# The Use of In-Cavity Data for LSR Applications

Mike Groleau, RJG Inc.
Greg Roembke, Roembke Mfg. & Design, Inc.

## Introduction

As liquid silicone molding applications continue to grow, we see increasing interest in the use of in-cavity sensors to improve part quality while reducing manufacturing costs. These types of sensors have been used for years in thermoplastic injection molding applications. However, the unique demands of LSR molding require a different strategy for in-cavity sensing.

In this paper, we will discuss the types of sensors available for liquid silicone applications, and show some common uses for this technology. We will focus on two sensor types: cavity pressure and cavity temperature. After describing each of these sensors, we will show how in-cavity data can be used to detect a variety of part quality problems.

To highlight the differences between these sensors, we will use data mostly from a single mold, shown in Figure 1. The sensors were located near the last point to fill (End of Cavity). For the cavity pressure data, one End of Cavity sensor was placed in each of four cavities. For the cavity temperature data, the pressure sensors were removed and replaced with cavity temperature sensors.

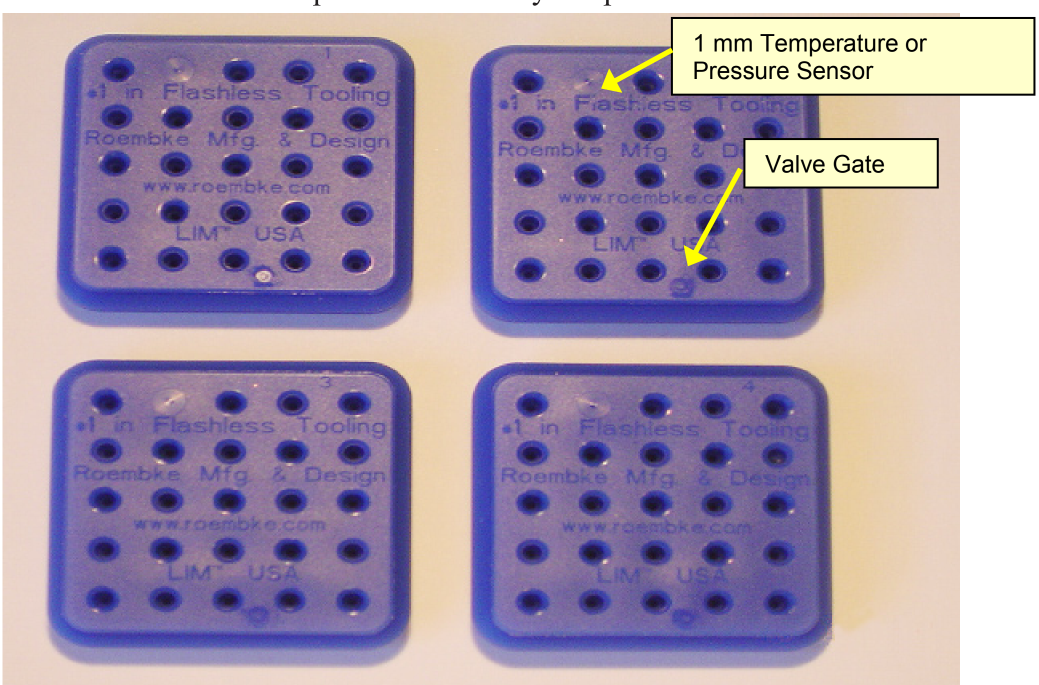



*Figure 1: This is the part used for most of the data presented in this paper. Both cavity temperature sensors and cavity pressure sensors were used in the same End of Cavity position.*

## Why use in-cavity data?

In-cavity sensors provide a window into the mold to detect changes in process conditions that directly impact part quality. For thermosets such as liquid silicone, there are four fundamental process variables that determine the quality of part, and each process setting on the press drives one or more of these:

- Material Temperature: the temperature of the liquid material as it is delivered from the barrel (or from the cold manifold) into the mold.

- Flow Rate: the rate at which material is injected into the cavity. This is measured from the mold's perspective, and can be thought of as the time to fill each cavity. It is particularly important for each individual cavity to have the same flow rate (cavity fill time).

- Pressure Gradient: pressure inside the mold, particularly after the cavity is volumetrically full and has begun to pressurize during cure.

- Cure Rate and Time: this is driven by the temperature of the mold steel itself and the time the material remains in the cavity.

If each of these four process variables is reproduced from shot to shot, the process will create consistent parts. Of these, material temperature has the least impact, while flow rate, pressure gradient, and cure rate/time can have a significant impact on part quality and can vary significantly inside the cavity. In-cavity sensors can be used to improve the consistency of these in-cavity conditions,

## Overview of Sensor Types

There are two general types of sensors used for in cavity monitoring: cavity temperature and cavity pressure. We will introduce these independently.

### ***Cavity Pressure Sensors:***

Cavity pressure sensors directly measure the Pressure Gradient inside the mold, which correlates well with a number of part quality characteristics, like flash, short shots, backgrind, and dimensions. They also indirectly measure Flow Rate by detecting the time for the flow front to reach the end of the cavity (at which time the cavity begins to pressurize). This is important in multi-cavity molds where filling imbalance may be a problem. An example of cavity pressure data is shown in Figure 2.

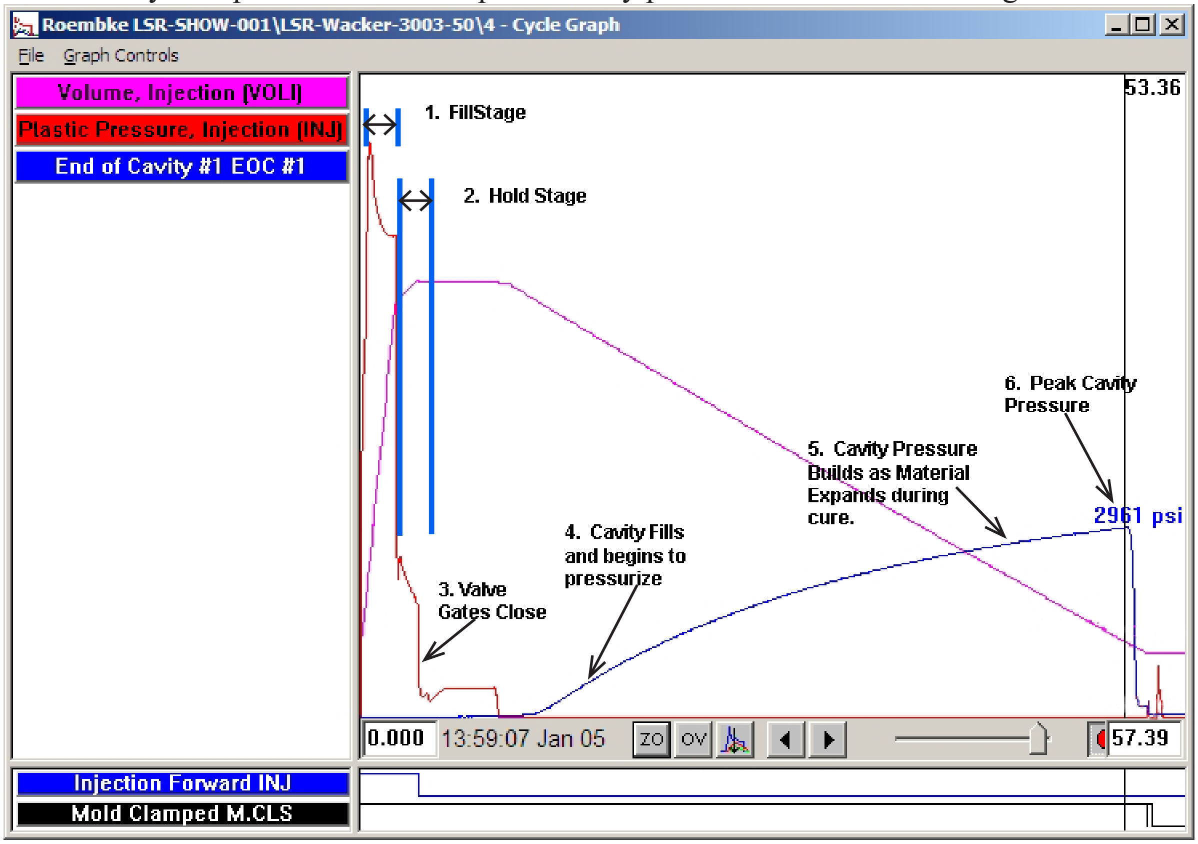



*Figure 2: Example of cavity pressure data*

There are two general types of cavity pressure sensors: flush mount, and button style. An example of a flush mount sensor is shown in Figure 3. Flush mount sensors are mounted directly in contact with the cavity. The sensors are available in sizes ranging from 1 mm to 4 mm diameter.

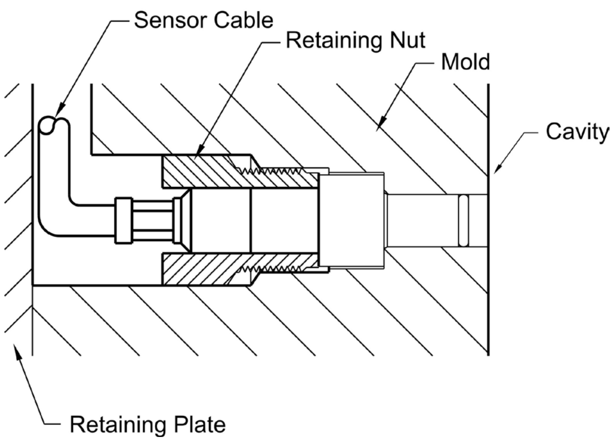



*Figure 3: Example of a flush mount pressure sensor*

Button style sensors are an alternative to flush mount sensors in some applications. The button sensor is mounted behind a static pin whose primary job is to transfer pressure in the cavity to the sensor. These sensors can be less expensive to install and maintain, and can often provide greater flexibility in sensor installation. Button sensors are available in diameters ranging from 6 mm to 1/2 inch. An example of a button sensor behind a static pin is shown in Figure 4. The force rating of the sensor is determined by the pin diameter and the expected cavity pressure. Generally, static pins work best with pin diameters 2 mm or larger.

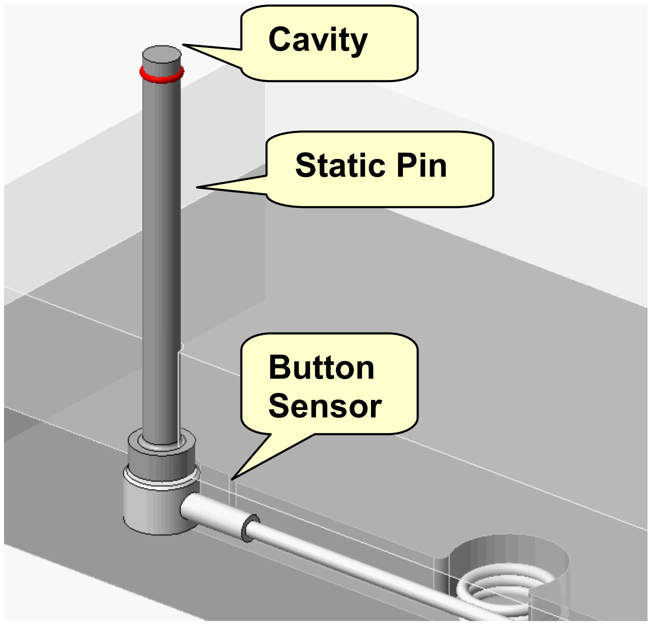



*Figure 4: Example of a button sensor behind a static pin*

For either flush mount or button style sensor applications, sensor installation is critical. The fit of the sensor or static pin into the primary bore must be tight enough to prevent flashing, but loose enough to allow the sensor to move freely when loaded. The tolerance on this fit is in the range of 0.0002” for most applications. It is best to use an O-ring where possible to minimize the potential for flashing, as shown in Figure 5. For applications where O-rings are not an issue due to sensor or pin size, Roembke has techniques available to minimize flash problems.

*Figure 5: Example of a static pin with an O-ring. The O-ring helps minimize flashing around the flush mount sensor or the static pin*

## ***Cavity Temperature Sensors***

Cavity temperature sensors are fast acting thermocouples that rapidly change temperature when colder material flows over them. They directly measure the temperature of the mold steel, which is directly related to Cure Rate and Time. They also measure Flow Rate indirectly by detecting the time at which the flow front passes over the sensor (if the sensor is located near the last point to fill). Cavity temperature sensors can detect short shots if the sensor is located at the very end of filling. They can also detect problems with improper cure and filling imbalance. An example of cavity temperature data is shown in Figure 6.

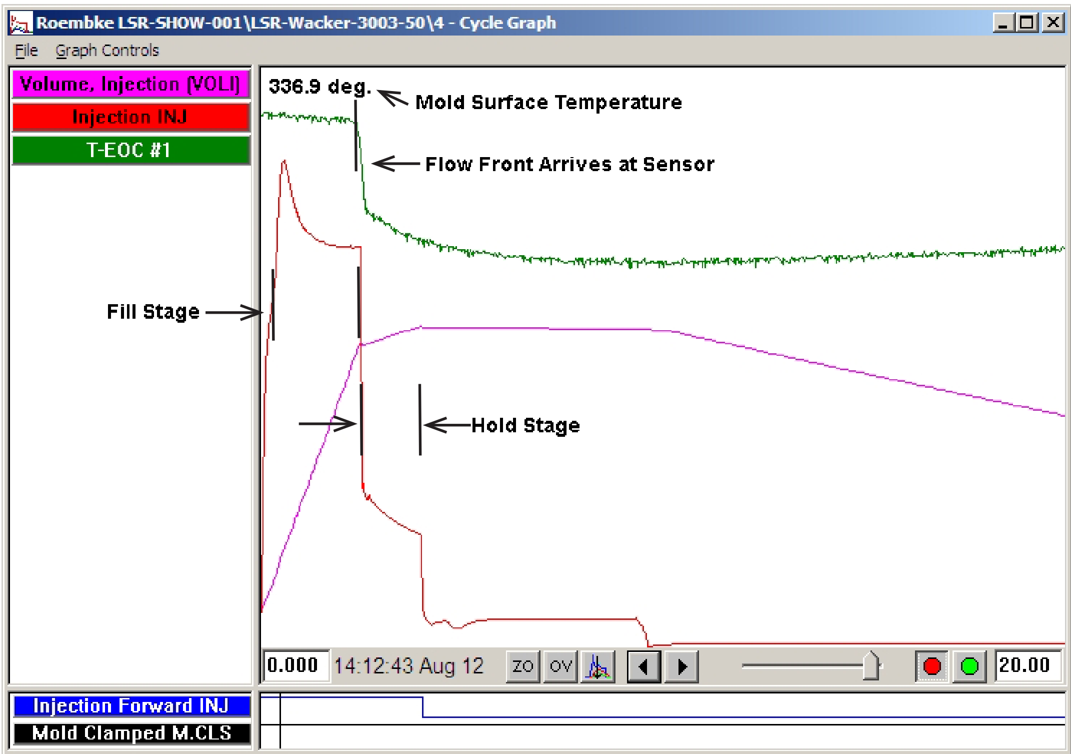



*Figure 6: Example of cavity temperature data. Note that this is the same process as is shown in Figure 2, with sensors located in the same position.*

Cavity temperature sensors are available in flush mount and pressfit models. An example of a flush mount cavity temperature sensor is shown in Figure 7. These sensors are available in sizes ranging from 0.6 to 4 mm diameter, with 1 mm being the most common. These are particularly useful in tight applications where size is an issue.

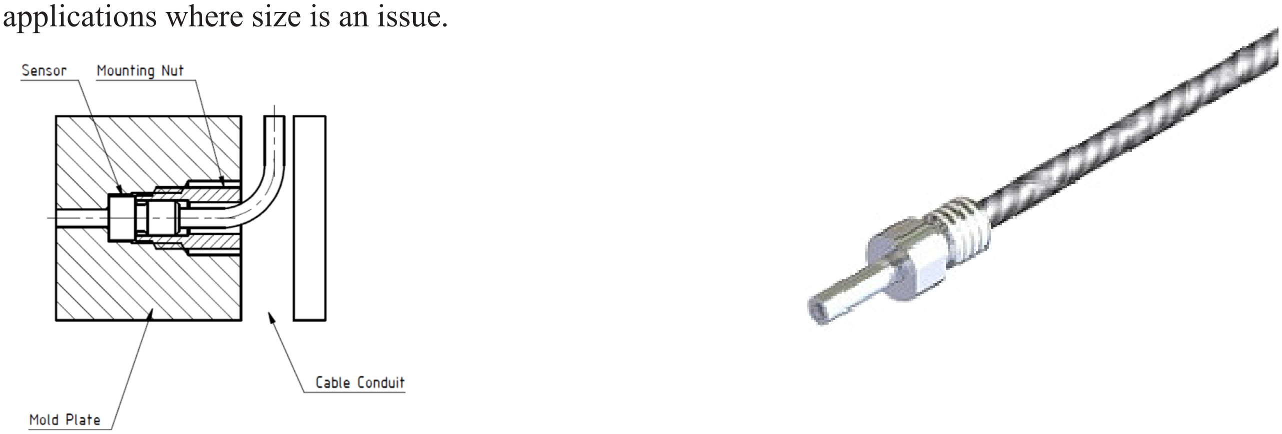
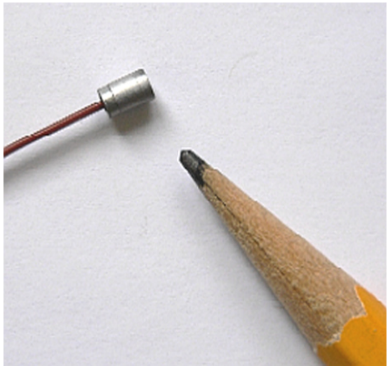



*Figure 7: Flush mount cavity temperature sensor*

Press fit a cavity temperature sensors are less expensive and easier to install, and can be blended into the surrounding tool steel to virtually eliminate witness marks. However, they are only available in 3 mm diameter sizes and are harder to remove once installed. These are illustrated in Figure 8.



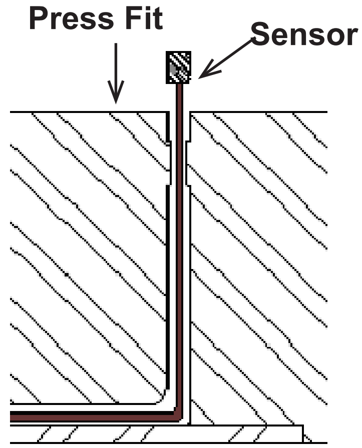



*Figure 8: Press fit cavity temperature sensor*

Cavity temperature sensors are generally lower cost than cavity pressure sensors. They are also easier to install since they do not require tight tolerances for the sensor pocket. However, they often do not provide as much information about part quality, which we will discuss further.

## Detecting Part Quality Issues Using In-Cavity Data

### ***Short Shots***

A short part is created when material does not reach the last point to fill (End of Cavity). A short shot is often accompanied by surface imperfections such as bubbles and poor texture. If a sensor is located strategically near the last point to fill, it is possible to detect the absence of material that causes the short. An alarm output can then be sent to automatically remove the short shot when the mold opens.

Cavity pressure sensors detect a short part by measuring a lack of a pressure at the End of Cavity. Figure 8 shows the cavity pressure data for a short part (solid line), compared to data for a normal part (dashed line). Note that the pressure for the short shot is essentially 0psi.

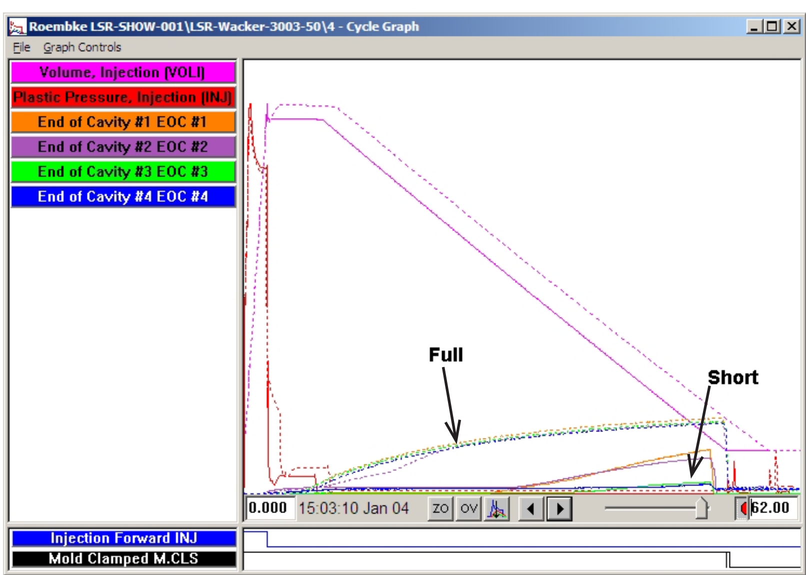



*Figure 8: Cavity pressure data detects a short shot due to very low pressure in cavity*

Cavity temperature sensors detect a short part by detecting the lack of a temperature drop at the End of Cavity.  This means material did not arrive at the sensor location.  Figure 9 shows the cavity temperature data for a short part (dashed line), compared to data for a normal part (solid line).

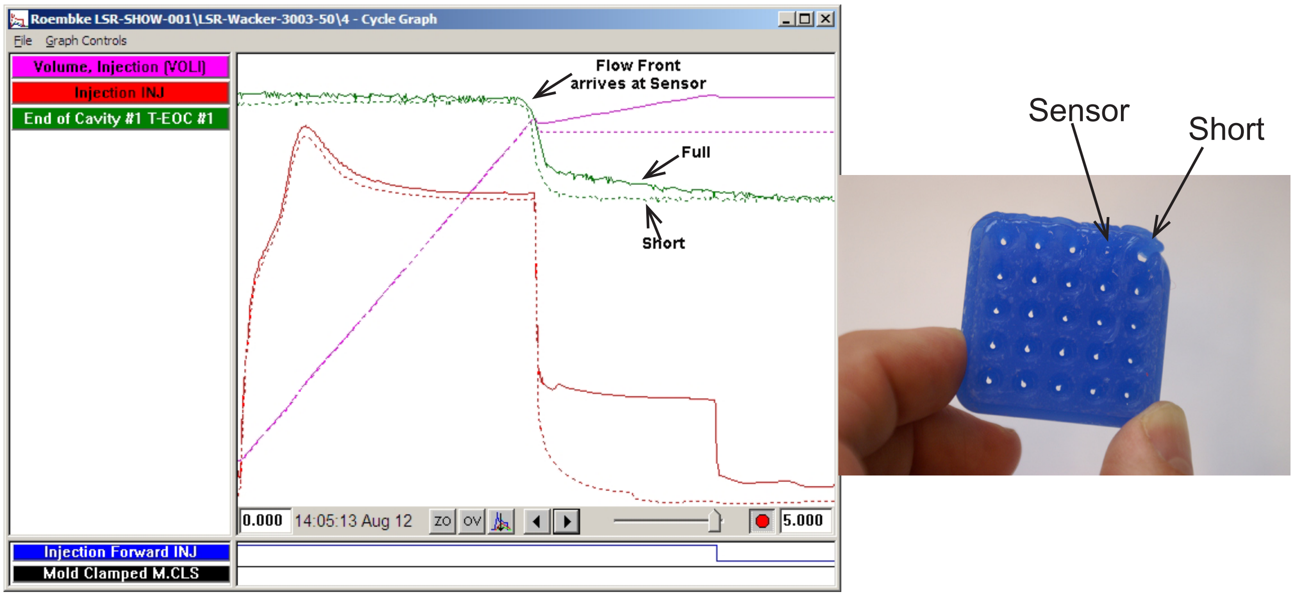



*Figure 9.  Cavity temperature data misses a short shot because the flow front already arrived at the sensor*

Note that if a cavity pressure sensor is not exactly at the End of Cavity, there is still a high likelihood that the pressure sensor will detect the short shot, since the pressure in the area near the short part will also be very low.  However, for a cavity temperature sensor, the arrival of the flow front at the sensor does not indicate that the part is full.  The short may have occurred near the sensor, but since material arrived at the cavity temperature sensor, the sensor could not detect the short.

## ***Flash and Backgrind***

Flash and backgrind are created when material is over-pressurized inside the cavity. In the case of flash, this over-pressurization occurs early in the cycle, causing uncured material to escape into the parting line. In the case of backgrind, the over-pressurization occurs later in the cycle, where cured material is extruded into the parting line and tears.

Cavity pressure sensors detect flash and backgrind by measuring a high pressure condition inside cavity. In some cases, pressure sensors detect flash by measuring early pressurization of the cavity. In this case, the pressure builds before a cured skin layer forms on the outside of part, making it easier to flash. Figure 10 shows the cavity pressure data for a part with flash and backgrind (solid line), compared to data for a normal part (dashed line).

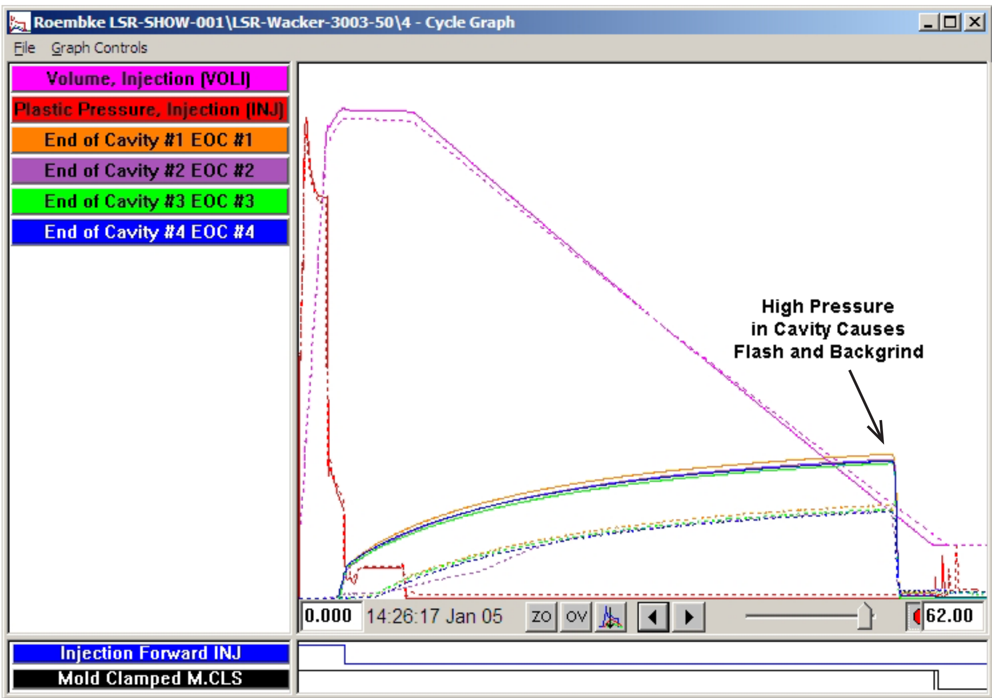



*Figure 10: Over-pressurization of the mold results in flash or backgrind*

Note that flash can also be caused by mold damage, which cannot be detected using in-cavity data. Cavity temperature sensors are much more limited in their ability to detect flash and backgrind. They cannot measure the pressure inside the cavity, but can measure the time at which the flow front arrives at the sensor. If the flow front arrives too early, there is a greater chance for over-pressurization of the cavity before a cured skin layer forms. Figure 11 shows the cavity temperature data for a part with flash and backgrind (solid line), compared to data for a normal part (dashed line).

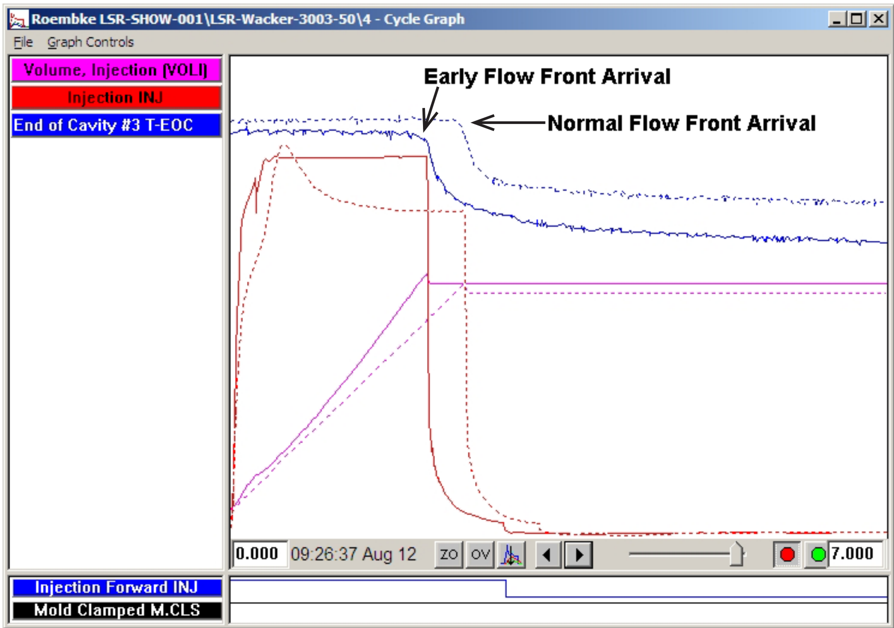



*Figure 11: Early flow front arrival may indicate flash or backgrind*

Again, the sensor should be located as close to the End of Cavity as possible, particularly with cavity temperature sensors.

## ***Dimensions***

Dimensional variation in silicone parts occurs when different amounts of material have been injected into the cavity, or when the degree of cure has changed.

Cavity pressure sensors detect changes in pressure inside the cavity due to changes in the amount of material that has been injected. The more material that has been introduced, the higher the pressure will read inside cavity, usually resulting in larger outside dimensions and smaller inside dimensions (e.g. inside hole diameters). Figure 12 shows the cavity pressure for a part that is slightly too large (solid line), compared to data for a normal part (dashed line).

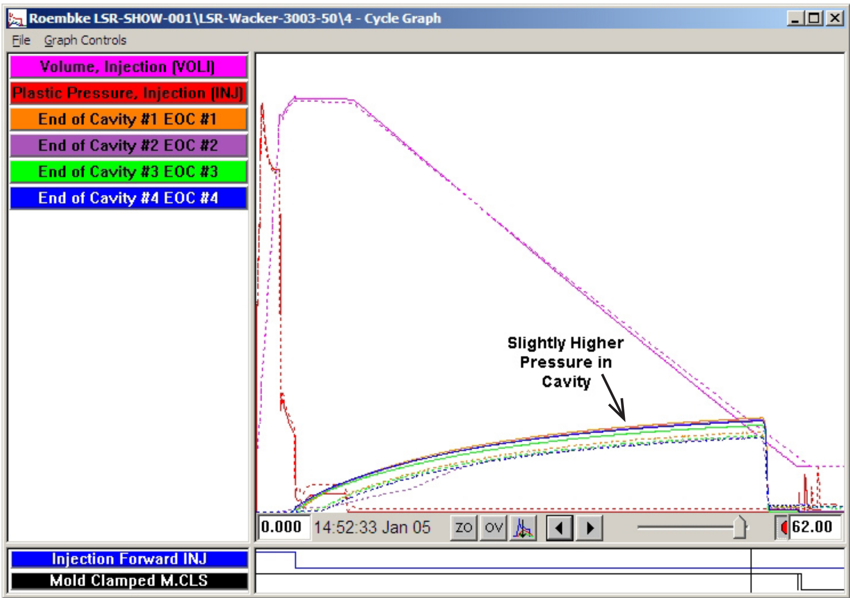



*Figure 12: Over-pressurization of the cavity creates a part that is slightly large*

Cavity temperature sensors detect changes in steel temperature that can affect the degree of cure. Higher temperatures lead to a higher degree of cross-linking, which increases shrinkage resulting in lower dimensions. Figure 13 shows the cavity temperature data for a part with a low steel temperature, which can create larger part dimensions.

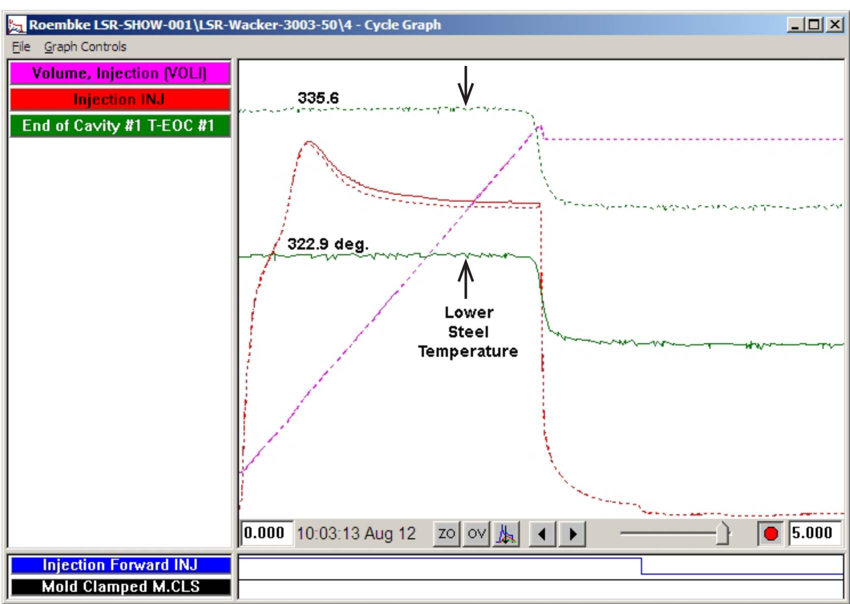



*Figure 13: Low steel temperature creates a part that is larger*

Note that the importance of pressure versus temperature varies from part to part and material to material. Generally, pressure plays a dominant role in determining part dimensions, but it may be necessary to monitor both temperature and pressure in some applications.

## ***Knit Lines***

Knit lines form when two flow fronts come together and leave a witness mark. Knit lines form when the flow front arrives at the end of cavity late, after the material has begun to cure, or if the pressure in the cavity is too low to pack out the knit line. Knit lines create cosmetic problems and leakage problems when used on sealing surfaces.

Cavity pressure sensors detect lower pressure in the cavity or a late cavity fill time. This is shown in Figure 14, where the dashed line shows data for a normal part and the solid line shows data for a part with a knit line defect.

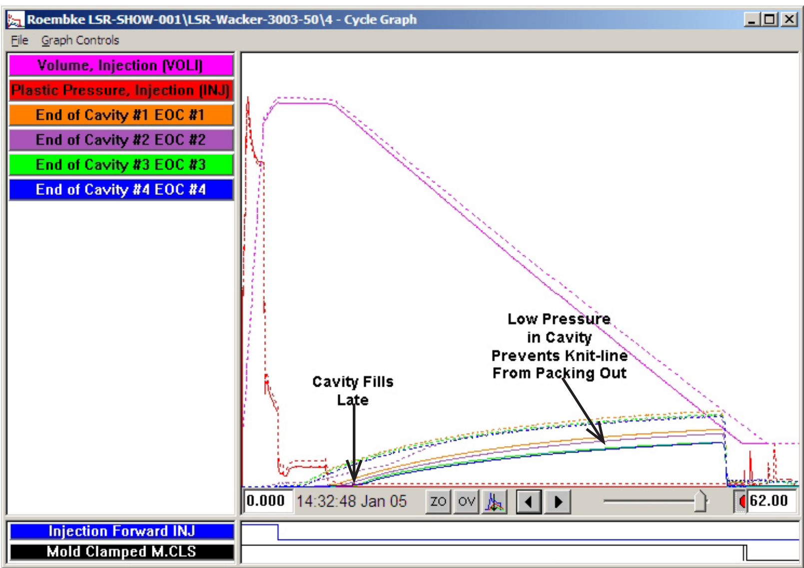



*Figure 14: Late flow front arrival and low pressure can cause a knit line*

Cavity temperature sensors are more limited in their ability to detect knit lines because they cannot measure the pressure available to pack out the knit line. If the temperature sensor is located very near the End of Cavity, it can detect late arrival of the flow front, as shown in Figure 15.

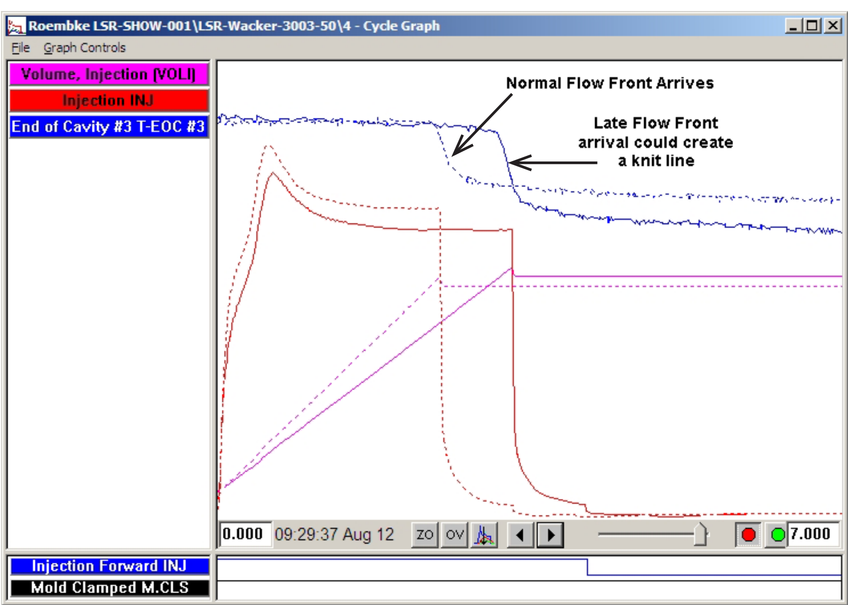



*Figure 15: Late flow front arrival may indicate a possible knit line*

A number of other cosmetic issues can also be associated with late flow front arrival. These issues can also be detected using in-cavity sensors.

## ***Improper Curing***

Improper curing can be caused by improper mold temperature or improper mixing of material. While the latter is more difficult to detect using in-cavity sensors, improper mold temperatures are easily detected using cavity temperature sensors.

An example of cavity temperature data from an application with improper mold temperature was shown previously in Figure 13. This type of improper temperature can be a result of incorrect mold temperature set-points used in the temperature controller, or it can be due to mold temperature fluctuation over time.

Figure 16 shows a trend of mold steel temperature data trended shot to shot over time. In this 4 cavity application, the cycle was interrupted, allowing the mold temperature to increase. As the mold began cycling, the temperature dropped 30 – 40 °F over the next 60 shots, creating the potential for a curing problem.

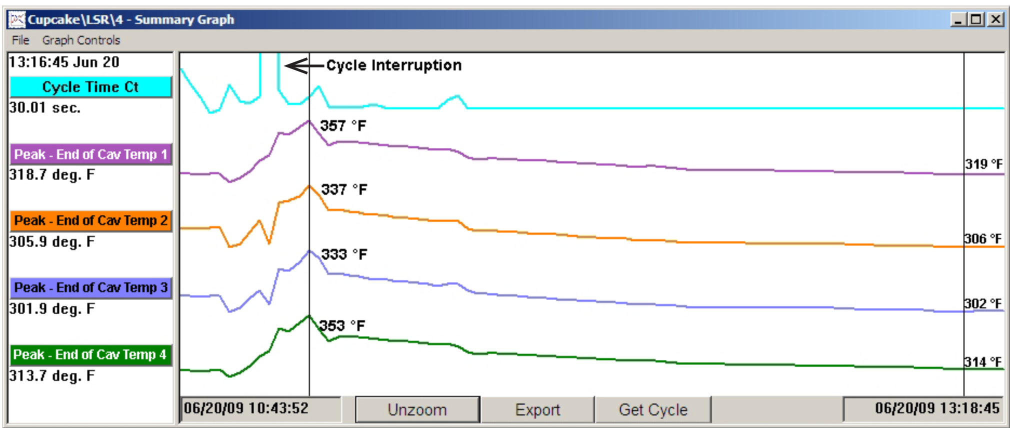



*Figure 16: 80 shots of mold temperature data including a cycle interruption which created a dramatic change in mold temperature over time*

In addition, there is a wide range in temperatures from cavity to cavity. This "temperature balance" can create curing problems in individual cavities, leading to variation in dimensions and degree of cure. An example of temperature imbalance during a single cycle is shown in Figure 17.

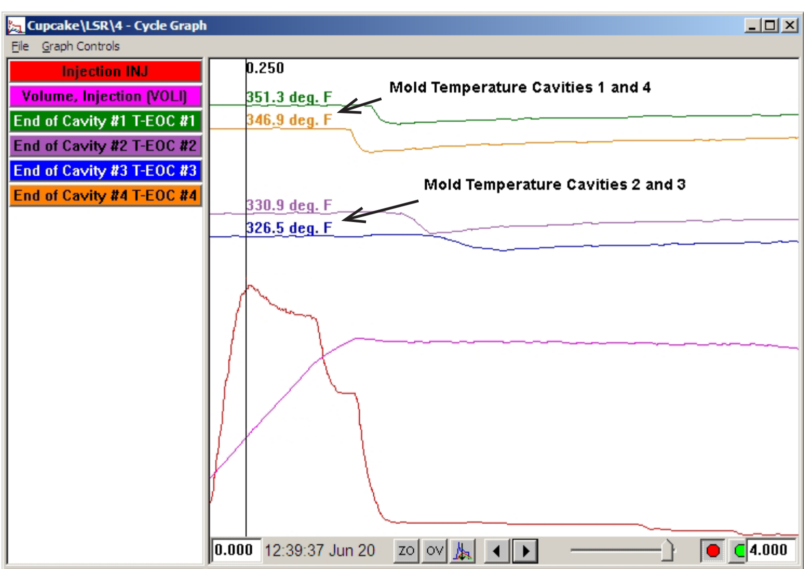



*Figure 17: Mold temperature in cavities 1 and 4 is higher than 2 and 3*

Cavity pressure sensors, on the other hand, are generally unable to detect a change in mold temperature, and are usually not able to detect significant changes in curing.

## ***Fill Balance***

Filling imbalance occurs when one or more cavities fill at a different rate than other cavities. Figure 18 shows a comparison of two cavities that have been intentionally made short in order to compare the filling rates.

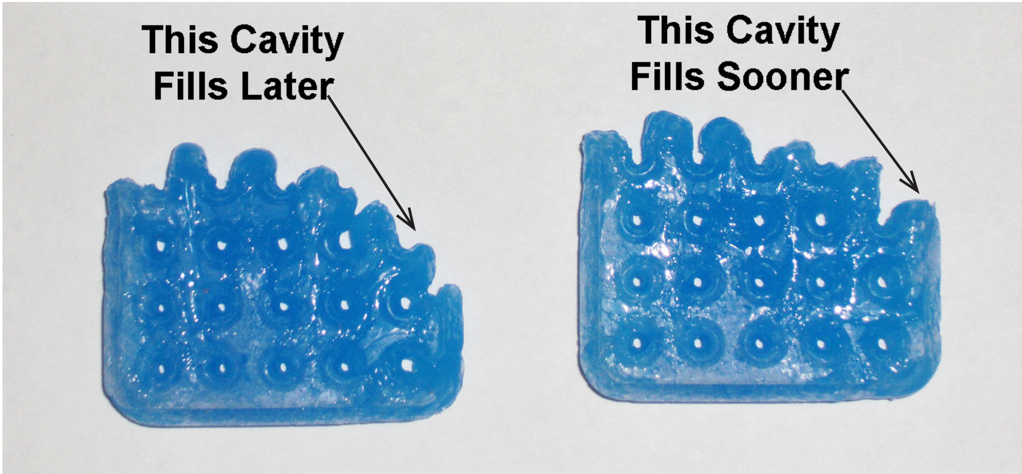



*Figure 18: An intentional short shot allows comparison of two cavities. The cavity on the right fills slightly faster and is therefore heavier than the cavity on the left.*

Imbalanced filling can cause a number of part quality problems. Cavities that fill too early can have flash, backgrind, or large dimensions, while parts filling too late can have shorts, knit lines, cosmetic problems, or low dimensions. Detecting imbalance problems can be the first step to solving many of these types of problems in multicavity molds.

Cavity pressure sensors detect imbalance by measuring the time at which the flow front reaches the end of the cavity and begins pressurizing. An example of imbalanced filling is shown in Figure 19. Note that the filling imbalance also causes an imbalance in pressurization later in the cycle.

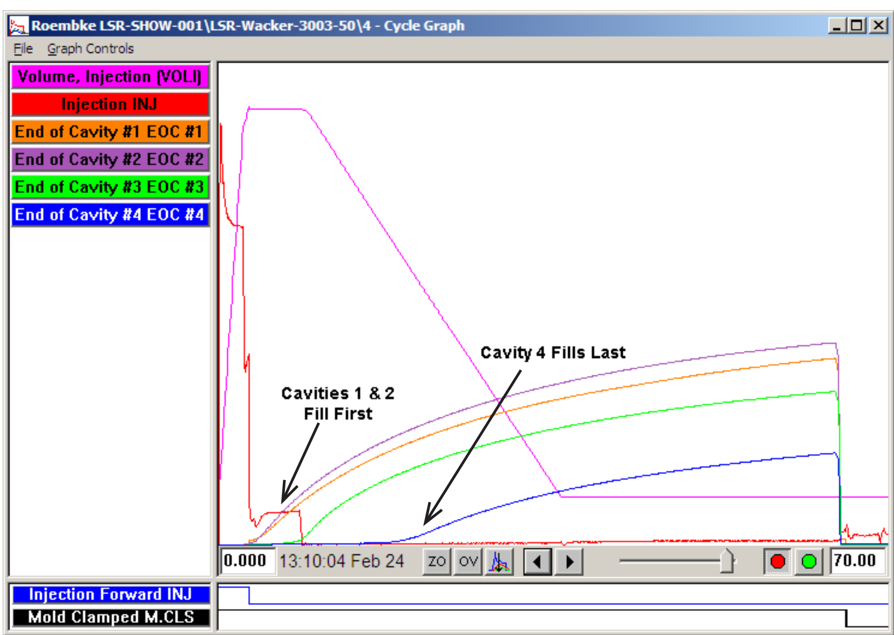



*Figure 19: Cavity pressure data showing fill imbalance*

Cavity temperature sensors detect fill imbalance by measuring the time at which the flow front reaches the sensors, which are located near the last point to fill. An example of imbalanced filling is shown in Figure 20.

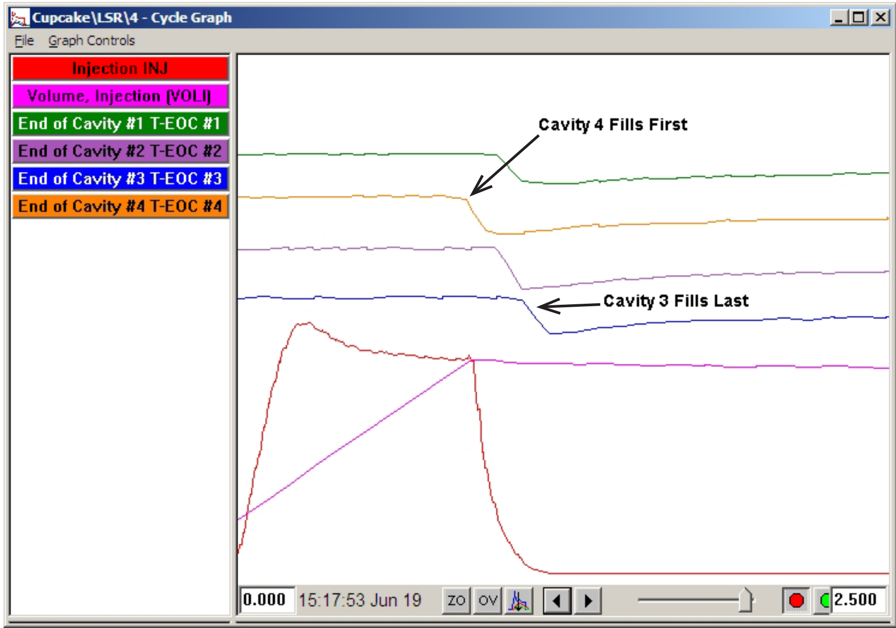



*Figure 20: Cavity temperature data showing fill imbalance*

Balance can change over time, especially in cold deck molds without valve gates. Here, partially cured gates can delay filling of some cavities, and this varies from shot to shot. Both pressure and temperature sensors can detect this variation well. An example is shown in Figure 21, where 4 consecutive shots are overlaid.

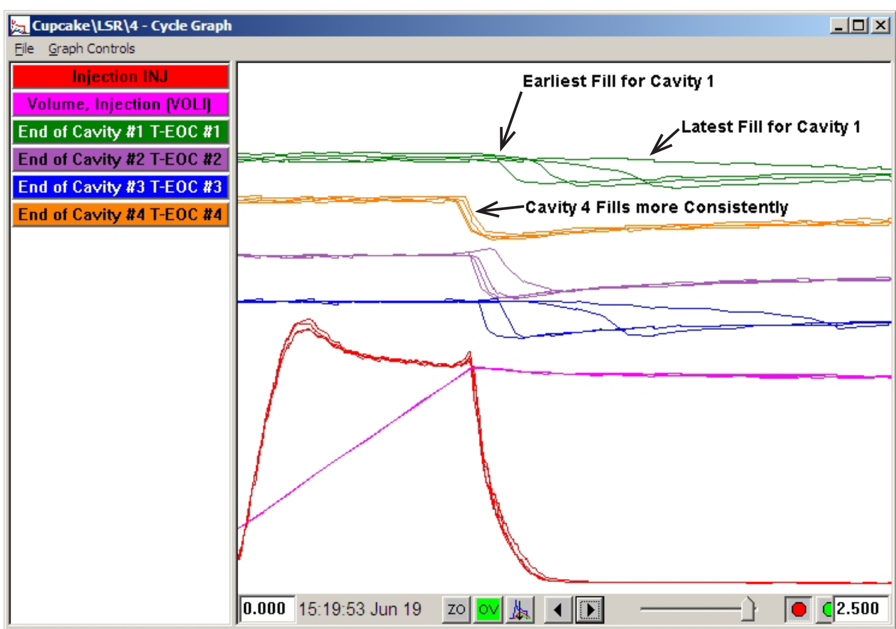



*Figure 21: Four consecutive shots overlaid, showing variation in filling balance on a non-valve gated cold deck*

Note that the *eDART*™ Valve Gate Software can be used to balance filling on valve gated cold deck molds. This will be the topic of a future paper.

## Summary

In-cavity sensors can be used to detect a variety of quality issues in LSR parts. This data can be used to troubleshoot and solve problems, or to automatically separate suspect parts from good parts at the press. The topic of cavity pressure control to improve process consistency will be a topic of a future paper.

Cavity pressure sensors are most effective at detecting problems like short shots, flash, dimensional variation, knit lines, and filling imbalance between cavities. However, they are more difficult to install and maintain than cavity temperature sensors.

Cavity temperature sensors are useful for detecting filling imbalance between cavities, and can sometimes detect other problems like short shots and flash. They also are useful for detecting curing problems due to temperature variation over time or between cavities. While they do not provide the same capability as cavity pressure sensors, they are less expensive and easier to install.

## Contact Information

Mike Groleau is a Project Manager with RJG Inc. in Traverse City, MI. RJG works with molders to help them supply absolute quality parts to their customers by providing in-mold sensors, process monitoring and control, and process training. Mike can be contacted at 231-947-3111, or at mike.groleau@rjginc.com. Link to website www.rjginc.com

Greg Roembke is President of Roembke Mfg. & Design, Inc. in Ossian, IN. Roembke Manufacturing is a leading supplier of flashless molds for LSR applications. Greg can be contacted at 260-622-4135, or at groembke@roembke.com. Link to website www.roembke.com.