Working with the Machine

LESSON 5: Molding Strategies and Process Control

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Process control is the system that is used to monitor and correct the four most important molding parameters: cavity pressure, injection pressure, melt temperature, and mold temperature. In this lesson we will look at some of the many approaches to monitoring and controlling these parameters.

Objectives of Lesson Five

1. Understand the difference between open loop and closed loop control
2. Learn how transition points are set
3. Learn how to control fill with speed profiling
4. Learn why molding parameters change
5. Learn about tuning controllers

Objective One

Open Loop versus Closed Loop Control

Process control is usually divided into open loop systems and closed loop systems.

Open Loop Control

Open loop process control systems are sometimes called monitor-ing systems. Open loop control systems carefully watch the process parameters and compare their values each cycle with ideal settings that are known to make a good part. When the process parameter slips out of an acceptable range, the open loop system turns on a light, or rings an alarm, to alert the operator. Open loop systems leave corrective action to the operating personnel.

Many open loop control systems are built into newer molding machines. For example, an open loop system might record the barrel temperature on each cycle. A molding technician or supervisor tells the controller that the ideal barrel temperature is 400° F. The controller has also been told that the barrel tempera-ture can vary up to five percent without a big effect on part quality. The controller monitors the barrel temperature by reading tem-perature thermocouples each cycle.

When the temperature climbs outside the acceptable range, the controller might turn on an indicator light, print a report showing the out-of-tolerance barrel temperature, or display the barrel temperature on a screen with flashing numbers to signal the need for attention. Figure 1 is a diagram of an open loop control system.

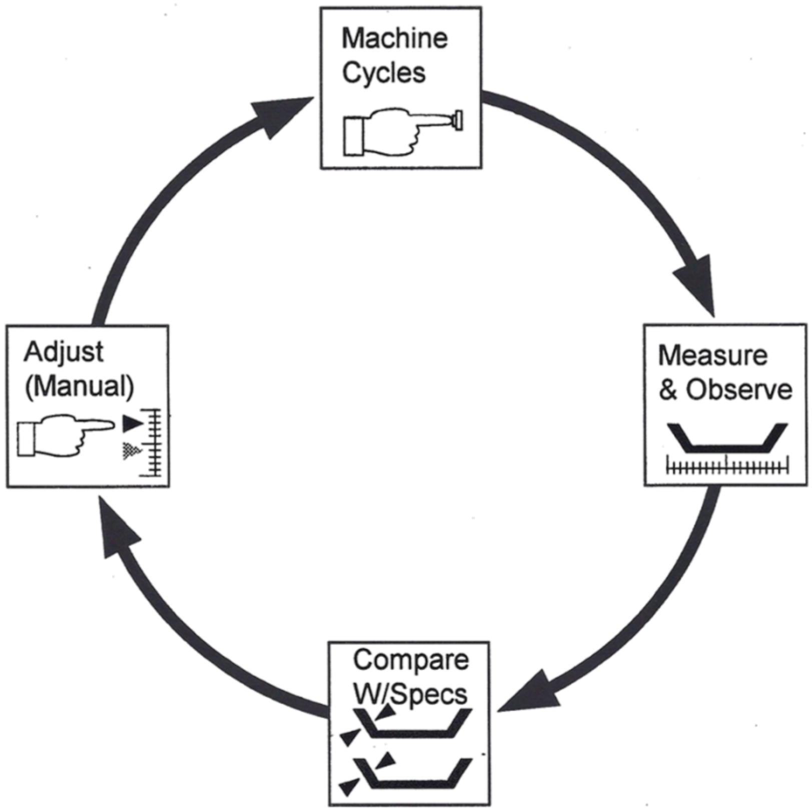

Figure 1 - Open Loop Controls

Closed Loop Control

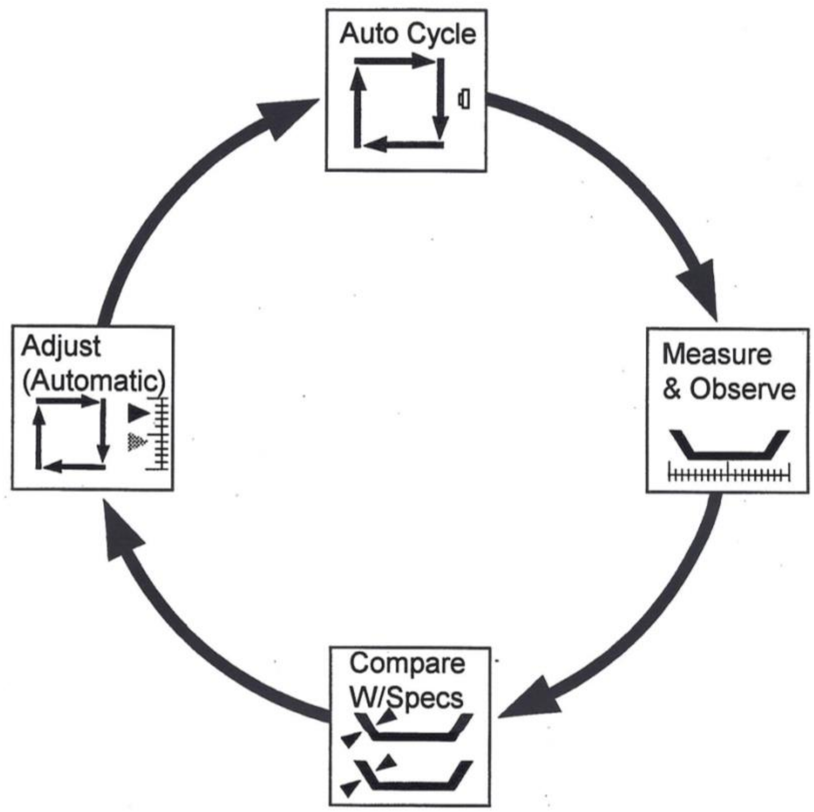

Figure 2 - Closed Loop Control System

Figure 2 is a diagram of a closed loop control system. Closed loop systems are able to make corrections on the machine. The loop is closed because the process controller can actually change valve settings, temperature settings, and other machine parameters to try to bring process parameters back into line.

For example, a closed loop system might monitor a cavity pressure sensor located behind an ejector pin in the mold. Each cycle, a computer records the cavity pressure measured off the sensor. A molding technician or supervisor tells the computer that the ideal cavity pressure is 1200 psi. The computer has also been told that the pressure can vary by up to five percent without a big effect on part quality. A closed loop controller monitors the cavity pressure each cycle. When the cavity pressure falls outside the acceptable limits, the controller can send signals to a hydraulic servo-valve, opening the valve to send more oil to the screw and plunger. When the screw moves faster, it causes the cavity to pack sooner, bringing the cavity pressure back up to where it should be.

Closed loop systems cannot decide what parameters make a good part. They can only respond to input from the technician. You must still know how to make a good part. Closed loop systems make the process more repeatable and consistent.

There are two types of closed loop systems: real time and adaptive. Real time process control systems try to make changes in machine parameters during the current cycle. Real time process control systems depend on valves and sensors that work fast enough to react to machine changes during the shot. Adaptive process control systems try to make changes in the machine parameters on the next cycle.

Objective Two

Setting Transition Points

The forward motion of the screw is usually divided into two phases, as shown in Figure 3. The first (boost) stage that is usually used to fill and pack the cavity, and the second (hold) stage that is used to hold the plastic under pressure while it cools.

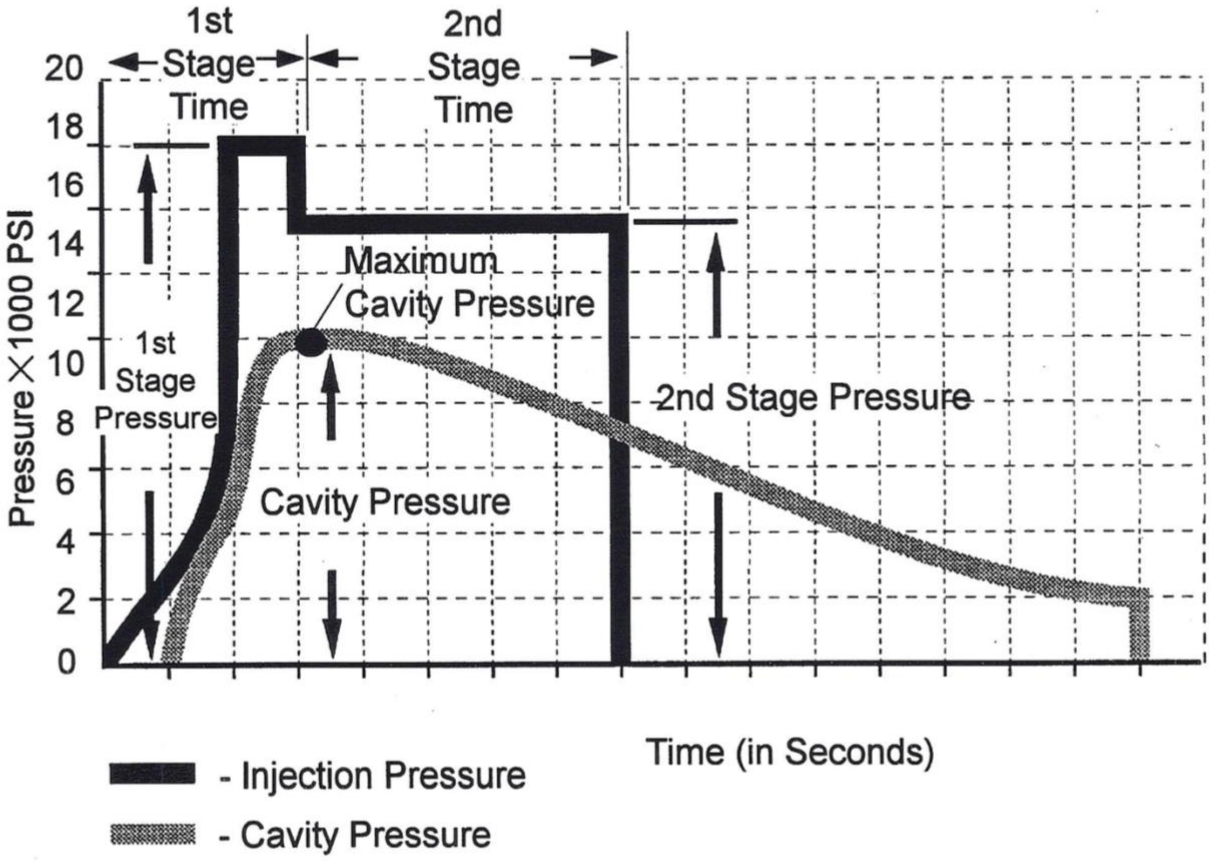

Figure 3 - Fill Time and Hold

The main purpose of the first stage injection pressure is to move the screw forward and fill the cavity rapidly. A high volume hydraulic oil pump moves the screw forward very quickly, and injects the plastic into the mold. The first stage pressure is usually higher than the second stage, and therefore does most of the packing.

The second stage, or holding pressure, pump is a lower volume pump that takes over the job of maintaining pressure on the melt in the cavity while the part solidifies. The main purpose of the holding pressure pump is to save energy by maintaining pressure with a lower volume pump. Lower volume pumps do not use as much energy as higher volume pumps.

The transition point is the point where the machine switches between the first stage pump and the second stage pump. Switch-ing at the proper time between the first and second stage greatly influences the fill rate, and the amount of packing. These parameters affect the amount of orientation put into the part, and determine the cavity pressure and packing effects at the gate.

Cavity pressure is one of the four most important parameters that determine part characteristics. The switchover from first stage to a lower second stage pressure can keep the cavity from over packing. The pressure change needs to occur at the same time for every cycle. If the transition point occurs too soon, the peak cavity pressure will not be reached during the first stage time. This means the part will be packed under the lower second stage pressure causing a lower peak cavity pressure. This could result in sink marks or undersized dimensions. If the transition point occurs too late, the part could easily be over packed and stick in the mold. Excess energy will also be expended if the first stage pump is allowed to run too long. Finding and maintaining the right transition point is critical to good molding.

Some machines may use three stages of injection. They may be set up to fill and pack with different pressures, and then go into the holding pressure.

Many newer machines have multiple holding stages. Each successive stage can be set to a lower holding pressure. If done gradually, this allows a smoother reduction of pressure on the cavity. This can help control warping caused by abrupt changes in part densities due to quick hold pressure changes during cooling. When using this type of control system, the boost pressure and primary hold pressure should be established first, and then the reduced holding pressure profile can be set.

Setting Transition Points in Open Loop Control

There are two different ways that transition points can be speci-fied on open loop systems. The switchover can be based on injection time or screw position. They both have their advantages and disadvantages. Most open loop machines can be set either way. The molding technician often needs to decide which one to use.

Remember that with open loop controls, there will not be a cavity pressure curve for the technician to view. The main characteristic that can be used as a reference point is the end of the screw or the screw travel indicator. The end of the screw travel signifies that the cavity filling is complete.

Time

The examples in the lesson up to this point have used "time" to determine when the transition point occurs. The length of the first stage timer determines the transition point. -When it times out the system will VP-transfer to the second stage timer (Figure 4).

Time based systems are usually easier to visualize and to set up. One disadvantage of time based systems is that the transition point will trigger at the same time, regardless of the position of the screw.

For example, if the viscosity of the material was to increase, the screw would move slower, and the timer would trigger the holding pressure too soon. This could cause under-packing of the cavity. It is safer to set the first stage time about a second longer than the point where the screw bottoms out to allow for natural variations.

Exercise Two

VP Transfer

On several machines, determine the VP transfer position and pressure.

Machine Number	Transfer Position	Transfer Pressure

Instructor Date

Screw Position

The other way to set up the transition point is by using screw position as a reference point. The molding machine must be equipped with a screw position transducer that tells the machine controls exactly where the screw is in the barrel. The machine controls must first be put into the position (or stroke) mode, instead of the time mode. Then, on the first few shots, the shot size must be established. Finally, a stroke position transition point can be set near the end of the screw travel, as shown in Figure 5.

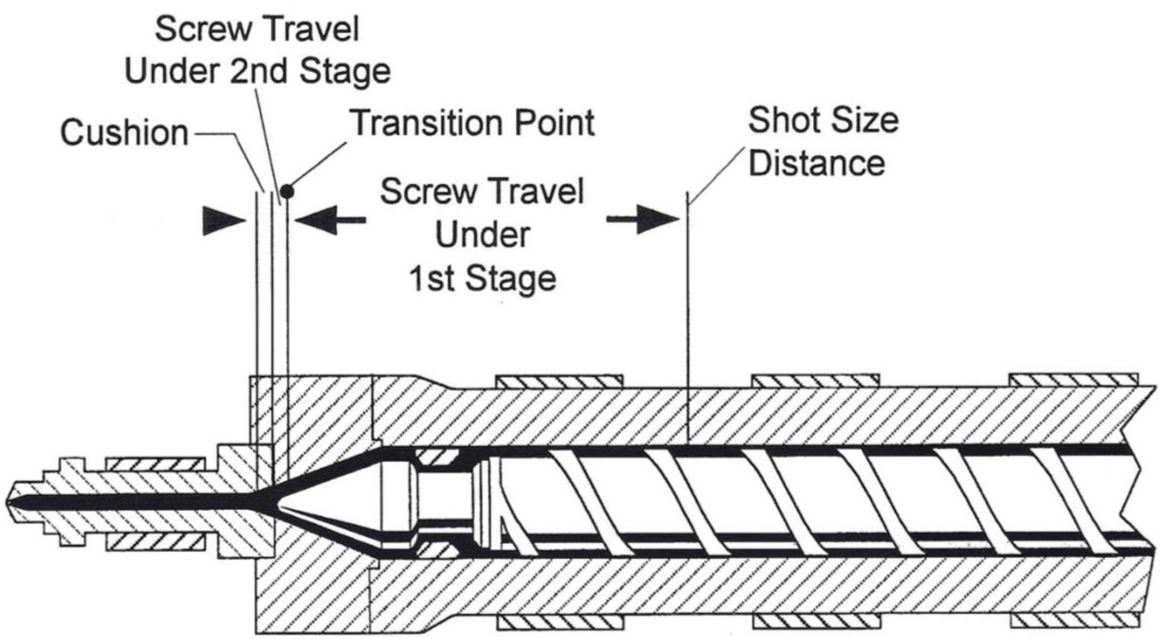

Figure 4 - Transfer Based on Screw Position

When the screw passes the transition point, the second stage pressure will be activated. The second stage is still a timed stage, and will continue to hold the screw forward until the timer times out. The transition point is activated during the injection forward movement, regardless of how long it may take the screw to reach that point. Position based controls are less sensitive to viscosity changes, and are also more adaptable to closed loop control.

One disadvantage of position based systems is that, in some circumstances, the screw may pick up extra plastic material. If the transition point has been set very close to the end of the stroke, the screw may never reach the transition point. If the transition point is not reached, t e machine will not kick into second stage. The second stage timer will not time out to signal the start of screw recovery, and the cycle will not continue. This will shut down the machine until the cycle can be restarted. The transition point may need to be reset at a point further back in the barrel to prevent the problem from occurring.

Closed Loop Transition Points

Injection molding machines typically use one of two main ap-proaches to closed loop process control. The transition to second stage is usually based on feedback on the hydraulic injection pressure, or cavity pressure.

Injection Pressure

Closed loop systems that monitor injection pressure typically read hydraulic oil pressure from a pressure sensor or transducer. The controller is set to make the transfer to the second stage pump when hydraulic oil pressure reaches a certain level or set point. The assumption is that hydraulic oil pressure will climb as the cavity pressure climbs. When the hydraulic pressure reaches its set point, the cavity will be filled and packed, and the transfer to the second stage pump can take place. Closed loop control systems based on injection pressure are generally very reliable. They are dependent, however, on the accuracy and durability of the pressure sensor in the hydraulic system.

Cavity Pressure

Closed loop systems that monitor cavity pressure typically read the cavity pressure from a sensor or pressure transducer mounted behind an ejector pin in the mold. The controller is set up by the molding technician to keep cavity pressure within certain limits. The controller is instructed to make the transfer to the second stage or holding pressure pump when the actual cavity pressure reaches a certain level.

Since cavity pressure is one of the four key processing variables, using it for closed loop feedback is one of the most accurate ways to maintain consistent part properties. One disadvantage of cavity pressure systems is that the sensors are prone to damage from the repetitive shock of the mold closing.

Packing the Cavity under Second Stage Pressure

Occasionally, a large mold is put into a machine without quite enough clamping capacity to hold it shut. This can make it difficult to fill and pack the part without flashing. In other cases, the parting line might be damaged, or have a poor fit, which can create the same problem.

One processing solution in these cases, is to fill the mold about ninety-five percent full under low pressure, which allows the skin to start to solidify. Then the transition can be made to the second stage. This is done with a higher second stage pressure that completes the filling and packing.

The higher second stage pressure will not flash the part as easily as the same first stage pressure would have, because the skin has already started to solidify. This procedure can be done with either a time, position, or pressure based transition point. Figure 5 shows the transition point between first and second stage, when packing the cavity with second stage pressure.

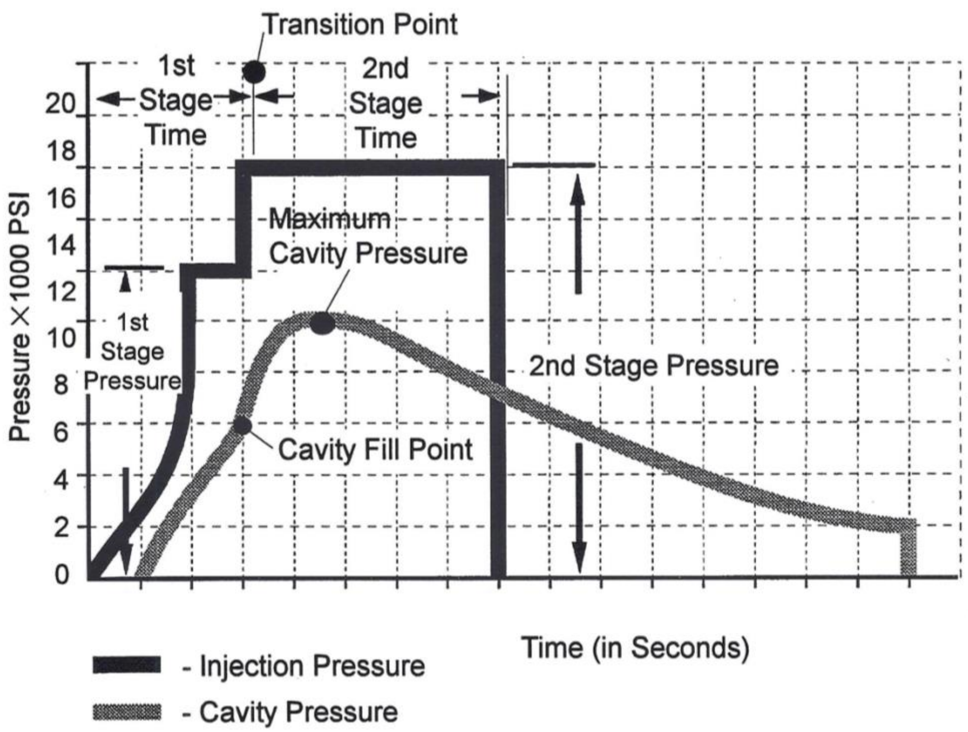

Figure 5 - Packing the Cavity with Cavity Pressure

Objective Three

Controlling Fill Time with Speed Profiling

The goal of cavity filling is to fill as fast as possible without creating any part defects, or flashing the mold. Faster fill reduces orientation, reduces the difference in cavity pressure between the gate and the far end of the cavity, and improves the cycle time.

The typical speed profiling procedure for minimizing surface defects, while maximizing fill rate, is to inject the melt slowly until it passes the gates. At this point, the speed is rapidly increased to fill the cavity as quickly as possible .

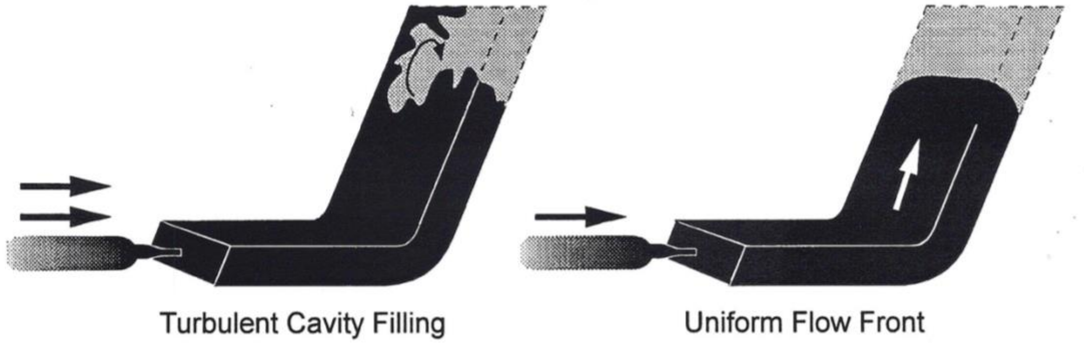

Figure 6 - Cavity Flow Rate

Filling the cavity too quickly can lead to problems such as jetting, splay, or blush at the gate. Jetting is snakelike marks on the surface of the part near the gates. High injection speeds push the melt through the gates so fast that the plastic splits into individual streams. Turbulent flow is also caused by excessive injection speed. The plastic comes into the mold so fast that it sprays against the cavity walls and freezes before it can be properly packed. This causes splay or blush marks. Ideally, the fill rate has a single smooth flow front that fills out into the cavity. Figure 6 shows plastic filling a cavity with turbulent flow, and ideal flow.

If molds were transparent, you could see the melt reach the gates and adjust the speed accordingly. In reality, you have to make an educated guess as to where the flow front reaches the gates.

Think about the overall volume of the runner system. Then think about how much of the barrel that much melt would fill up. After a little trial and error, you should be able to visualize the inside of the mold, and translate those ideas to screw position.

It is also a good idea to fill slowly whenever passing ribs, side walls, or projections. This allows the melt to fill the adjoining feature more easily. If the melt front goes too fast past one of these features, the side wall will end up back filling later. By then, the plastic that partially filled the side wall earlier will have cooled off and will not pack out as well.

Objective Four

Why Molding Parameters Change

There are many reasons why machines drift out of tolerance. Even the best closed loop control technology is challenged to make fine adjustments continuously. The process can change because of variations in the machine, the environment around the machine, or the material.

Changes in the Machine

Injection Speed Variations

Injection speed can vary for a number of reasons. The speed of the screw/plunger during injection is dependent on the amount of force pushing it, and the amount of resistance slowing it down.

Changes in the hydraulic system will change the amount of force pushing the screw forward. If the hydraulic pressure to the piston changes, the force that moves the screw will also change. The hydraulic force can also change because of a change in oil temperature.

Oil is a viscous liquid. Like plastic, the viscosity of oil depends on its temperature. Hot oil is less viscous (runnier) than cooler oil. If the temperature of the oil in the hydraulic system changes for some reason, the flow of oil to the piston will also change, adjusting the force pushing the ram forward and finally changing the injection speed (Figure 7).

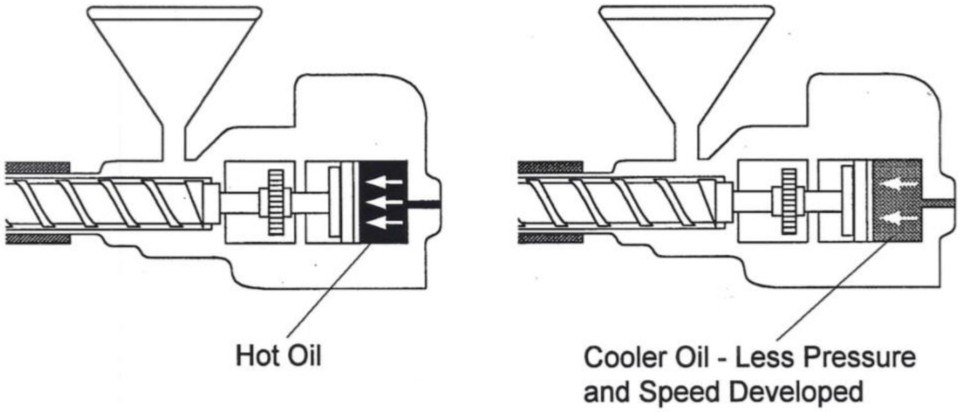

Figure 7 - Oil Viscosity

Even if the hydraulic system is completely steady, changes in the resistance to the screw can also change the speed. More resistance will slow the screw down. Less resistance will speed the up screw. There are a number of ways the resistance to the screw might change.

Internal friction between the screw and the barrel can change due to wear. As interior surfaces wear away, there may be less contact between the screw, the check ring, and the barrel. This will reduce the resistance to the screw and cause the screw to speed up. On the other hand, tramp metal or other foreign material can clog the check ring. This creates a pressure drop, and will cause the screw to move slower.

The viscosity of the melt is its resistance to flow. The more viscous the melt, the more of a fight it will put up against the movement of the screw. The melt viscosity can be affected by many different variables. The amount of regrind may have changed, a heater band may have come loose, or a bay door could have been left open and let in enough cold air to cool off the barrel.

If there is a change in the viscosity of the melt, the resistance to the screw will change, which will change the fill rate of the cavity and the physical characteristics of the parts. Figure 12 shows how screw speed varies as the viscosity of the plastic changes .

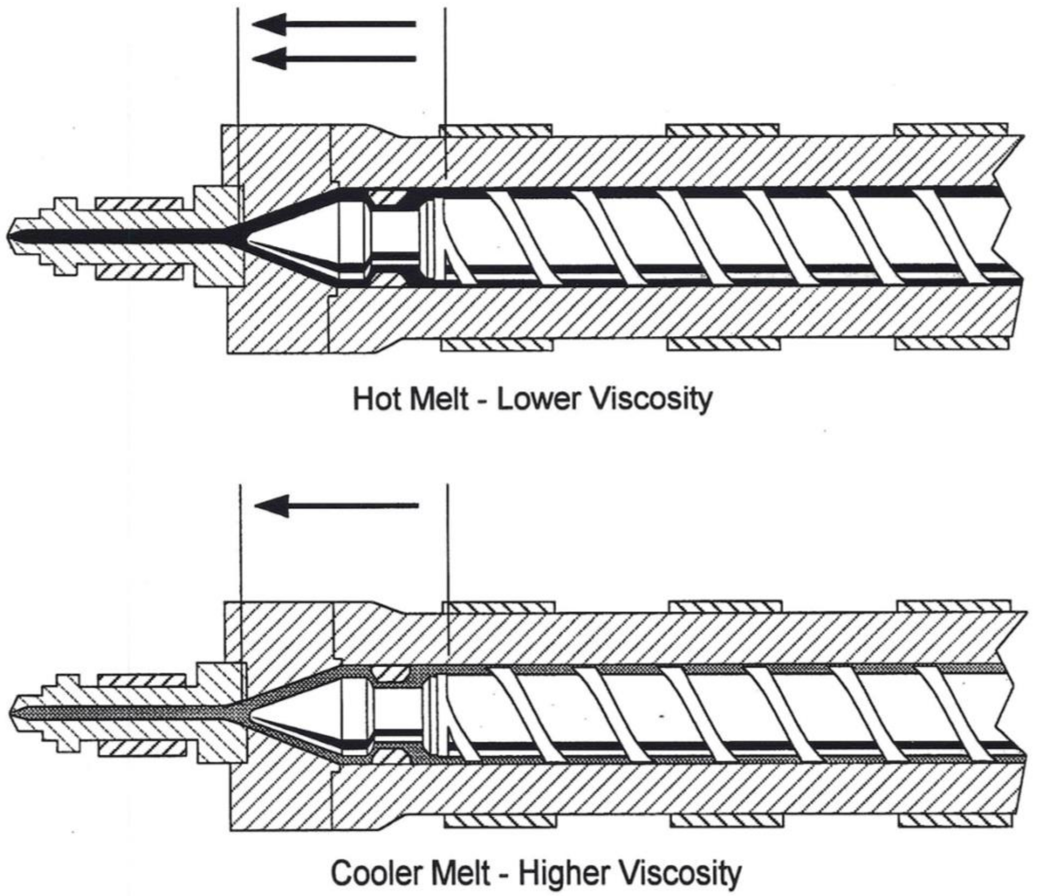

Figure 8 - Plastic Viscosity

Temperature Variations

Barrel temperature, nozzle temperature, and mold temperature, are monitored by temperature controllers. In a sense, the tempera-ture controller's job is more difficult than other controllers. Temperature changes usually do not happen suddenly. Changes in barrel temperature or mold temperature may take hours or days to become evident. Even worse, corrections to temperature settings are also gradual. It may take half an hour before a change to the heater band's setting actually changes the melt temperature.

Because of the ever changing nature of temperature settings, temperature controllers are set or tuned to respond more gradually to changes in temperature. Temperature controllers need very sophisticated instructions on how to adjust temperatures when they fall out of tolerance. For example, if the controller waits until the temperature is unacceptable before changing the heater set-tings, it may be thirty minutes before the temperature comes back to acceptable limits. All the parts made during that time would be scrap. That would be thirty minutes of unnecessary downtime. The controller must take action quickly to solve the problem early.

On the other hand, it is easy for the controller to react before anything is really wrong. If the temperature drifts only a few degrees (say for example, that for ten minutes each day the morning sun falls directly on the barrel, making the temperature thermocouple read higher) the controller may change the heater settings, when the problem would have corrected itself, without interference by the controller. The controller will later have to react to these changes as further deviations from the desired temperature.

Overall cycle time can also account for changes in temperature readings. The amount of time the melt spends in the screw waiting for the next injection has a direct bearing on its temperature during injection. Even slight changes in cooling time, mold open time, or the time it takes the molding technician to pull the part out of the mold can cause a change in the material temperature and therefore the rest of the process.

The Molding Technician

When a molding technician is pulling the parts out of a machine, the overall cycle time is dependent on how long the safety gates stay open. If molding technicians get tired at the end of the shift, they may start leaving the gate open longer. Inconsistent mold open times can change the process considerably.

Exercise Three

On several machines where the parts are being re-moved by hand, count the number of seconds that the safety gate is open. Do this for several cycles and record the times below.

Machine Number	Part Being Made	Time Gate Open

Instructor Date

Changes in the Environment

The molding machine does not exist in a vacuum. It stands in a factory, surrounded by people and an environment that constantly influence its behavior. There are a number of human and environmental factors that can cause molding parameters to change, as shown in Figure 13.

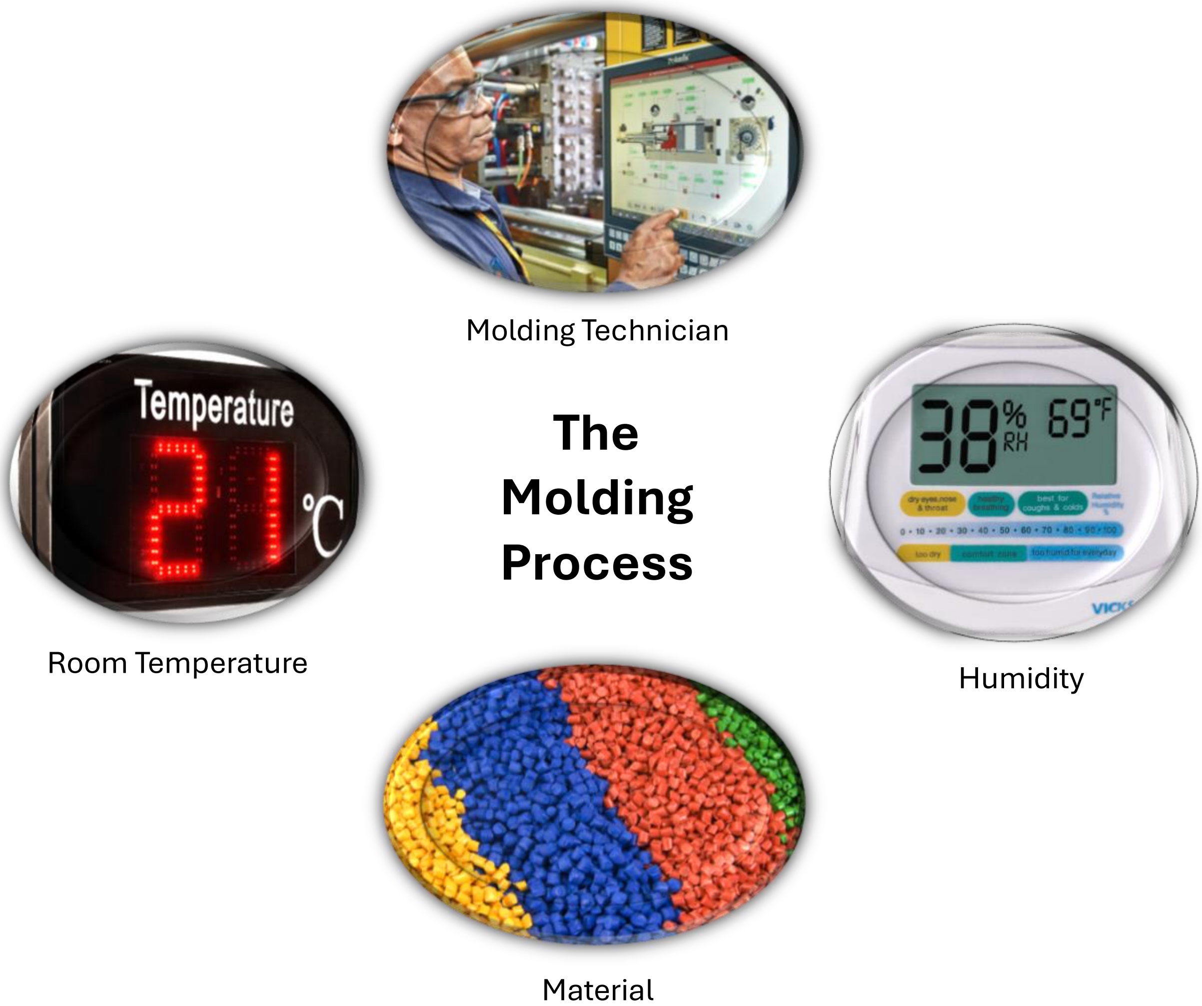

Figure 9 - Variables in the Molding Process

Room temperature and humidity can have a great effect on the process. Except in outer space, no temperature exists in isolation. Room temperature has a direct effect on the melt and mold temperature. As room, or "ambient," temperature changes during the day, or from one day to the next, the overall process will change to reflect these differences.

Humidity also greatly affects the molding process. On a humid day, there is more water in the air. Water in the air can be absorbed by the plastic, causing more splay problems. High humidity can cause condensation on the molds. This is one reason for keeping the mold closed during a shutdown period.

Changes in the Material

Changes in the character of the plastic material can easily change the overall process. The percentage of regrind added to virgin material can have an effect on the viscosity of the overall melt. Different lots of material can have slightly different properties. The processing conditions should always be checked if a different material or additive is introduced to the process.

Objective Five.

Tuning a Controller

Tuning the controller means specifying how the controller should respond when a molding or machine parameter falls out of the allowed values. Tuning tells the controller when to make changes, how fast to make the changes, and how big a change to make on the machine.

Controllers need sophisticated and detailed instructions on how to respond to changes. If we tell a temperature controller, such as the one in Figure 10, to turn on the heat when it gets below 165°F, and turn off the heat when it gets above 185°F, the temperature could fluctuate wildly. What we really want is to find a way of teaching the controller some type of logic that will keep the temperature very close to 165°F all the time.

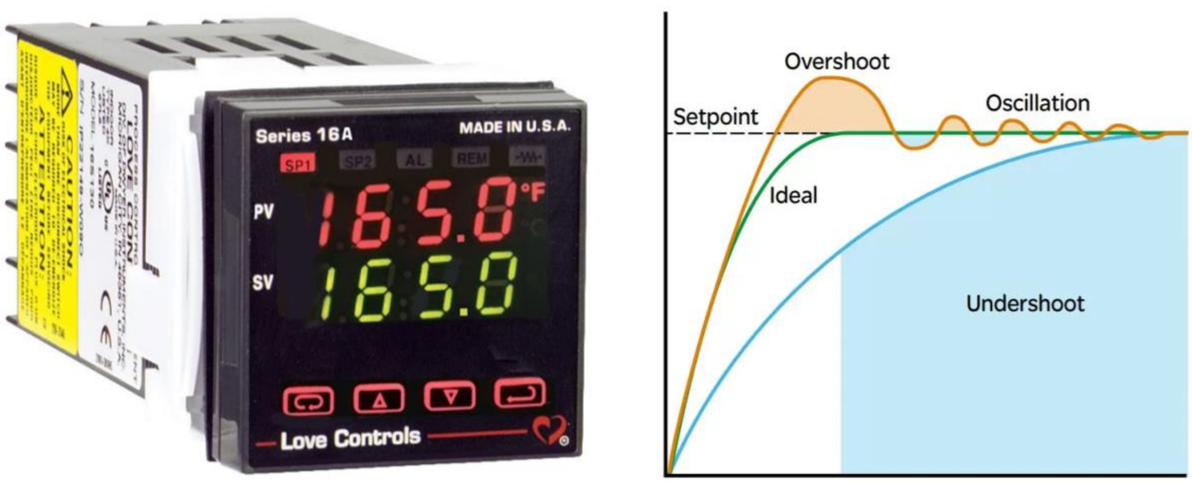

Figure 10 - Temperature Controller Tuning

PID

PID tuning stands for Proportional, Integral, Derivative tuning. It is one of the most effective and popular ways to tune a controller. Proportional, integral, and derivative tuning are descriptions of the kinds of logic we want the controller to use when it makes changes. Each type of tuning is a kind of logic that tells the controller how to respond to changes. The three types of logic, or tuning, work together to force the controller to keep the machine at or near the desired set points, no matter what happens in the machine's surroundings.

Proportional Control

Proportional control is sometimes called gain. Proportional control means the controller makes changes based on how far off the measured parameter is from the set points. Changes are made proportional to the deviation from the setting.

Integral Control

Integral control is sometimes called reset control. It resets the size of the allowed windows for proportional control. Proportional, control alone tends to stabilize somewhere off the exact desired set point. Integral control adjusts the size of the allowed deviation so that the proportional control will bring the process to the really desired set point. Integral control fools the proportional control logic by adjusting the size of the allowed window, until proportional control is keeping the parameter where it really needs to be, instead of where proportional control thinks it is supposed to be.

Derivative Control

Derivative control is sometimes called rate control. Derivative control responds to the rate the parameter falls out of tolerance. The faster the parameter keeps falling out of tolerance, the stronger the response from derivative control. Derivative control, in effect, intensifies the effects of proportional control. If the parameter is getting a lot worse with each shot, falling more and more out of tolerance, derivative control speeds up the changes to bring the parameter back. If the parameter is only nudging out of tolerance, derivative control keeps the response changes reasonable. Rate control helps avoid the constant fluctuations that sometimes occur with proportional and integral control only.

Together, proportional, integral, and derivative controls teach the process controller the logic it needs to respond to parameter changes.

Self-Test

1. Open loop controls monitor the process, and then make adjustments to the process?
   a. True
   b. False
2. The most important transition point during the injection phase of the cycle is between:
   a. Injection Velocity and Pressure
   b. Injection Time and Pressure
   c. Injection Position and Pressure
3. When time is used to transfer from injection velocity to pressure, the transition point is usually set:
   a. Just as fill is complete
   b. About a second after fill is complete
   c. About a second before fill is complete
4. When position is used to transfer from velocity to pressure, the transition point occurs:
   a. Just as the cavity fills
   b. Before the cavity fills
   c. After the cavity fills

5. Other than cavity pressure, the most common method of transfer is:
   a. Injection Pressure
   b. Fill Time
   c. Screw Position
6. The major problem associated with injection speeds that are too fast is:
   a. Surface defects
   b. Burning the material
   c. Over-packing
7. The typical speed profile is set up to get the material:
   a. To the gate quickly and then slow down
   b. To the gate slowly and then speed up
   c. To fill the cavity quickly and slow down for packing
8. Variation in which one of the following parameters should <u>not</u> affect melt viscosity:
   a. Regrind percentage
   b. Hydraulic oil temperature
   c. Room temperature

9. If an operator starts to allow the safety gate to remain open longer each cycle, the process can change considerably:
   a. True
   b. False
10. The purpose of PID tuning of controllers is to minimize fluctuations in a machine parameter.
   a. True
   b. False

Glossary

Cavity Pressure Sensor - a sensor or transducer that is usually used behind an ejector pin to measure the melt pressure in the cavity.

Closed Loop Control - a control system that monitors and automatically adjusts parameters which exceed their preset range.

Injection Speed Profile - the preset variations in the forward speed of the screw throughout its complete travel during ejection.

Open Loop Control - a central system that monitors processing parameters according to a preselected range.

PID Control- a specific type of tuning used on machine controllers to maintain a set point accurately within a very small range.

Pressure Transducer - the actual pressure sensing device that can be used to measure mold cavity pressure or hydraulic pressure.

Velocity-Pressure Transition Point - the time or stroke point where the injection process is switched over from velocity control to pressure control.