Developments in multi-cavity hot-runner tooling for medical moulds

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Multi-cavity moulds with 16, 32, or more impressions, are a long-established method of manufacturing large production quantities of moulded medical device components. Such moulds are fed by hot runner systems, often with pneumatically operated valve gates. The use of valve gates as against hot tips improves the accuracy of the moulding as the polymer in the mould gate can be kept in a molten state until an exact preset time when the gate is closed. Despite this, controlling the accuracy of all the parts moulded in multi-cavity tools can be challenging, and various systems have been developed aimed at improving the process control.

Integral Closed-loop Control in the Mould

Sensor systems for injection moulding have been used for many years for monitoring cavity pressure & temperature, or injection pressure at the nozzle of the machine. These systems can be used for quality monitoring or to help in optimising the process set up. This type of system can also be used to initiate a switch over to holding pressure based on a preset level of mould cavity pressure.

Closed loop filling control of multi-cavity moulds within the mould itself, controlled and monitored by an external personal computer (PC) platform or laptop, is a more recent development. In this case, the position of the melt front flowing into each of the individual cavities in the mould is linked to the control of the polymer being injected at the gates of each specific cavity.

The pictures in Figures 1 and 2 show the temperature ramp due to the injection of melt across 32 mould cavities with the system switched off (Fig1) and with the system switched on (Fig 2). It can be seen from these two figures, how the control system brings the temperature profiles on filling close together for all the cavities, within a fraction of a second.

Temperature vs. time – control off

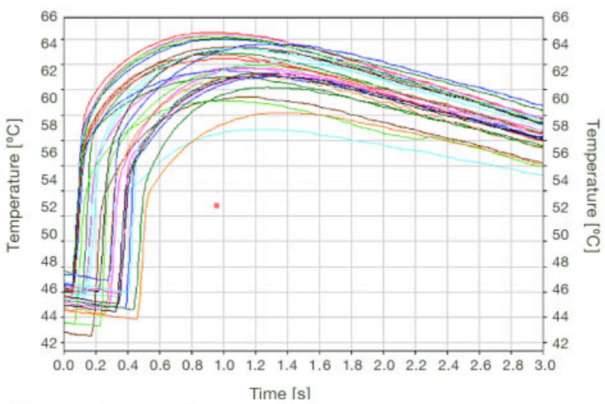

Fig1: Temperature increase across 32 cavities with system switched off.

Temperature vs. time – control on

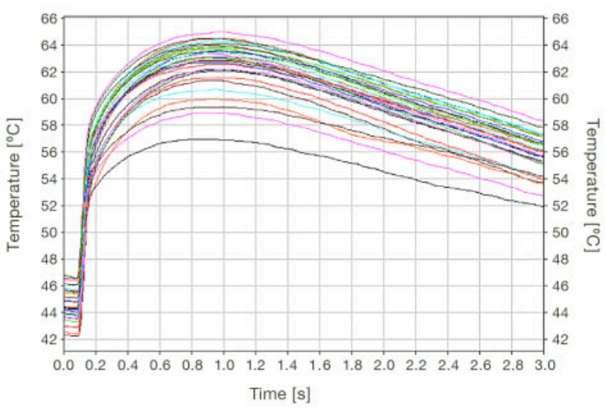

Fig 2: The same plots with the system switched on. Note the simultaneous temperature rise across all 32 cavities.

The system works by using a temperature sensor placed near to the end of fill in each mould cavity and linking this to the temperature control of the relevant hot runner tip. As the injected hot polymer melt reaches the sensor, the temperature recorded rapidly increases. The PC sees the temperature ramp start for each cavity and automatically tells the valve gate heat controller to increase or decrease the temperature of each valve gate. Changing the temperature of a valve gate changes the viscosity of the polymer melt at that point, fractionally changing the speed at which the polymer flows into the mould cavity. As the filling speed of each cavity is automatically adjusted, the melt fronts are trained to hit the sensors at exactly the same time.

Implementing this type of system on multi-cavity moulds allows the accuracy and repeatability of the moulding process to be dramatically improved. The charts in figures 3 and 4 show the thickness measured on the moulded parts near to the gate and at the end of flow for a medical component. The nominal thickness for both areas of the part is 0.8mm. By using the closed loop control system for the valve gates, the difference in thickness between these two points is dramatically reduced. The chart in fig 5 shows the difference in thickness for each cavity. The thickness variation has been reduced from between 22-54 microns to less than 18 microns, and in some cavities less than 5 microns.

A part moulded using this system is shown in figure 6. The position of the valve gate and sensor are indicated in the Moldflow simulation, which shows how the temperature sensor is located near the end of flow. In this case, the sensor is of diameter 1mm.

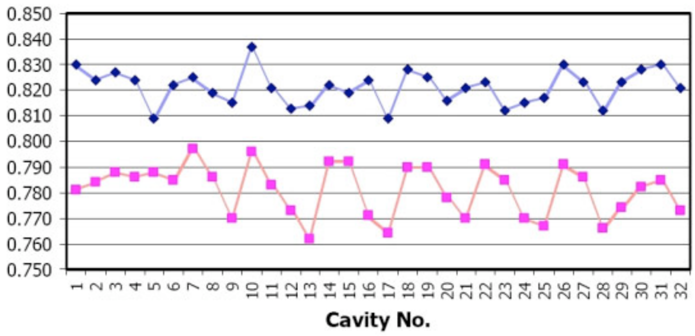

Fig 3: Thickness (mm) near the gate (blue) and at the end of flow (red), system off.

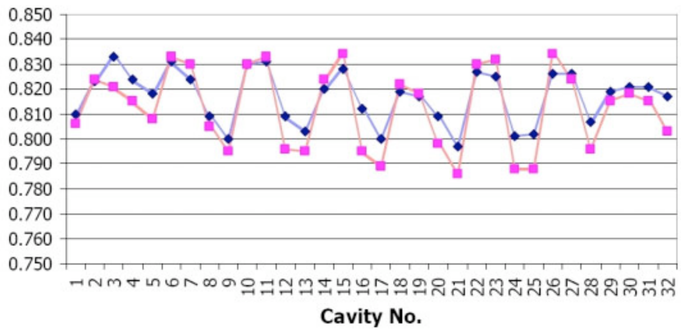

Fig 4: Thickness (mm) near the gate (blue) and at the end of flow (red), system on.

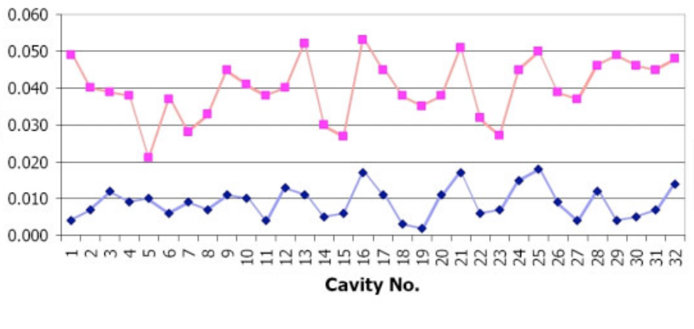

Fig 5: The difference between the gate area thickness and the end of flow thickness (mm) plotted per cavity with system off (red) and system on (blue).

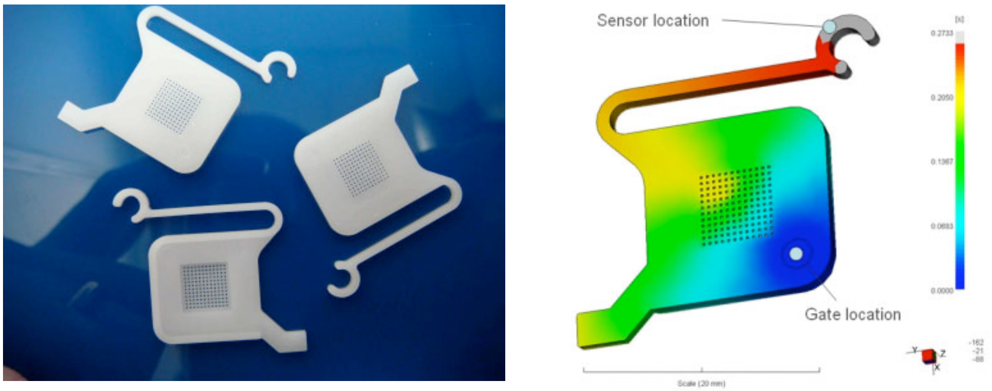

Fig 6: A component moulded using a system with integral closed-loop control in the mould, and the component design in Moldflow showing the valve gate and temperature sensor locations.

Servo-actuated valve gates and synchronised valve stems

The majority of valve gates are pneumatically actuated, with a smaller proportion being activated by hydraulic means in industries where cleanliness is not so critical, and large parts are moulded in hydraulically actuated moulds.

In the medical device industry, pneumatic systems are very popular because they are relatively clean, and can be simply integrated into a production system. Typically, they provide reliable actuation, and maintenance of the systems is relatively straightforward. They provide an effective valve gating technology for many medical device moulding applications. The limitations of pneumatically actuated valve gates are in the pressure available to operate the gates (which may necessitate the use of larger cylinders than desired resulting in larger valve gate spacing in the mould), and in the need for special attention to the system setup to avoid delays between valve gate pistons resulting in inconsistent cavity filling.

The recent development of electrically actuated valve gates overcomes the pressure and spacing limitations of pneumatic systems whilst maintaining a set up suitable for a cleanroom environment. There is no dust, debris, or oil involved as the electrical power is converted into mechanical movement through a servo motor, bearings and cams. Electrically actuated valve gates arguably provide the best features of pneumatic and hydraulic systems without the associated disadvantages. By using a servo motor to control the valves, the valve stem speed can be adjusted and high stem force can be delivered for good gate quality.

It is possible to precisely synchronise the movement of the valve stems by coupling them together in a plate in the mould. This eliminates the lag that is sometimes present in pneumatic systems, ensuring that each stem is in exactly the same position during opening and closing of the gates. Coupling the valve stems together in this way and using an electrical actuation system also allows the valve gates to be positioned very close together. For example, valve gate pitch dimensions as small as 18mm have been used.

Because it is sometimes necessary to individually shut down valve gates, the synchronised valve gates using plates are designed in such a way that the individual valve stems can be decoupled from the plates when needed. The systems are also designed with a safety feature allowing the stems to automatically decouple at a predeterimined force if any blockage occurs in the gate. The only specific instance where a synchronised system could not be used is where sequential injection is needed which would require individually actuated valves.

Improved balancing and thermal control of manifolds

The way in which hot runners for technically demanding parts are designed has changed over the last few years to provide better gate balancing, repeatability, and thermal control. Gate balancing and repeatability are particularly critical where small components are to be moulded in multi-cavity systems.

Some materials are particularly heat-sensitive or shear-sensitive and the design of the hot runner system is critical to how the process performs with such materials. Typically more heater zones are used and the hot runner is designed in such a way as to avoid hot spots and minimise the temperature deviation across the manifold. Manifolds can be designed to suit specific materials and shot volume / filling speed, so that the shear rate is not too high.

The overall aim of precise hot runner manifold design is to improve the process window available so that the process is more reliable and cost effective.

Conformal cooling for reduced cycle times

The principle of conformal cooling is to get the cooling water in the mould to conform as closely as possible to the shape of the mould cavity in order to reduce cooling time and provide more uniform temperature distribution and shrinkage. Take up of the technology has so far been limited although it has attracted a lot of interest.

Conformal cooling channels are created by one of three methods. The oldest is to use a stack-up of plates, held together by vacuum brazing, each of which contains individually milled cooling channels. More recent methods are the use of laser sintering to build up a solid steel 3-dimensional channel design by fusing together steel powder, or the use of alloys with high thermal conductivity that are sintered by diffusion bonding into cavities previously introduced into the mould insert.

By any of these methods, cooling channel designs are possible that could not be manufactured by more conventional means. This facilitates more effective cooling including more options for independently controlled cooling channels running close together. This type of cooling system can potentially have benefits for medical moulders in terms of reduced cycle times.

Ongoing development

Hot runner processes and multi cavity moulding would be considered by many to be mature technologies. However, developments in specific areas are continuing to enable advances in terms of quality control, repeatability, and reduced cycle times.

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