THE EFFECT OF THE SWITCHOVER ON THE INJECTION MOULDING PROCESS AND CAVITY PRESSURE

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Switchover is the most important moment in the injection moulding of the product. A difference of few hundredths of a second is able to change the built-up pressure value in cavity by several hundred bar, which greatly effects the quality of the manufactured products.

1. INTRODUCTION

It has been common knowledge for a long time, every professional in the field of injection moulding heard about, but almost nobody is using the pressure switchover in Hungary. The switchover is the most important part of the injection moulding of the products. Even a difference of few hundredths of a second is able to change the built-up cavity pressure value by several hundred bar, which naturally greatly affects the quality of the manufactured products. In our article we will show through practical examples the switchover's effect on the cavity pressure and machine parameters.

During the setting of the injection moulding machines the parameters influencing the moulding have the biggest effect on the product quality. The most important of these are: injection rate profile, switching point, holding pressure profile, holding time, temperature profile of the cylinder and hot runner, back pressure, screw rotation, and mould temperature. The correct combination of the parameters is enough to describe the entire process. The injection moulding can change from cycle to cycle depending on material, environmental conditions, and repeatability of the injection moulding machine, which can lead to variable product quality.

The first phase of the injection moulding is the filling, during that the material flows in the cavity. During the flow, the cavity pressure is usually around several hundred bar, so in this phase there is no flash, or if there is, it is probably due the misalignment of the mould elements [1]. In the moment of 100% filling the flow stops and the compression of the material starts. The polymer according to their type can be compressed by even 3...10% in melt condition [2]. In packing phase there is a momentary high pressure, and the cavity pressure increases steeply. The flash on the product usually builds in this phase, as the melt touched the wall of the mould, the outer shell did not solidify to a sufficient wall thickness. In the packing phase the fast-building cavity pressure can cause the plates to open a few micrometer, which increases the possibility of flash. The compression is a very interesting phase because depending on the settings it can built up by either injection or holding phase. The holding and cooling phases follow the compression. The whole injection moulding process was demonstrated before [4].

Since the flash is a very common problem, in the industrial practice the method of early switchover is used. This means that the filling of the product is finished in the holding phase, so the product is "only" filled up to 90-95% in the injection phase [4]. The result of this is that the end of filling, the built up and the maximum of the compression pressure shift in time and scatter, while the machine parameters (switching pressure, injection time) will stay on approximately constant value. If grind is used and their amount fluctuates, the time of drying or the duration of stay after the drying, the quality of the arriving material changes, which can greatly influence the cavity pressure curve, a material structure, therefore the quality of the product too [5]. The feeding parameters also strongly affect the conditions of the injection moulding, but this is also often underestimated. If the cavity pressure could be stabilized, the product quality can be controlled more precisely. With the cavity pressure measurement method, we can know more about the processes in the mould, so we can control them better, seemingly random faults will not appear, then disappear.

The results of the research from Prof Nick Schot and his partners show that the less precise injection moulding machines are able to manufacture accurate products, if they are operating with method of cavity pressure switchover [5,6]. According to the publication in 2001, the average age of the injection moulding machines used in the USA is more than 10 years, so with the technology of switchover by pressure makes possible to keep these machines in production.

2. USED MATERIALS, EQUIPMENT

The measurements were performed at the BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS, DEPARTMENT OF POLYMER ENGINEERING, using an ENGEL Victory 60 (330/60 Tech) type injection moulding machine with screw diameter of 35mm. The machine offers the option to save the different parameters of the cycles on an external data carrier, and to compare this data to the data measured in the cavity. For the measurement, instrumented specimen mould and Cavity Eye pressure measuring system are used. Along the flow path at 5 different measurement points we could examine the pressure, while using pressure switchover. During the examination we used the sensor near the end of flow path for the switchover tests. The pressure was measured through a standard ejector pin with 3 mm diameter. The product, the leftover of the canal, and the position of the pin used for the pressure measurement are shown on figure 1. For the tests Ineos PP 100-GA12 type PP polymer was used.

3. EXPERIMENT

SWITCHOVER ACCORDING TO PATH AND CAVITY PRESSURE

During injection moulding the goal is to fill out the cavity as fast as possible, what the compression (controlled cavity pressure built up) follows. The filling and packing are not the same as the injection and holding pressure, so the machine operator has to determine what task the injection and holding phase should do. The importance of the switchover between the injection and holding phase is critical in terms of product quality, and short- and long-term repeatability.

In the injection phase the filling of the cavity is speed controlled. In holding phase the screw movements can be described by pressure controlled parameters. In both cases there is an option to use profiles. The main reason for speed and pressure profiling is quality, but cannot be forgotten that with this the repeatability of machine and the stability of the production can be greatly increased. During our experiments we examined the effects of the screw speed and speed profile, and the switchover on the process capability.

1. Figure: Injection moulding specimen and channel remainder

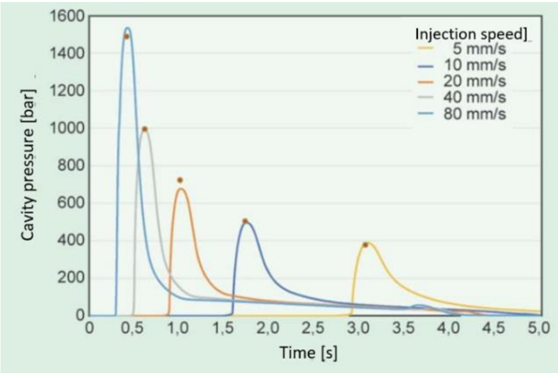
When setting the injection moulding machine, it is not enough to watch "only" the product quality, but it should also be checked if the machine is able to precisely repeat the set parameters. If the machine is not able to achieve the set parameter combination, then in long term it will result in a lot of hidden production failure, as the operator lost control over the process. Important to know how the given machine can achieve the set technology, how much inertia, response time it has, so the first measurements focused on the examination of these. During the first experiment a stable technology (parameter combination) was determined for the production of the specimen, and we examined the screw movements and the pressure built-up during the process in function of injection rate.

1. Table: Injection moulding parameters

Parameter	Value
Material temperature (T_3; T_2; T_1; T_g) [°C]	235; 230; 220; 50;
Mould temperature [°C]	50
Injection speed [mm/s]	5; 10; 20; 40; 80
Dose [mm]	25
Switching point [bar], [mm]	300; 500; 8,5
Holding pressure [bar]	

The important parameters for testing are collected in table 1. The measurements were performed with switchover according to both path and pressure, and speed profiling was not used.

Examining figure 2 the cavity pressure curves of the different injection speed are well separated. Increasing the injection speed, the filling time decreases. When using cavity pressure switchover we have to be aware that the cavity pressure peak will always exceed the set switchover pressure, which will appear in the measurement results at increasing speed. This comes partly from the delay of the electronical system (<0,01 sec) and more so from the inertia of the mechanical elements (hydraulic cylinder, screw etc). In small injection speed interval, the overshot of the cavity pressure is relatively smaller, but increases greatly by increased speed. Examining the steepness of the rising section of the curve, it can be seen that the compression speed is increasing. The faster the compression speed, the less time the system has for slowing down, so for the switchover. So the screw and the whole system overflows after the switchover signal, therefore extra pressure will form in the cavity. Figure 2 shows the cavity pressure peak with the path switchover. The position of the switchover is not changed. It comes from the comparison that there is no significant difference between the switchover according to the path and cavity pressure at unprofiled injection speed.



2. Figure: Change of maximum cavity pressure in case of different injection speeds

Important to mention that using switchover by pressure, the built up of the cavity pressure, so the compression process, happens in the injection phase. In the industry this called late switchover.

The measurements were performed at switching cavity pressure of 300 and 500 bar. The cavity pressure peak and switching pressure difference are summarised in figure 3.

3. Figure: Pressure increase from overshot at different switching pressures

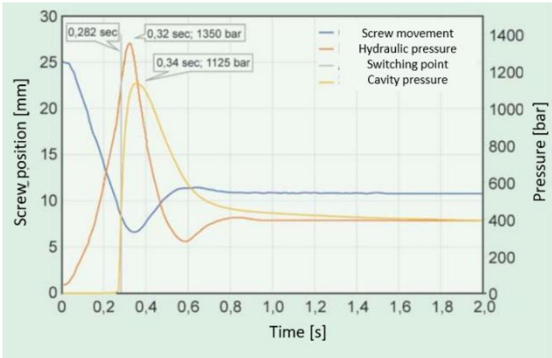
It is visible that the calculated lines run almost parallel, and the difference is constant 200 bar. This means that the cavity pressure increases so quickly in the compression phase that it does not matter if the switchover happens at 300 bar or 500 bar. Only at 10 mm/s injection speed can be some differences experienced.

If we fit a linear trendline on the measured values, then the inertia and response time of the machine can be determined from the steepness of the line. In this case it is approximately 15bar/(mm/s), so 1 mm/s increase of injection speed results in 15 bar cavity pressure increase at identical settings.

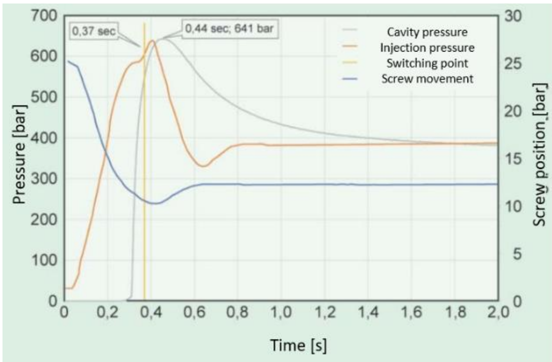
Comparing one- and two-step injection moulding profile

The simplest way to avoid the phenomenon of overshot is the profiling of injection speed, which means that a moment before switchover we start to slow down the screw cylinder, therefore increasing the built-up time of the cavity pressure and decreasing the kinetic inertia of the screw. The technology used for the moulding of the previously mentioned specimen was completed with holding pressure, its value was 400 bar and its time 3 s. We intentionally chose lower holding pressure than the cavity pressure maximum. Figure 4 shows the cavity pressure determined with one-step speed, hydraulic pressure, and screw position curves. On figure 5, the curves determined with two-step setting are displayed.

The results show well that when using one profile the maximum cavity pressure is 1125 bar instead of the set 500 bar. This is more than 600 bar difference compared to the set value. The injection time is 0,28 s but the built-up time of the cavity pressure is 0,34 second. So, the rection time of the machine 0,06…0,07 second at the given set, which primarily comes from the kinetic inertia of the screw. Examining the screw movement, it is prominent that in the holding phase the screw moves back around 5 mm. This phenomenon can be explained primarily by the compressibility of the material. Since the injection speed is constant, the required pressure to overcome the flow resistance (viscosity) and the compression pressure form a resultant hydraulic pressure peak.



4. Figure: Analysis of one-step, constant speed injection profile



5. Figure: Analysis of two-step injection profile

Figure 5 displays the effect of the two-step injection profile on the pressure conditions and screw movement. Until the 90% filling of the cavity high speed is used (60 mm/s), then the screw movement is slowed down on 10 mm/s in the compression phase. For easier comparison, the measured values are summarised in table 2.

2. Table: Values determined with one- and two-step injection speed

Parameter	Constant injection speed	Two-step injection profile
Injection time	0,282 s	0,37 s
Cavity pressure peak time	0,34 s	0,44 s
Cavity pressure peak	1125 bar	641 bar
Hydraulic pressure peak	1350 bar	632 bar
Screw backswing	5 mm	1 mm

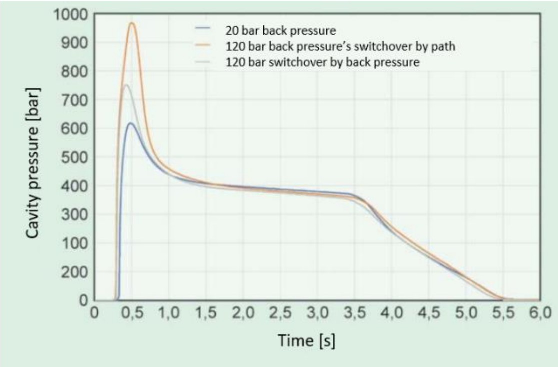
Thanks to the profiling, the injection time and compression pressure peak built up 0,1 s later in the cavity. As the result of slowing down the cavity pressure peak is reduced to almost half, to the value of 640 bar. More interesting that at the two-step setting the hydraulic and cavity pressure is almost the same, which means that the in the low-speed section the pressure was used to build up the cavity pressure, not to overcome the flow resistance. If we analyse the movement of the screw, we can see the deceleration phase and its start at around 0,2 second. The rebound of the screw measured in the moment of the switchover decreased to approximately 1 mm, which further increases the stability of the process, since there is no uncontrolled swinging in the system unnecessary, which would not be beneficial from both rheological and control technic point of view.

Based on the measuring results it can be stated that in case of pressure switchover it is recommended to choose the two-step injection speed profile as the compression starts in the injection phase. Compression with high speed is not beneficial for the stability and repeatability of the process.

THE EFFECT OF BACK PRESSURE ON THE CAVITY PRESSURE

In theory the back pressure should not affect the cavity pressure. But in practice in almost every case decompression is used, which is the little back draw of the screw after dosing. The decompression reduces the pressure in the dose but not in the thread ditch of the screw. As result the material flows through the flow restrictor into the space before the screw, therefore increasing the real volume of the dose.

The effect of the change in back pressure was examined in cases of path and cavity pressure switchover. The rev used for dosing was set to 60% in every measurement, which means approximately 150 /min. The injection speed profile was determined in two steps with similar parameters as before.



6. Figure: The effect of back pressure on cavity pressure

At the set original technology, the maximum pressure in the cavity was around 600 bar with the decompression path of 5 mm at back pressure of 20 bar (figure 6). The back pressure was increased to 120 bar and the measurement were performed with switchover by both path and pressure. In case of switchover by path, the maximum pressure increased to 980 bar, which means 63% increase. At the switchover by pressure the set switching pressure was 500 bar, the maximum built-up pressure in the cavity stayed under 750 bar. This is only 25% increase compared to the 63% difference. So, with the switchover pressure and with the use of the two-step injection speed, the maximum value of the cavity pressure can be more stable even at changing back pressure and unstable dose size.

4. CONCLUSION

In our paper we studied the effect of the switchover on the process, which is maybe the most important injection moulding parameter. For the measurements hydraulic injection moulding machine was used. The dosing path was relatively small compared to the screw diameter, so we were able to describe the response time of the machine too.

In the moment of switchover, the hydraulic system starts to reduce the outer pressure, and the screw starts to slow down. In the deceleration section due the kinetic energy of the screw and due inertia the cavity pressure is increasing but the hydraulic pressure is decreasing. As a result, the cavity pressure can often surpass the outer pressure and the set values. During our measurement we validated that in case of a one-step high speed filling the inner pressure switchover does not have significant advantage. Using the two-step injection profile with fast filling, then before reaching the full filling slow it down, can stabilize the production process. The switchover by cavity pressure can be a good choice for product from continuously changing grind (volume, properties) and in case of old, not very accurate hydraulic machines.

The switchover by cavity pressure has several practical advantages, as the mould cannot be overloaded in case of nozzle freezing, the insert breakage at start up and product reclosure from under-injection can be avoided.

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