# SEQUENTIAL VALVE GATE CONTROL
# A NEW OPPORTUNITY FOR PRODUCTIVITY

As injection molders of the world are constantly squeezed for lower costs and higher quality parts, the use of new techniques and new technology are the keys to accomplishing these goals. In addition, the elimination of standard runner systems is always an opportunity to reduce costs because plastic is essentially a pass-through in injection molding, and the use of regrind is both costly and generally limited by customer specifications.

An opportunity exists to improve productivity, quality and valve gate technology in conjunction with hot runners. Hot runner molding is a proven technology which is generally utilized with simple, timed valve gates simultaneously opening and closing for all cavities, in order to achieve some measure of control. In this paper, we will explore other alternatives that actually control each flow front independently in a way that process consistency can approach that of a single cavity, single flow front process.

It is commonly accepted that optimum consistency can be achieved with a single cavity mold with one gate. This controls a process with only one flow front. Therefore, the repeatability of the speed and direction of flow in the mold is predetermined. In most cases, however, with any high volume application, the paradigm of single cavity, single flow is not one that is readily acceptable from a cost perspective. Multiple cavity molds with conventional runners generally can be tuned using balancing techniques to approximate the consistency of a single cavity mold on a cavity-to-cavity basis with the use of in-cavity control techniques and Decoupled III molding. However, in hot runner tools where there are multiple parallel flow paths of melted plastic in the manifold, fill inconsistencies over time can cause a number of problems such as short shots, flash, dimensional variations, warp, sink, stringing, and knit-line inconsistencies. All of these add up to problems with quality and consistency that oftentimes make these hot runner molds more problematic than the molds they replaced.

In addition, process costs are generally machine size-related. The ability to run more parts with presses of smaller tonnage is another opportunity to save. In this regard, stack mold technology has been utilized. This has increased the complexity of the balance problem and has significantly added to the complexity and size of the tools.

Another approach, which will be shown in this paper, is the alternate cavity valve gate control, which can utilize existing valve gated molds with a process to sequentially fill the cavities. There are basically three different types of valve gate control:

- Independent control
- Alternate control
- Sequential control

## INDEPENDENT VALVE GATE CONTROL

An independent valve gate control sequence is shown in Figure 1. When the process is initiated, all cavities start filling, generally at the start of injection when all valve gates are opened. Parts can be identical, as in the case of multi-cavity molds, or of different sizes or shapes as in a family mold.

In this situation, flow is allowed into each cavity and is initiated in parallel. Any flow imbalances are essentially disregarded. Each cavity is equipped with a cavity pressure sensor, generally in the first area of fill, to measure pressures and determine the amount of packing required in the mold. During the filling process, early cavities may become packed prior to other cavities being filled.

In this situation, a cavity pressure sensor with an individual set point for each cavity is used. When the pressure setting is reached the valve gate closes, allowing the material to be held in the cavity while cooling takes place. Cavity sensing and control is done independently so when all cavities are packed, injection pressure is terminated and the cycle is completed conventionally.

Another technique in individual valve gate control is the controlled discharge approach. In this situation, each cavity is packed above the cavity pressure set point and, once all cavity pressures have been reached, the injection pressure is terminated with the valve gates open. Once the cavity pressure drops back below the set point the valve gates are closed. This gives one the ability to highly pack a part and then control the effective cavity pressure by discharging. This is another tool for the molder to use, especially on center gated parts where over-packing near the gate causes warp. The independent valve gate control can be an effective tool to cure what is called "multi-process disease". When multi-

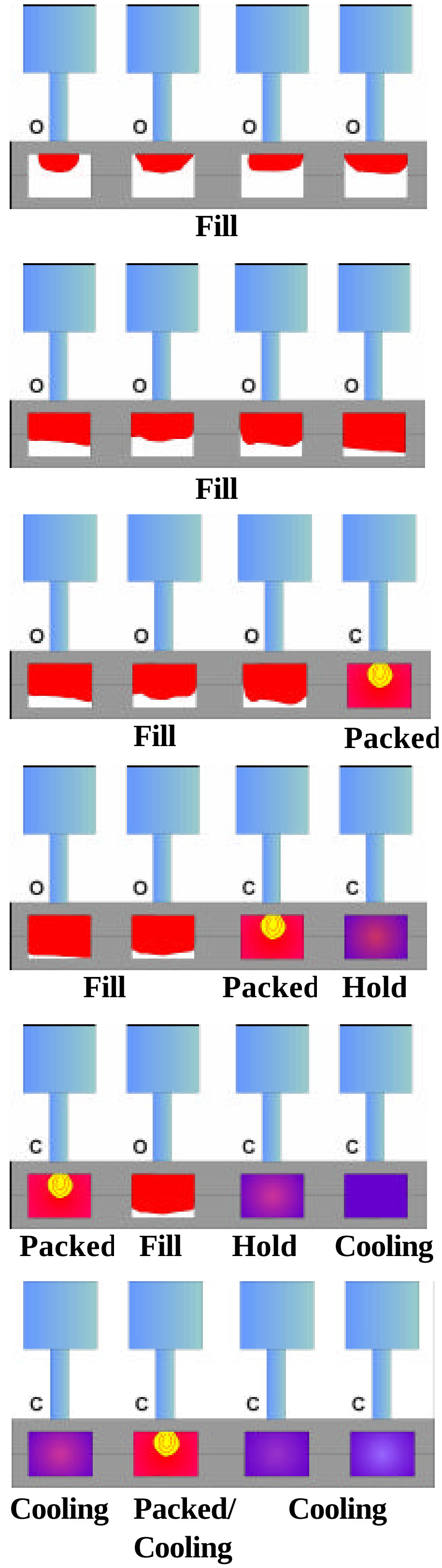


*Figure 1*

process disease is present in a mold, cavities are essentially independent processes because of the changes in the fill patterns between cavities over time.

Retrofitting existing molds requires a simple adaptation of the mold to allow hydraulic separation of each of the valve gate pistons, so that they can be controlled independently. Once this is done, the independent valve gate control can be easily implemented and there should be no cycle time penalties. However, any orientation effects where fill patterns could change could still cause some problems when utilizing this approach.

## ALTERNATE CAVITY VALVE GATE CONTROL

With alternate cavity valve gate control, the concept is to fill one cavity, pack it, close the valve, initiate filling of the next cavity and repeat the sequence until all cavities are filled. The sequence for the alternate cavity control is shown in Figure 2. Using alternate valve gate control, absolute control of flow speed, fill rate, packing and holding is optimized for each cavity. In addition, the parts with a projected area up to twice that normally used for a given clamp tonnage machine have been successfully filled and packed. Mitsubishi, who has a patent pending, has initiated this process. This can generally be used for large projected areas such as wheel covers, seat backs, bumper fascias, etc.

The sequence in Figure 2 shows the initial gate opening to start the filling process. When the part is 90% filled the injection rate is slowed down and the part is packed (using a lower velocity) to a cavity pressure set point in cavity one. When the pressure is reached, the valve

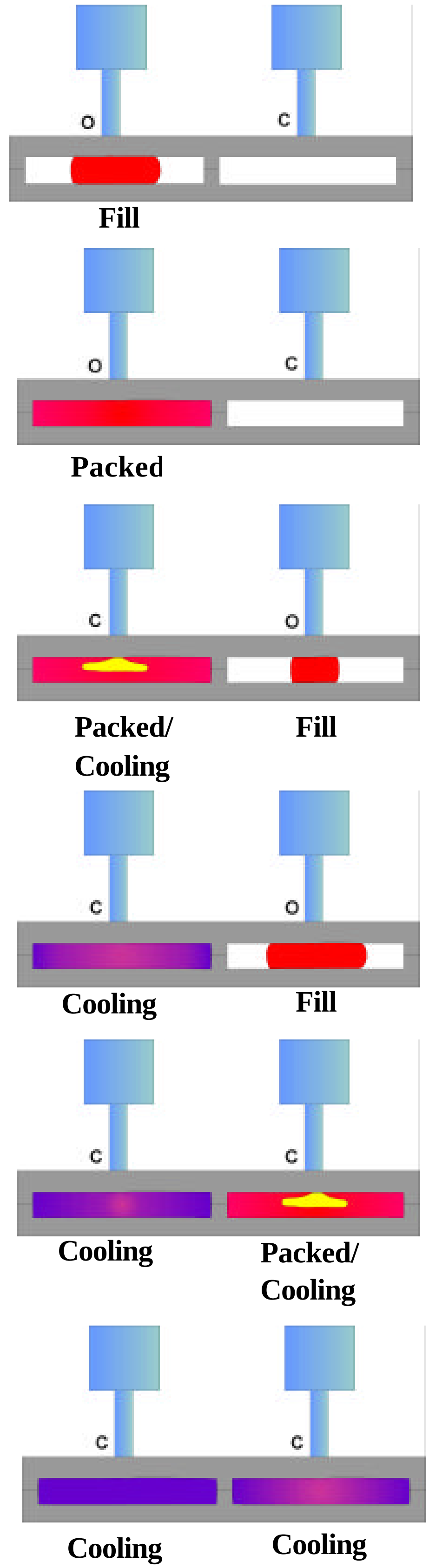


*Figure 2*

gate is closed, essentially closing off the gate and allowing holding to begin. Simultaneously with the closing of valve gate 1, gate 2 opens and injection velocity is accelerated to the filling velocity. When cavity 2 is 90% full, velocity is then reduced again to a packing velocity, which is used to obtain cavity pressure in cavity 2. Once this pressure is reached, the valve gate of cavity 2 is closed and injection is terminated.

This approach has been highly successful, even with class A surfaces, with presses of about half the clamp force normally needed to do both simultaneously. This results in large savings in machine cost. There is a theoretical penalty of having essentially two fill times. However, the injection rate of the machine can often times be the same as when filling cavities using parallel flow and, in those situations, there is really no cycle time penalty. Cooling is different for each cavity, but generally this can be adjusted by fill rates, packing rates, and cavity pressures which are set independently. This allows multiple cavity molds and family molds to be run with different processing parameters in the same mold within the same cycle. There are big savings with this approach. It is especially good for automotive parts where left and right-hand mirror images are often problematic due to the inability to modify the process for a specific problematic cavity.

**SEQUENTIAL VALVE GATE CONTROL**

Sequential valve gate control is generally used in large, long flow parts, which are hard to pack from one central area. Figure 3 shows a typical sequence. In sequential valve gating, it is common to

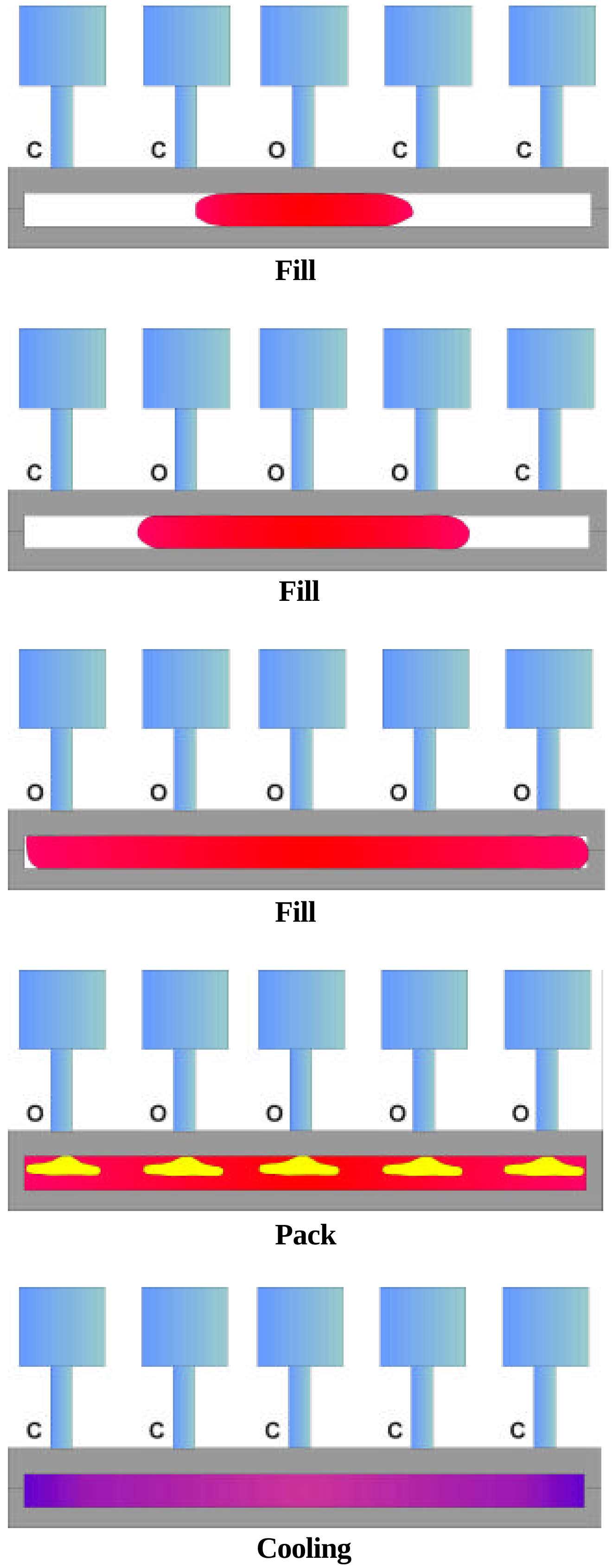


***Figure 3***

have an odd number of gates (generally three to five) so that flow can be initiated in the center of the part and flow radially outward. This is accomplished by opening the single gate at the start of fill and allowing the flow to extend radially outward until it passes the next set of gates. Once pressure is detected in the secondary gate areas, the valves are opened and the flow continues radially outward from the center of the part. Doing this minimizes the pressure loss in the system and eliminates knit lines, which would be present if the part was filled from each of the drops simultaneously.

Once the part is filled, the velocity of injection is reduced and all gates are left open for pack. Once the pressure is reached in the localized area, as set on the controller, the valve gate is closed to hold the plastic in the mold, or the injection pressure is terminated and the cavity is discharged until the cavity pressure set is reached. Both of these techniques allow different types of packing and holding to be initiated which is dictated by the specific geometry of the part.

Another form of sequential valve gating is shown in Figure 4. In this situation, the cavity is filled from one end to the other. The initial gate is opened at one end. As flow progresses, additional gates are opened until all gates are opened and packing occurs. This is simply another type of sequence that can be used. In all cases the sequence configuration is dictated by the geometry.

**OPPORTUNITIES**

Using the valve gate control scenario as described above opens up many opportunities for cost savings. The obvious large cost savings is with the

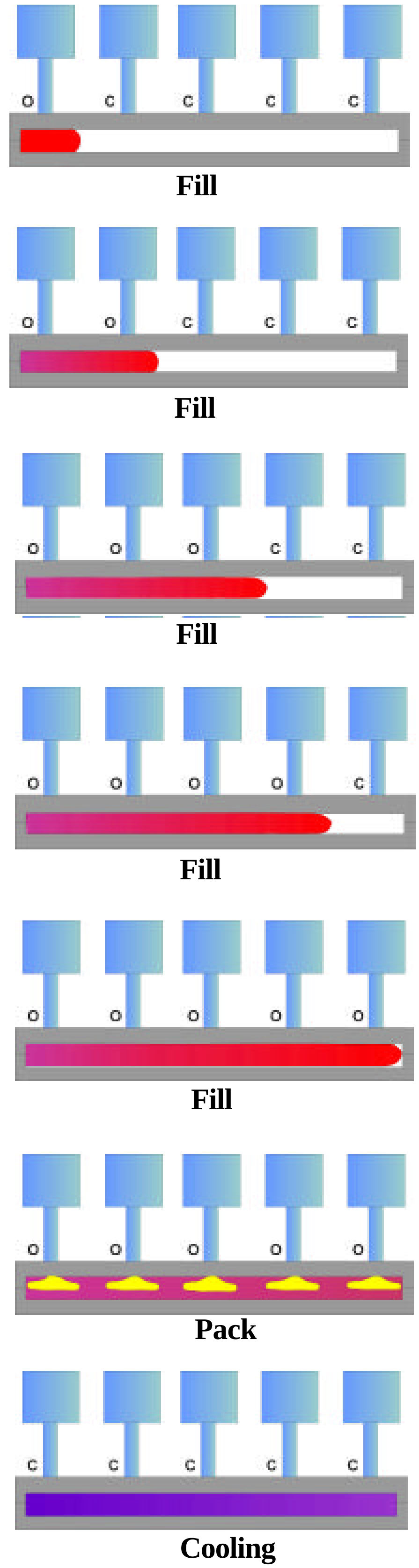


***Figure 4***

alternate cavity control, because clamp tonnage of the machine used for a given mold can generally be reduced in half without resorting to stack molds. However, probably the major saving in all of these scenarios is that unparalleled part consistency can be achieved over long periods of time due to independent control of flow fronts. This is true even with normal viscosity variations in the material. Inspection time of Class A surfaces can be reduced and the control of flash, sinks, short shots, knitlines and warp can all be made more consistent with the use of sequential valve gate control.

## CAUTIONS

It is important, when utilizing valve gates to control flow fronts, that sensor information be highly robust so that the proper sequencing is always assured to eliminate overpacking of a mold. It is critical that an automated sensor check during each cycle be employed to ensure that each sensor has the capability of performing in highly critical applications, and that redundant sensors are in use for fail safe and backup. Abort strategies should be implemented in the control strategy. All of these requirements have been addressed in the RJG Insight System™ valve gate control used in the scenarios as depicted here.

## THE GRAPHICAL SEQUENCE

The graphical sequence of data from valve gate control is shown in Figure 5 for independent valve gate control. The red graph is the plastic pressure of the molding machine. The green and the blue are different cavities in the same mold equipped with valve gates.

In this case, the cavity depicted by the green graph (cavity 12) shows filling happening faster than in cavity 32, and

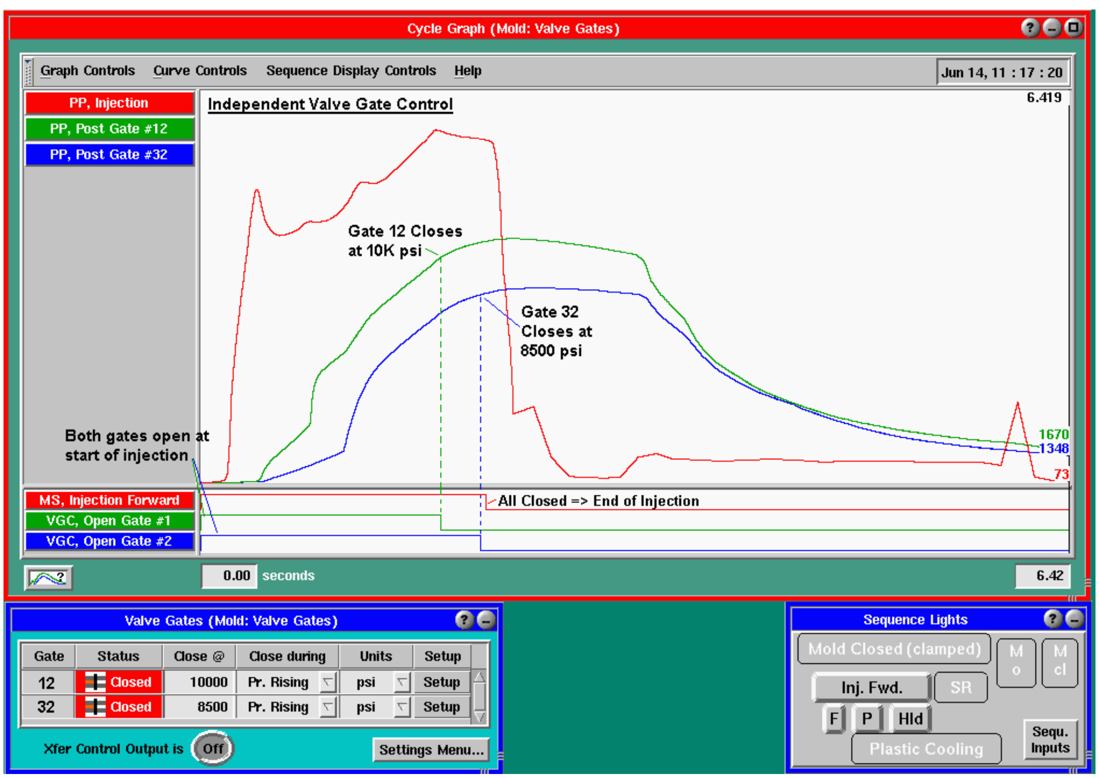


*Figure 5*

packing also proceeds earlier in cavity 12. The cavity pressure set point for gate 12 is set at 10,000 psi. When this is reached the gate is closed at the first vertical dotted line.

In this case, the pressure in the cavity begins to decrease while the cavity pressure in cavity 32 continues to build. When the pressure reaches 8,500 psi in cavity 32, that gate is closed and injection forward is terminated. Because all gates are closed, we see that the cavity pressure is then maintained until the start of screw run, at which time the valves are opened to allow discharge to occur during cooling.

The valve gate sequence is shown on the bottom of the cycle graph. The set points and the status are shown on the bottom left and the sequence of the machine is shown on the bottom right.

Figure 6 shows the alternate cavity control on a Mitsubishi machine making two parts as shown in Figure 7. These are large relish trays, which approximate the size of a wheel cover for an automobile. This part is run on a 700-ton machine at Mitsubishi in Wixom, Michigan and was featured at the last NPE.

As can be seen from the graph, the plastic pressure in the barrel builds up rapidly and we see a fast fill as depicted on the screw volume graph labeled "cavity one fast fill". At the point where the cavity is approximately 90% filled, the machine is transferred to a low velocity as depicted by a change in slope of the volume injection graph labeled "Cavity 1 Slow Pack".

***Figure 7***


***Figure 6***

The first vertical dotted line (green) shows the termination of packing of cavity one at 2,900 psi in the cavity, which is when valve one closes and valve gate 2 is opened. When this occurs, the machine is accelerated back into a cavity 2 fast fill mode and then cavity 2 slow pack mode until the cavity pressure of 2,700 psi is reached in cavity 2. At that point the valve gate closes, the injection forward is terminated, and no holding pressure is needed as depicted on the curve.

## SEQUENTIAL VALVE GATE CONTROL WITH DISCHARGE

Figure 8 shows the cavity pressure graph for the sequential valve gate control with discharge. In this situation, the injection starts through a center, non-valve gated drop with both valve gates closed. Valve Gate 1 opens approximately 1-1/2 seconds into the cycle when the flow front reaches 500 psi, then the flow begins through gate 1. Valve Gate 2 opens when the flow front reaches 500 psi. Valve Gate 1 closes when the pressure has fallen to 3,300 psi. Material at gate 2 reaches the maximum pressure and begins declining and gate 2 closes when the pressure falls to 2,700 psi. In this scenario, the discharge is used to minimize compressive stress in the valve gate areas and to minimize warp while eliminating knitlines in the part.

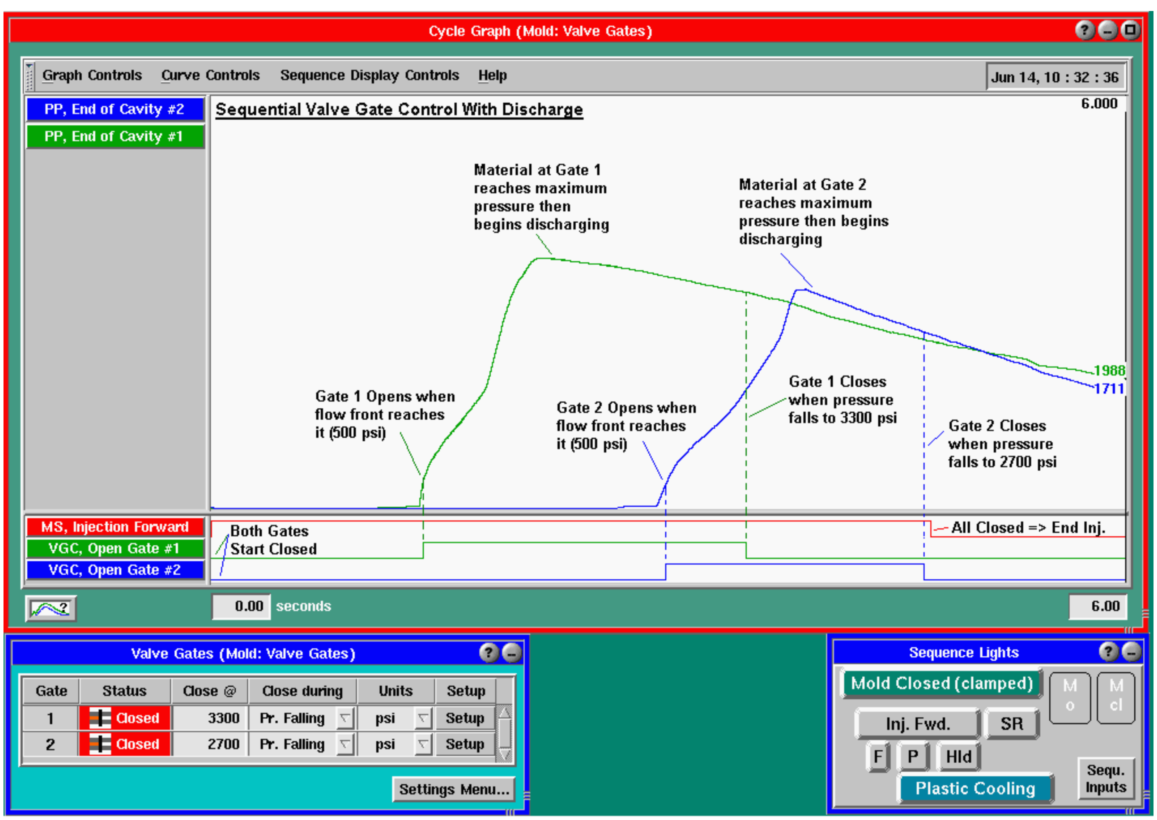


*Figure 8*

**SUMMARY**

In summary, sequential valve gate control of individual flow fronts in injection molding is a technology that has recently matured into a more sophisticated tool. This allows the precise individual control of melt flow fronts, the use of cavity pressure sensing, along with a sophisticated control of fail safe sensor capability and flexibility in terms of how the valve gates can be sequenced. This is the key to a robust system. Tying this to a networked production system, which allows machine independent set-ups of these complex tools, can be a key to maximizing uptime, process capability and performance, especially on large machines with complex processes using hot runner valve gates.