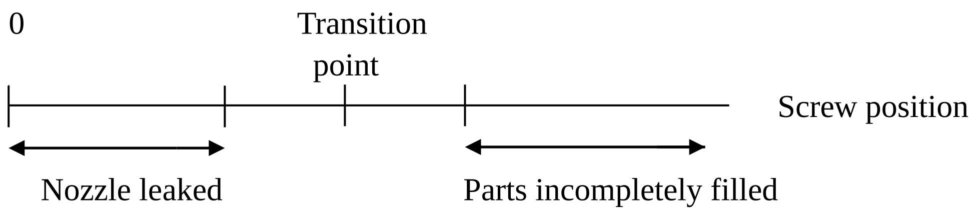
Hold press. stage 3				

Notice that as injection stages 3 and 4 use time injection, injection stages 1 and 2 (packing stage) have to use time injection as well, but cannot use the more precise position injection.

Microprocessor-controlled injection molding machines have the following functions.

（1） In ‘position+time’ injection, an upper limit to injection time could be set. When this upper limit is reached but the screw has not reached the transition point, transition to holding pressure will take place anyway. This could happen when a cavity is blocked in a multiple-cavity mold. If holding pressure stages are not used, this mode of injection could not be used. Only time injection could be used.

（2） To the left and right of the transition point are two ranges of screw positions which would cause alarms at the beginning of holding pressure stage. The zone where the screw is short of the transition point creates incompletely filled parts. The zone where the screw has passed the transition point indicates melt has leaked from the nozzle. Rejects could be created in either case. The alarms would have notified the operator of them. If holding pressure stages are not used, this alarm function could not be used.



If the controller could provide a linearly decreasing holding pressure setting, not using holding pressure stages cannot make use of this feature.

Precision injection and thin-wall injection uses closed-loop control. Closed-loop control only allows injection speed control, packing pressure upper limit control and holding pressure stages pressure control.

Some European and American controllers do not allow pressure control for the initial injection stages. There is only pressure control for the packing stage and holding pressure stages. This would avoid the inappropriate practice of using injection stages to do holding pressure.

Energy saving

Even if the injection molding machine is equipped with energy-saving variable displacement pump or variable frequency inverter, if the speed setting during holing pressure stages is high (>3%), the energy saving is reduced.

Conclusion

There are many parameters to set in multiple-stage injection and holding pressure. If there is no theoretical basis, using wide guesses to find the optimal setting is a long process. That injection is speed controlled and packing and holing pressure are pressure controlled reduces the number of parameter settings by half. Such settings are needed in closed-loop injection. Once packing is understood, one knows how to avoid flashing. Once the importance of transition point is understood, one could set for a stable injection. Once the purpose of holding pressure is understood, sink marks could be avoided. Of course, it helps to do an energy-saving setting too.

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