THE PROMISE AND PRACTICE OF VALVE GATE SEQUENCING

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Abstract

Injection molders commonly use valve gates to reduce cycle times, control gate vestiges and limit gate discharge. Here follow some real-world examples of sequencing valve gates for balance, pressure control (particularly in family molds), reduction of knit lines, and minimization of clamp tonnage.

In-cavity pressure sensing and DECOUPLED MOLDING℠ [1] techniques are becoming more common. When combined with control of valve gates these tools help create more robust processes or even processes that would otherwise be impossible. This in turn has reduced scrap, material used and cycle time on a variety of tools.

To put these techniques into practice the molder needs pay close attention to the details required for success.

Shortcomings in Non-Gated Hot Runners

Variation

Injection molds with hot runner systems eliminate runners and the need to dispose of or reprocess them. But without valve gate sequencing they create a new kind of variation not found in cold runner molds. The balance of flow in hot runners tends to fluctuate making the fill sequence vary from shot to shot. For example, cavity 1 may fill first on one shot, then cavity 4 fills first on the next shot, then cavity 8 and so on.

The non-Newtonian flow characteristic of polymers is at the heart of this variation. At the start of filling flow can begin first at any one tip. Once flow starts the shear thinning reduces resistance to flow. Thus the flow favors one path until the dynamic pressure is high enough to force flow in the other paths. Cycling of tip temperature control loops, changes in skinning of gates, non-homogeneous melt, runner residence time from the previous shot and build-up and release of material cause different gates to flow first on successive shots.

The resulting in-cavity variation is known as "multi-process disease"[2]. The net effect is often low process capability and poor part quality.

Imbalance

Hot runner molds commonly have consistent cavity imbalance as well as shot-to-shot variation: one set of cavities fills regularly before another set. Molders often attempt to thermally balance the molds, adjusting zone temperatures until all cavities fill simultaneously. Though this technique does improve flow balance it creates dissimilar melt temperatures between cavities.

Many family molds are naturally imbalanced because the volumes of the cavities are different. This causes the different sized cavities to fill at different times. This fill imbalance is usually too severe to allow thermal balancing of the mold.

Using Valve Gates to Improve Performance

The following examples show some uses of valve gates and cavity pressure sensing to reduce variation and improve balance in hot runner and family molds. These processes are running today using "eDART" ™ based valve gate sequence control from RJG Inc. or Incoe Corp.

This paper covers the following examples:

- Independent Cavity Sequencing: valves open and close at different times and all cavities fill simultaneously.
- Alternate Cavity Sequencing: one set of cavities fills and packs first, the gates close and then another set fills and packs.
- Sequential Gate Control: valve gates open in a long-flow cavity so that filling begins after the flow front has passed each gate, eliminating weld lines and controlling packing pressures.

Each example is accompanied by a figure that describes the process. The top portion of each figure plots volume and cavity or injection pressure curves over the filling and packing portion of the cycle. The x-axis represents time and the y-axis is pressure or volume.

The volumes (magenta curves) are shown as increasing after passing the decompress point (zero). This is because volume represents the quantity of material injected into the mold rather than a distance from screw bottom.

The traces at the lower edge of the graph show the opening of the valve gates. When a trace is high the gate is open; low indicates closed. The dark blue trace is the control signal that transfers the machine from velocity control (boost) to pressure control (hold) when all gates are closed. Since the gates hold the material in there is

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[1] DECOUPLED MOLDING℠ AS EASY AS 1 – 2 – 3 ," ANTEC Proceedings, May, 1994

[2] "Multi Process Disease in Hot Runner Molds" Author Rod Groleau: Moldmaking Technology, June, 2005

often no need for a hold pressure or time so the screw recovery starts directly.

The images at the bottom of each graph represent a view inside the cavities as each event occurs at various times along the graph.

Independent Cavity Sequencing

The term “Independent” implies that each cavity has its own controlled valve gate (or gates) and, for best results, cavity pressure sensors as well. The sensors are commonly located in areas of influence closest to sensitive features on the part. The controller closes the gates at a set pressure at a selected sensor. See figure 1 for the example, as applied to a family mold.

Open at Volume Levels for Balanced Fill

Use this technique to balance the flow in family molds and as an alternative to thermal balancing of imbalanced hot runner molds. The objective is to cause all cavities to finish filling volumetrically at the same time. The valve gates open in sequence with the smaller volume cavities opening last.

We use volumetric screw position (cubic cm) instead of stroke (cm) so that the tool can be transferred to presses with different barrel sizes and still operate with the same settings. The bottom portion of figure 1 illustrates how each cavity in a three cavity family tool begins filling at different volumes. Cavity #C (“center”) is about three times the volume of cavities #LS and #RS (left and right sides).

At 0.0 cc cavity #C opens (1) fills partially. Then cavity #RS opens at 16 cc (2) followed by #LS at 19 cc (3). Thus all cavities fill at nearly the same time at (4).

The sudden change in the slope of the volume curve is the change in speed from the fast filling speed to a slow packing speed. Because of the compressibility of the material in the runner system we set the machine to slow down (at a position) before the cavities are completely filled. This lets the melt decompress as packing begins which in turn allows much faster filling. Faster filling reduces sensitivity to speed changes. This is the essence of the fill portion of a DECOUPLED MOLDING℠ molding process.

We have found that using volume to open the valves has been reasonably robust in practice. Changes in material viscosity (due to lot changes or other factors) have had a negligible effect on the fill balance. Nevertheless each mold should be tested with materials of different viscosity to demonstrate adequate stability in fill balance.

While this example shows a family tool the same technique can be used for a tool that makes nominally all the same parts. If such a tool is perfectly balanced then all the gates could be set to open simultaneously. If not then small adjustments may be made to the gate open volumes as an alternative to thermal balancing.

Close at Cavity Sensor Levels for Pressure Control

Even though multiple cavities may have balanced filling (i.e. fill at the same time), they may not pack to the same pressure. Using valve gates to close each cavity at a specified cavity pressure can correct this, ensuring consistent packing of all cavities.

The remainder of Figure 1 illustrates the pack phase of the process. Here, cavities #LS and RS reach their cavity pressure set points first so the controller closes them (5). Cavity #C then reaches its set pressure last and the controller closes it (6). Once the last cavity is closed, the controller signals the machine to transfer out of velocity to pressure. Since the valve gates hold the pressure in the cavities the machine skips the “hold” phase and starts screw run directly.

This method requires a constant, low velocity pack stage. Packing at a low velocity controls the peak cavity pressure, pack rates and static pressure loss more reliably than using fast speeds. In turn this ensures more consistent dimensions.

Items to Notice in Independent Cavity Sequencing

Speed Control: As each cavity closes independently and the machine’s speed remains the same the rate of pack on the remaining open cavities will increase.

For example, after cavities #LS and #RS close all plastic flows into one cavity – cavity #C. While this has a minor impact in this 3-cavity mold, higher cavitation molds can suffer from excessive flow rates after most cavities have closed. Future controls may provide feedback to the press to adjust speed as cavities are closed. However, most presses do not currently support this feature.

Pin Pack: Notice on figure 1 how the pressure rises suddenly just after the gate for each cavity closes. As the gate pin moves forward it pushes more material into the cavity near the gate. The sensor near the gate sees the pressure rise but the sensor at the end of the cavity does not (due to compressibility).

Whether this is a “problem” or not depends on the part. Depending on how cool the part is at the time and how much material is packed in the pin may create a local area of increased stress.

Note that the pin packing phenomenon is common to all valve gate applications. The process in figure 1 shows a pronounced example of it.

Alternate Cavity Sequencing

The mold used in Figure 1 has reasonably similar flow restrictions and wall thicknesses. Consider a family tool in which some parts are many times thicker than others or have thin and thick wall sections at different distances down the flow path. In this case the material may “stall” while trying to fill one cavity if the flow front reaches a position in another cavity that reduces the resistance.

The Alternate Cavity method provides more independent control of the filling of dissimilar cavities and may help to reduce clamp tonnage requirements. Here the controller opens one cavity (or set of cavities), fills and packs, closes the first gate (or gates) and opens another set for a second fill and pack. This is illustrated in Figure 2.

Because the material in the first set of cavities is shrinking after the gates are closed the force required to keep the clamp closed may be reduced. So the Alternate Cavity method works for problematic family parts or to reduce clamp tonnage.

Alternate Cavity Process Steps

Figure 2 illustrates a family mold with two similar cavities (#1 and #3) and one that requires much more material (#2). In this example, the two similar cavities fill simultaneously, followed by the larger cavity filling alone. The velocity settings on the press are profiled to provide a fast fill and slow pack stage for each set of cavities. All of the speed changes are made by the machine at specific screw positions set on the machine controller. As in Independent Cavity Sequencing the gate sequence control closes each gate a set pressure level at each cavity pressure sensor.

In Figure 2 cavities #1 and #3 open at specific volumes (steps 1 and 2) in order to correct a slight imbalance between them. They fill quickly to a fixed position on the press whereupon the press slows to a controlled velocity pack. At step (3) cavity #1 reaches its closure level followed by cavity #3 at step (4). Once both cavity #1 and #3 close cavity #2 opens. Since #3 closes later it becomes the trigger that opens gate #2 (step 4).

The machine profile is set to speed up at a position for the filling of cavity #2. This must be set late enough to ensure that both cavities #1 and #3 are closed under low velocity before initiating high velocity fill for cavity #2. Being controlled by cavity pressure, the closure time of gates #1 and #3 can move right or left in time with changes in material, check ring leakage or other factors.

After the gap distance the machine speeds up to fill cavity #2 (5). At the next profile position the machine slows down to pack cavity #2 until it reaches its set pressure. Then the controller closes gate #2.

Since the controller has now closed all gates it signals the machine to transfer out of boost (velocity) into pressure. Since no hold pressure is needed the screw recovery starts as soon as practical.

Items to Notice in Alternate Cavity Sequencing

Speed Control: It is probably obvious that synchronizing the fill and pack speeds in the cavity with the proper positions on the machine can be daunting. The Alternate Cavity method is another that can benefit greatly from speed feedback from the gate sequence control to the machine.

Extra Large Cushion on First Cavities: When cavities #1 and #3 have completed packing and their gates close there is still something more than 1/3 of the entire shot volume ahead of the screw. Think of this as a very large cushion. In some molds this excess cushion can reduce the ability to control pack flow in the early cavities because of the large volume of compressible melt ahead of the screw.

Differences in Cooling Time: Another fact that can be observed from the graph is that cavities #1 and #3 get much more time to cool than does cavity #2. This may or may not be significant to the quality of those parts.

Importance of Backup Control on Volume:

In the event that the first cavities to fill (cavities #1 and #3 in Figure 2) have not closed by the time the press transfers to the next high velocity stage, there is a serious risk of over-packing and damaging the mold. Therefore it is imperative that the controller also be set to close the gates on the first cavities (and thereby open the gate on the remaining cavities) at a shot volume that matches the speed-up position on the machine. This is a backup that protects the first cavities from being over packed on high speed fill.

Clamp Force Balancing:

Depending on the mold configuration the filling and packing of one side of the mold before another can cause the mold to “rock” open as pressure builds in the first cavities. Where possible, it is best to fill cavities in a manner that balances opening forces on the mold.

The above explanation notwithstanding, we have found much less mold deflection across the tool than we expected when the filling and packing cavities were not balanced across the center line.

Sufficient Boost Time: In one case we found a machine that had an inherent limit on boost (speed control) time of 20 seconds. Since the alternate process took longer to complete in sections we ran out of time to continue speed control before the second set of cavities was completed. Ensure that the machine does not have an arbitrary limit on boost (velocity control) time.

Very Slow Controlled Pack: In the alternate method you will be packing one or more cavities individually. Thus the required pack speed on the press could be quite slow. Some presses do not have good speed control at very slow speeds.

Staged Process Adjustments: In an alternate cavity control scheme you must consider how changes in the processes of the first cavities that fill affect the following cavities. For example, if you raise the pressure set point to pack the first cavity more then the machine speeds for the later cavities may need to be shifted down. This is because it will take longer (more volume of material) to reach the new pressure level.

Sequential Gate Control

This is the process used for long parts where the aspect ratio is so high that the part cannot be filled using one gate alone. With multiple gates in a single cavity opening all gates at the same time will inevitably produce knit (or “weld”) lines as the flow fronts from each cavity contact each other.

Figure 3 shows how Sequential Gate Control of a long part can prevent knit lines and provide better packing control across the entire part. Filling begins at the central gate (#1) only. As the flow front passes the sensor at each gate downstream, the sensor detects the presence of the flow front, causing that controller to open the gate. Once the cavity is nearly volumetrically full the machine slows down to pack the cavity at low velocity. As the cavity is packed the controller closes each valve gate when its corresponding sensor reaches a set cavity pressure. When the controller closes the last gate it transfers the machine and screw recovery begins

Items to Notice in Sequential Gate Control

Sub-gate Back Fill: Figure 3 shows the gates injecting directly into the part. In some molds the gate tip injects into a sub or cashew gate which then is gated into the part. If the flow front passes by the gate and the sub-gate is not already filled then flow from the cavity can go out into the sub-gate and prevent good filling. Some have used multiple openings and closings to pre-fill the sub-gate. A better option may be to place the flow front detecting sensor slightly upstream. Then the controller can detect pressure and open the gate in time to give the sub-gate a chance to fill before the flow front arrives.

Temperature Sensors to Open Gates: If the controller provides the option to open gates with temperature sensors instead of pressure this is also an option. The advantage of a temperature sensor is that it responds very dramatically even if there is only very little pressure in the mold. This is particularly useful in coining processes. However the rising temperature slope is so steep that to change the detect point the sensor may need to be moved rather than simply changing a temperature set point.

Practical Considerations and Details

Planning and Design Details

Sensor Placement: Proper sensor placement is crucial. It depends on part geometry and whether the sensor will be used exclusively for control or whether it will also be used to monitor for part defects. It is particularly important to place the sensor in an area of influence near to the most sensitive areas of the part.

Choice of Control Sensor: In a non valve-gated control system the only method of stopping packing is to stop the ram on the machine. We have always recommended that the control sensor be “upstream”, i.e. near the gate. This is because the material pressurized in the runner system can cause over packing if the press is transferred from pack to hold too late.

In a valve gated mold all of that runner energy is stopped by the closing of the gate. So the control sensor can be at the end of the cavity, middle or gate. The primary consideration in choosing the sensor is to place it in an area of influence near to the most sensitive areas of the part.

Ensure Sufficient Valve Force: The pressure in the valve cylinders must be sufficient to close the pin against pressure in the cavity. In the past some valve gate systems were used as simple leak stoppers and only needed to close after the end of injection when cavity and machine pressures were low. Use the following equation for air or hydraulic pressure required:

$$\text{Pressure Required} = \frac{\text{Pressure in Cavity x Gate Area}}{\text{Cylinder Area}} \quad (1)$$

The gate area is the area on the face of the shut off pin on which the cavity pressure will project.

Ensure Enough Flow at Pressure: The valve gate must close rapidly when commanded in order to prevent overshoot of cavity pressure set points. This requires sufficient air or oil flow into the cylinder. A good rule of thumb is to fully close the gate within 0.1 second as noted in the following equation.

$$\text{Flow Rate} = \frac{\text{Cylinder Displacement}}{\text{0.1 second}} \quad (2)$$

Use fast-acting control valves: Another source of delay can be the valves that control the flow to the gate cylinders.

Use an Independent Power Source: Valve gate users have sometimes tried to use spare machine hydraulic circuits (e.g. cores) or shop air to power the valve gates. This often leads to inconsistent control because of limited flow, limited pressure or changes in both over time. Whenever possible use an auxiliary power source to drive the gates.

Consider Viscous Drag: During fill the flow of material over the valve pin exerts a viscous force trying to close the pin. With very long pins the force pulling the valve closed during can exceed the force applied to the valve gate piston that is trying to hold the valve open.

Ensure Exhaust Flow: Commonly overlooked is the need to exhaust the air or hydraulic fluid from the back side of the valve piston as it is being moved by pressure on the other side. If the exit is restricted then pressure will build up and the valve may move slowly or not at all. If the same line sizes and lengths are used to push the valve open or closed and they are too restrictive then install a "quick exhaust" on each side at the mold.

Obtain quality seals on the valve pistons: If there is leakage around the seals it is seldom consistent. It will probably vary over the long term as well as shot to shot. This can introduce dramatic inconsistency in the opening and closing delay times of the gates and, by extension, the process and the parts. This becomes particularly frustrating in that the problems are often intermittent and can appear out of nowhere on a process that was once running perfectly.

Consider thermal design to prevent sticking: In controlled valve gate applications it is critical that the gates perform on command. For example if 8 gates are to open at the start and two of them stick then the other six cavities can get severely over-packed. One common cause of sticking gates is over-heating of the valve pins, especially during down times. Ensure that tolerances take thermal expansion into account.

Setup and Operating Details

Naming: Always choose names that represent the cavities and the sensors and gates in them. We recently had a mold damaged because the setup person thought that gate #4 was in cavity 2 when instead it was in cavity #1. Thus he was setting up control for that gate on a cavity in which the gate remained closed.

Plumbing and Wiring: If the control solenoids and relays are not a permanent part of the mold then label them carefully and insure they get reinstalled properly when the mold is set.

Start-up Testing: Always run a test of the control by checking that the correct gates open and close on the correct signals and that those gates are in the cavities that you expect them.

Leaking Valve Lines: This may seem obvious. Still, be sure that the connections from the solenoids to the valves are properly maintained. Leaking air will reduce flow and pressure so that the valves do not perform properly.

Seal Wear: Seals can wear out over time. Develop a proper maintenance schedule to replace them during preventative maintenance.

Control with time discouraged: Many early controllers used time to open and close the gates. We have found that time based control is much more inconsistent and should be avoided. While the machine speeds should be constant from shot to shot, this is not always true. Also if an operator adjusts a speed then the time settings require adjustment as well. Furthermore machines often vary considerably (shot to shot) in the time from the start of injection until material begins to move.

Cooling Sink Effect: In typical DECOUPLED MOLDING℠ processes without valve gates the controller transfers the machine to hold on a cavity pressure. During hold, a small amount of material continues to enter the part as the part shrinks until the gate seals.

With a valve gated tool the closing of the gate prevents any further addition of material. As a result, it can be necessary to pack to higher pressures than normal to ensure proper packing. Figure 4 illustrates this phenomenon. The dashed line is a typical pressure curve with hold pressure while the solid line is the pressure profile with the gate closed.

One way to add material is to re-open the gate at transfer and add hold pressure as in a normal decoupled process. However this is often not possible with the first set of cavities in an Alternate Sequence because the material near the gate has cooled so that no more can be added. In that case a controlled deceleration pack (instead of controlled velocity pack) can reduce sink in thick walled parts without causing flash. This can even further reduce the required clamp forces.

Valve Gate Shift Time: As discussed above the valve shift time must be considered. In actual operation this can cause some overshoot in cavity pressure (from the close setpoint). It can also cause discharge of material when switching from one gate to another (open on close).

The actual time is visible in the cavity pressure data by observing the valve gate close signal and then noting how much later the peak occurs. We have found that this is usually 0.1 to 0.15 seconds. If the cavity pressure is rising very quickly this can cause significant overshoot in pressure.

Instant Pressure Drop at End of Injection: We have discovered that some very quick electric molding machines are able to drop their injection pressure on transfer quicker than the valve gate can close. Usually the controller signals the machine to transfer out of the velocity phase at the closing of the last valve. But it takes some finite amount of time to move the valve pin. If the machine's pressure drops to zero before the pin can close the gate then some of the material in the cavity will discharge before the pin can close. Add a small amount of hold time and pressure to prevent this.

Pin Packing: As the gate closes and the valve pin engages the land the gate pin will push the material ahead of it into the cavity. This will increase cavity pressure as the new material compresses the un-cooled core of the part. The amount of pressure rise on closing increases as the pin packing pressure spike. The affect on the part must be determined case by case.

Variations on the Above Examples

??-? Re-open on hold, falling pressure control, controlled decelerating pack. Multi-cavity alternate, balance and multi cavity alternate sequential combined

Summary

These examples illustrate common practices using valve gate sequencing, cavity pressure and decoupled molding techniques. Consider them as only a beginning. Creative minds will find even more ways to create gate sequences to mold parts hitherto either difficult or even impossible.

However these new techniques require a focus on many details not present with single cavity or simple hot runner molds. It is perilous to ignore these details. Yet if they receive proper attention the results can be dramatic, creating new competitive advantages for technical molders.

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Keywords

Injection, Molding, Valve Gate, Sequence, Family, Knit Line, Balance

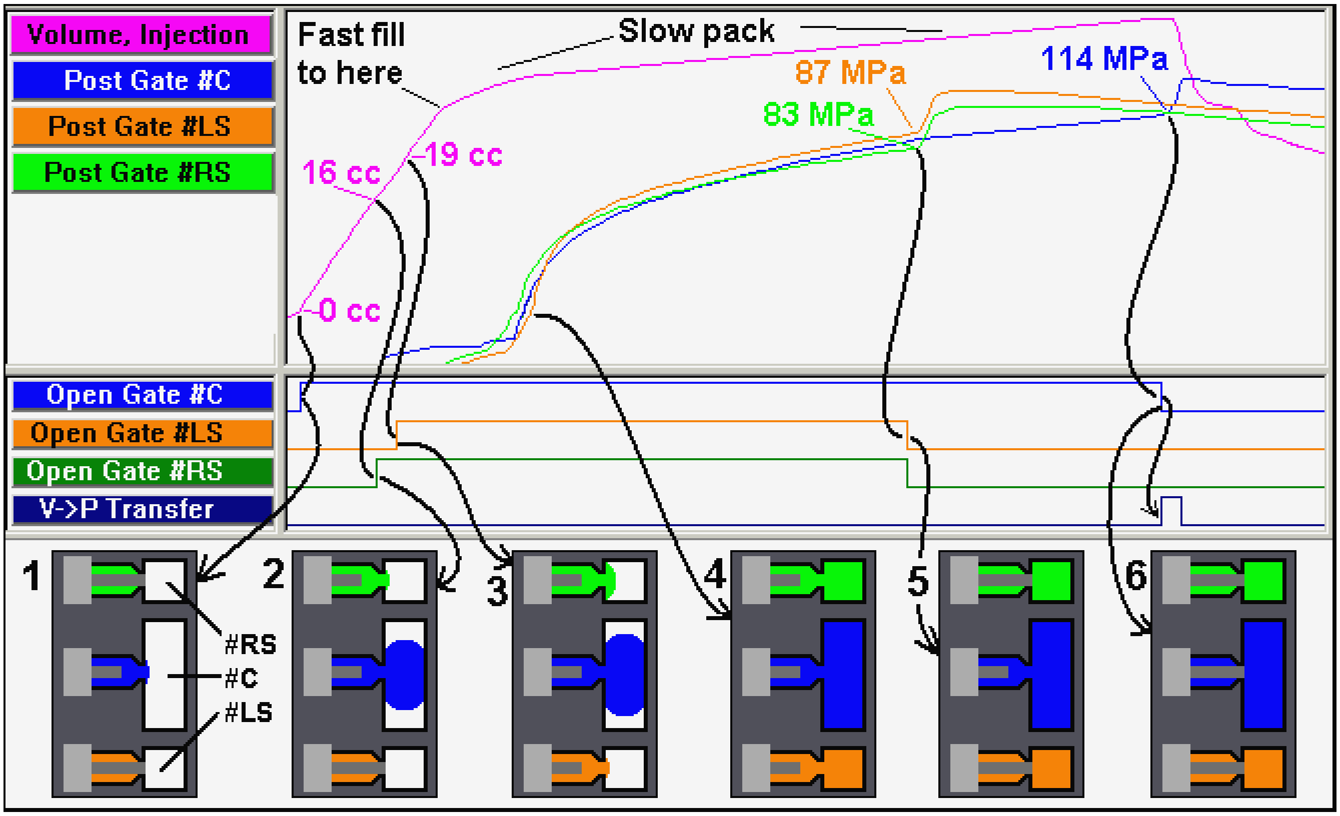

Figure 1: Independent Cavity Sequencing of Family Tool with Fill Balanced

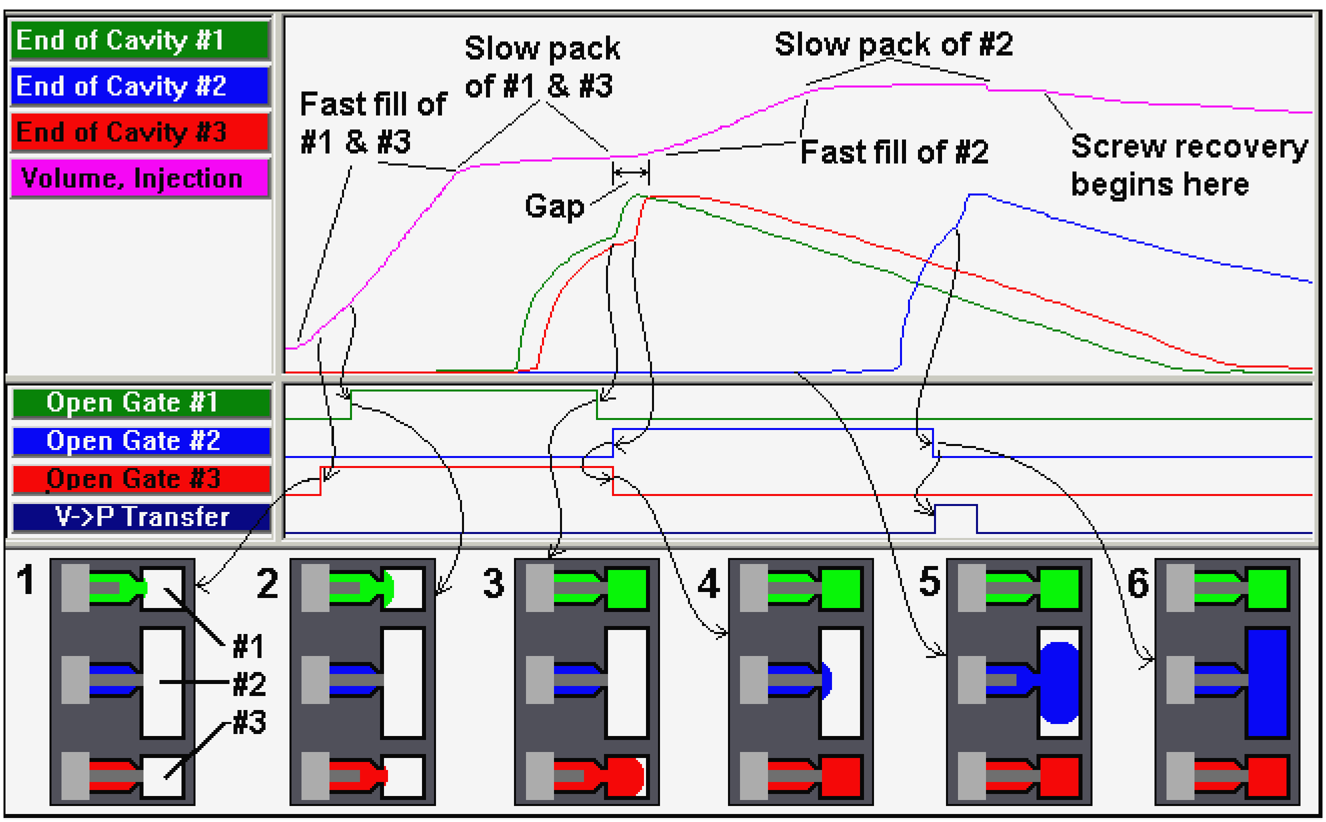

Figure 2: Alternate Cavity Sequencing of Family Tool with Fill Balanced

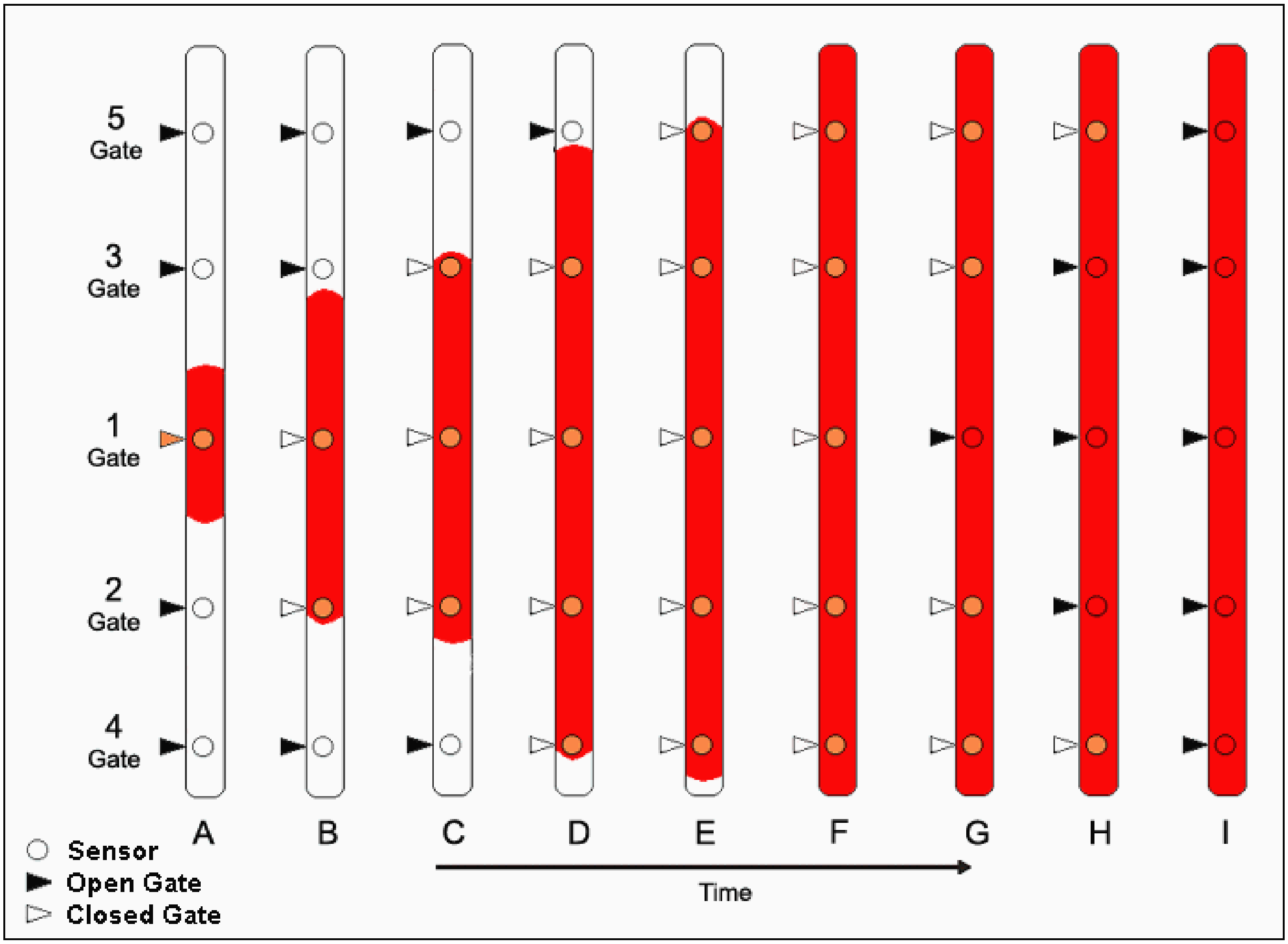

Figure 3: Sequential Gating in Long Part with Pressure Sensors

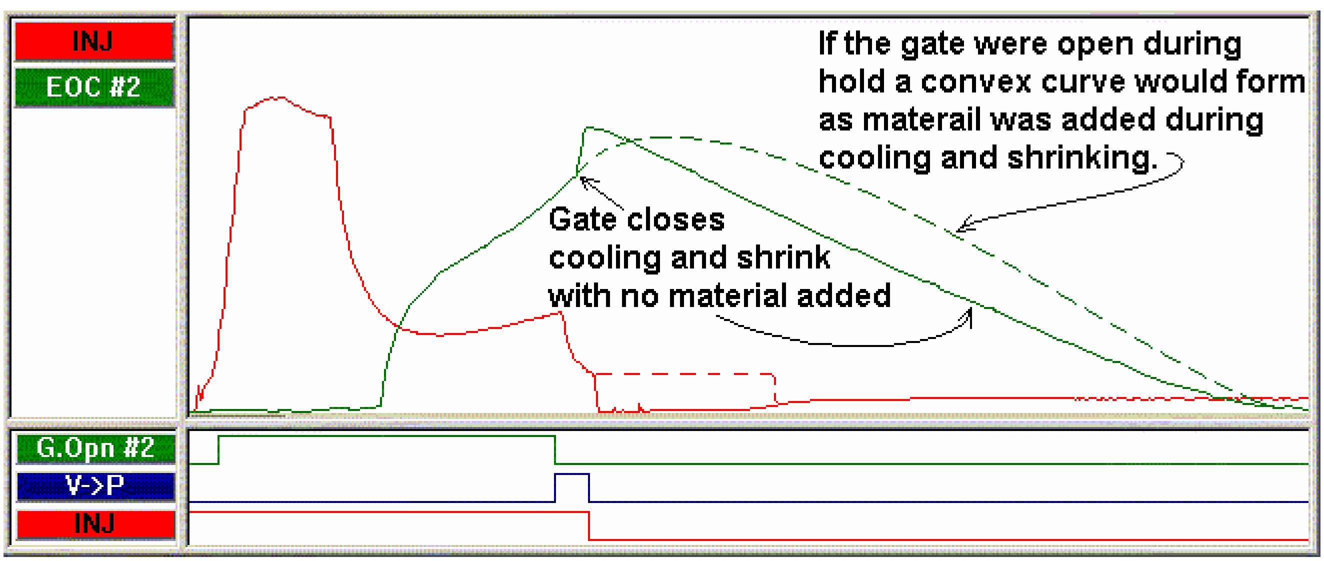

Figure 4: Comparison of Pressure Decrease During Cooling in Valve Gated and Cold Runner Molds