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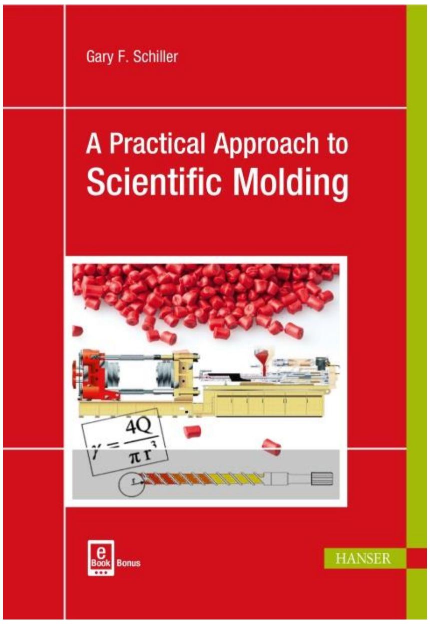

Sample Pages

A Practical Approach to Scientific Molding

Gary F. Schiller

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Preface

This book is designed to help today's plastic molding technician deal with processing issues found day to day in the injection molding environment. It not only describes the functions of the molding machine, but also the auxiliary equipment associated with the process to produce quality parts. The chapters in this book will help the user to have a more thorough and hands-on understanding of the molding machine and the material.

It explains the process from the plastics point of view, and how the material is heated, flowed, packed, and cooled to produce the desired quality parts.

This processing guide not only shows users how to find a solution to the problem but also lets them understand why they are making the change, and what effect it has on the plastic. It details solutions from a hot runner/cold runner standpoint.

Each material has a different characteristic and will present problems in different ways, but through learning to read the part and analyzing the machine, the necessary insight will be provided to remedy most issues seen in everyday molding.

The most important thing to remember when processing or making adjustments to any machine is to make just one adjustment, review the effects on the part, and if that change has no effect, return to the previous set point, before implementing another change. By making a lot of changes in the hope of solving the molding issue, it becomes unclear which change had the effect on the part. Look at the parts, watch the molding machine, and observe what each change is doing to the process and machine.

Never neglect the details:

- Walk around the machine and make sure the water is on to all lines going to the mold, or have any water lines been left off? Is the machine functioning properly (pressures, times, heating, with no unusual noises)?
- Make sure the mold is functioning as intended and able to produce the quality parts desired.
- Observe the material: make sure it is free of contaminants (dirt, foreign resin, or water) and is dried properly.

- Then review the process and make sure there are no shortcomings (process is not pressure limited, transfer position is being achieved, not timing out and cycle time achieved).

There are no magic solutions for eliminating all molding issues, but a solid understanding of these scientific molding principles will help eliminate the unnecessary waste and scrap generated from not knowing.

There are three major components to the injection molding process: the injection unit, the clamping unit, and the mold.

In the next chapters, we will discuss the different functions of each major component and how they affect the process and conditions of the material.

I would like to acknowledge and thank the following companies and people:

- RJG Inc. Traverse City, MI, especially Gary Chastain, Pat Mosley, and Shane Vandekerkhof.
- AIM Institute, Erie, PA, especially John Beaumont and Dave Hoffman.
- Technimark LLC, Asheboro, NC, especially Brad Wellington and Bruce Winslow.
- Milacron LLC, Batavia, OH, especially Kent Royer.
- I would also like to thank Gary Mitchell.

Gary Schiller

About the Author

- 37 years in the plastics industry
- Certified Master Molder I, II, & Train the Trainer; past RJG instructor with over 27 years of scientific molding experience
- AIM Institute graduate and alumnus – Plastics Technology and Engineering
- AIM Institute Advisory Board
- Practical Rheology in Injection Molding – Penn State, Erie, PA
- Design of Experiments & Quality Engineering Methods – University of Colorado
- TQM – Front Range Community College, Denver, Colorado
- Certified Mechanical Inspector ASQ
- Certified Quality Technician ASQ
- Processing expert with a wide array of plastics

Core Competencies

- Stack molding
- Cube technology molding
- Two shot molding
- Insert molding
- High cavitation molding
- Engineering and commodity resins

1 Injection Unit: Screw

In this chapter we will discuss the components and functions of the injection unit, and how each play a role in the preparation of the plastic.

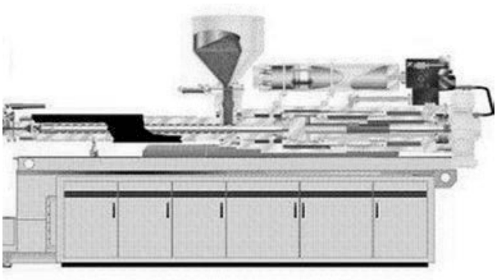


Figure 1.1 Injection unit

1.1 Prepares the Melt

There is mechanical heating, caused by the friction or shear inside the barrel, from the plastic pellets being rubbed against the barrel wall and compressed inside the flights of the screw.

There is electrical heating, from the heater bands on the barrel. They are used from a cold start to heat up the barrel and plastic. After a proper amount of soak time (30 minutes), start to rotate the screw. The barrel heater bands are to maintain the temperature in the barrel so the plastic does not hit any cold spots.

Once the barrel is up to heat, start to extrude plastic through the barrel. About 80% of the heat comes from the shearing process and 20% from the electrical portion. In Figure 1.2 you can see the shaded sections representing the different sections of the screw.

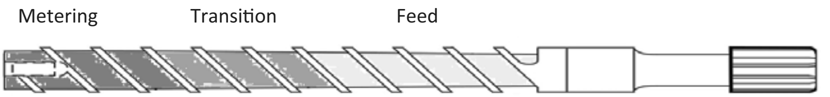


Figure 1.2 Reciprocating screw

In Figure 1.3 it is shown how the plastic in each section has a circular motion inside the flight. There is a melt pool on the back side so that as the screw rotates the melt pool pushes the unmelted pellets forward and up against the barrel wall. As the unmelted pellets rub against the barrel wall it creates friction, and that friction causes the pellet to melt and go into the melt pool.

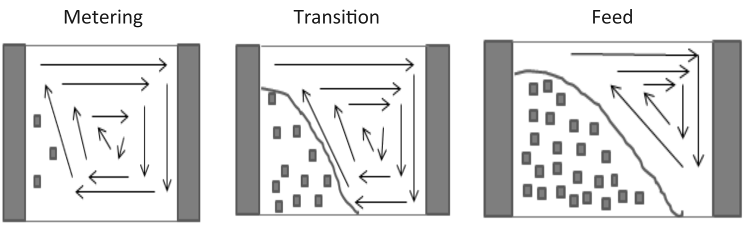


Figure 1.3 Melting of the plastic in different sections of the screw. Courtesy of AIM Institute

1.2 Flows the Melt

There is a hydraulic unit and valves that provide the oil flow and pressure needed to inject the plastic.

The injection velocity set point will give and maintain the speed of the ram coming forward and it must have ample pressure and flow to push the plastic. To ensure the injection high limit pressure set point is never reached (pressure limited) the valve is either restricted or opened depending on the feedback it receives from the linear transducer on what velocity or injection speed is desired. Also understand the influence the injection velocity has on the rheological properties of the material: plastics typically show non-Newtonian behavior, which means the faster the material is shot or the faster the flow rate of the plastic, the thinner the material becomes and the easier it will flow.

1.9 Injection High Limit Fill Time

The injection high limit fill time is a safety feature added to the machine to protect the tool and process. This timer should be set just above the actual fill time of the press. It provides the protection that if the transfer position is not met, then the timer will engage and transfer the press.

This timer provides the safety needed so that if one of the cavities blocks off in a multi-cavity tool, the high limit timer takes over and transfers the machine to the lower pack/hold pressure.

For example, if the molding machine has a constant fill time of 0.74 seconds, set the timer 0.1 seconds above to 0.84 seconds. Another purpose is if there is a viscosity change and the fill time starts to increase, then this timer will alarm out and notify that something has changed in the process.

1.10 Injection Pack Pressure/Time

Injection pack pressure is used to complete the filling process and imprint the plastic to the cavity surface. This pressure is used to pack all the material in that is needed to achieve gate seal and hold dimensional tolerances, in a two-step process (fill and pack). This pressure is usually lower than the fill pressure and depending on part geometry and wall thickness, this part of the process is time dependent and will require enough time to complete the process.

1.11 Injection Hold Pressure/Time

Injection hold pressure is used to hold the material that was injected into the part; this phase requires just enough pressure so the screw does not move backwards. If the screw moves backwards then the plastic that was put into the cavity is now starting to push back out because of the internal cavity pressure and cause dimensional variation, and a reduction in pack around the gate area. Watch the cushion! (The cushion is the amount of plastic left in front of the screw at the end of fill-pack-and-hold, and should never move backwards during any of these phases.)

This part of the process is time dependent and will require enough time to complete the process.

It is all about the pack rate of the material and part, and sometimes you do not want an actual gate seal because the flow front has stopped moving furthest from the gate and still packing at the gate causes differential pack rates or differential shrink rates, which can cause dimensional variation.

1.12 Non-return Valve Function

The function of the non-return valve is to allow plastic in front of the screw while the screw is rotating back (see Figure 1.10, Figure 1.11, and Figure 1.13) but to seal off during injection. Even though various non-return valves are designed differently, they serve the same function. There is a clearance between the outside diameter of the non-return valve and the inside diameter of the barrel. this clearance is generally 0.003″ to 0.005″ per side but can vary depending on manufacturer; review the specifications for individual presses. This clearance allows for thermal expansion of the steel as it heats.

When this gap increases or wear happens, leakage over the non-return valve will increase. When this happens, the non-return valve not only loses the ability to pressurize properly; there is a loss of the cushion of material left in front of the screw at the end of pack and hold.

When the material is squeezed between the non-return valve and barrel wall, the material will shear heat. When material shear heats because of the leakage, there are two different viscosities of material, and therefore there will be two different shrink rates from two different cooling rates in the material.

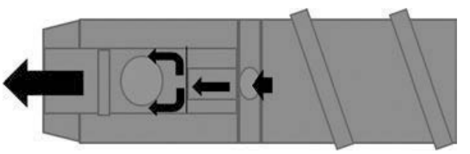


Figure 1.10 Flow through a ball non-return valve (cut-away)

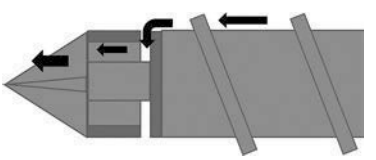


Figure 1.11 Flow through a sliding (3pc) non-return valve (cut-away)

■ 2.2 Thermocouples

Thermocouples provide feedback to the HMI controller; they sense the temperature of the steel in that section of the barrel. Looking at the barrel on the injection unit, it can be noticed that the thermocouple is located between the two heater bands in that zone. This is to reduce the chance of over- or under-heating in a certain zone.

Care must be taken at the thermocouple holes to avoid debris and contamination as this can cause a false reading. Avoid spilt material and make sure the T/C touches the bottom of the hole without interference.

Figure 2.3 Spade-type thermocouple. Photo Courtesy of Technimark LLC

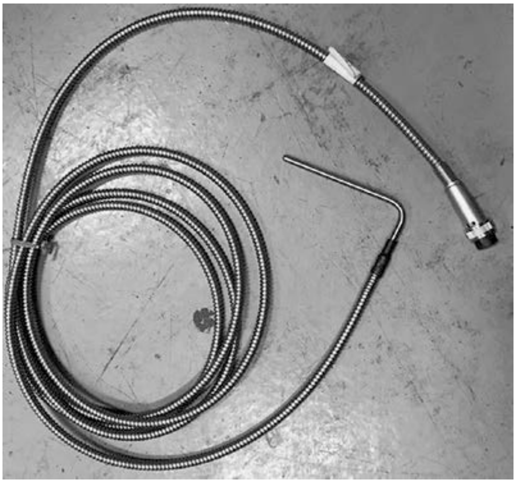


Figure 2.4 90 degree bend. Photo Courtesy of Technimark LLC

Thermocouples are two dissimilar materials or metals that have a predictive voltage at a specific temperature when combined. See Figure 2.11 for type and color coding.

The two wires are fused or soldered together at the very end. This is the contact point (Figure 2.5). If the thermocouple wires are separated or broken away at the true reading location, the new touch area is where the reading will come from (Figure 2.6). No matter where the wires touch, that is where the voltage for reading is generated, and if it is in the wrong place, a false reading of temperature is received.

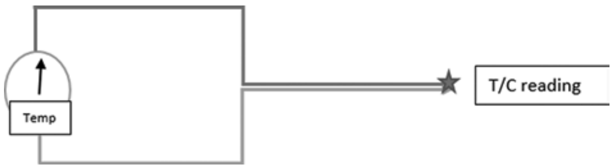


Figure 2.5 Proper T/C reading

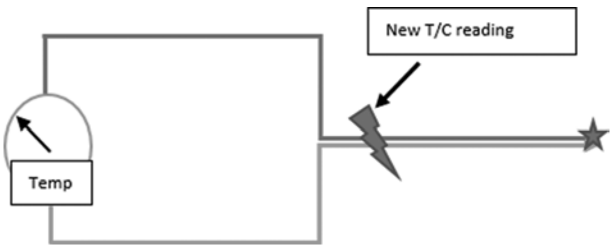


Figure 2.6 Broken or pinched T/C wire

Figure 2.7 J type T/C plug

For the diameter, a value of 3.990″ is given here. Most locating ring holes in the platen are 4.000″ so make the purge disk just under that so it does not stick in the locating ring hole. Some machines have a larger locating ring hole and that is where the magnet comes in handy.

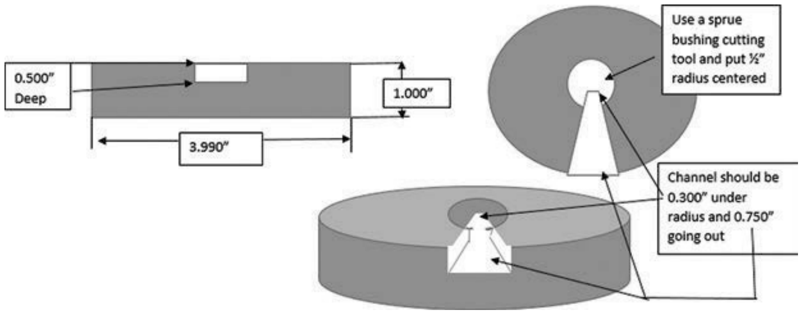


Figure 5.3 Drawings for a purge disk

5.3 Pressure Response

Pressure response is a test that is done to find out when the pressure stabilizes after machine shifts from transfers to the pack phase.

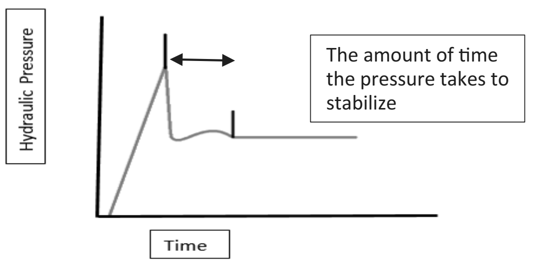


Figure 5.4 Pressure response

The importance of this test is to understand when the pressure drops below the pack pressure setting. The melt front has a chance to hesitate, and if this happens then it starts to freeze, which could cause visual and dimensional defects along with variation in process.

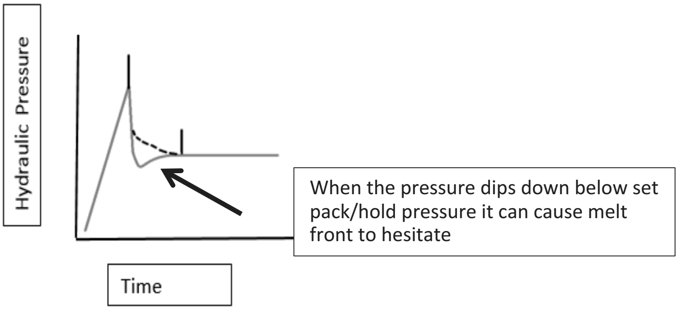


Figure 5.5 Melt front hesitation caused by pressure drop

If pressure is dipping down below set point, then it is necessary to set a profiled pack phase where a higher pressure is added for a couple tenths of a second as the first pack profile. This will help stabilize the pressure that is coming down from transfer to pack pressure set point.

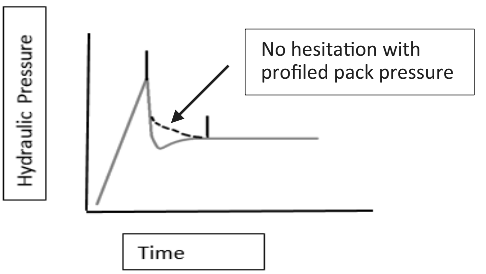


Figure 5.6 Pressure drop

Let's say there is a transfer pressure of 1850 psi and a pack pressure of 800 psi. To resolve the dip in pressure or screw bounce, add a pressure of 1200–1400 psi for 0.2 seconds. This will help with the transition of pressure and keep the melt front moving forward.

Experiment with the time and pressure to get the right combination; this will resolve the hesitation that was noticed previously.

5.4 Dynamic Non-return Valve Test (FILL)

1. Set machine to run 95%–98% fill process
2. Turn off pack/hold time and pressure
3. Increase the cooling time to compensate for the change in cycle time
4. Make 10 fill only shots, weigh the parts and runner(s), and record
5. Calculate the percentage change

Remember, the reason to weigh the runner with the parts is to determine the % change in the fill only shot, and how the non-return valve is working and shutting off. The acceptable limit is less than 3%. If the % change is higher than 3% then add some extra decompression or suck back to the machine and run the test over again. Adding the extra suck back or decompression will allow more room for the non-return valve to seat shut-off properly.

$$\frac{\text{Heaviest shot} - \text{Lightest shot}}{\text{Average shot weight}} \times 100 = \%\,\text{of change}$$

Acceptable range =< 3%

Example:

If our heaviest shot is 110.45 gm, our lightest shot is 109.21 gm, and the average shot weight is 110.01 gm, the equation would be as follows:

110.45 − 109.21 = 1.24

then 1.24 divided by 110.01 = 0.01127 × 100 = 1.13% → Acceptable

But if it had more variation shot to shot, then look at it like this:

111.25 − 106.24 = 5.01

then 5.01 divided by 110.01 = 0.0455 × 100= 4.55% → Unacceptable

If there is too much in the variation seen shot to shot, then it is confirmed that our non-return valve is not working properly during the dynamic or fill phase.

The example shown in Figure 5.7 below shows how an Excel spreadsheet is constructed.

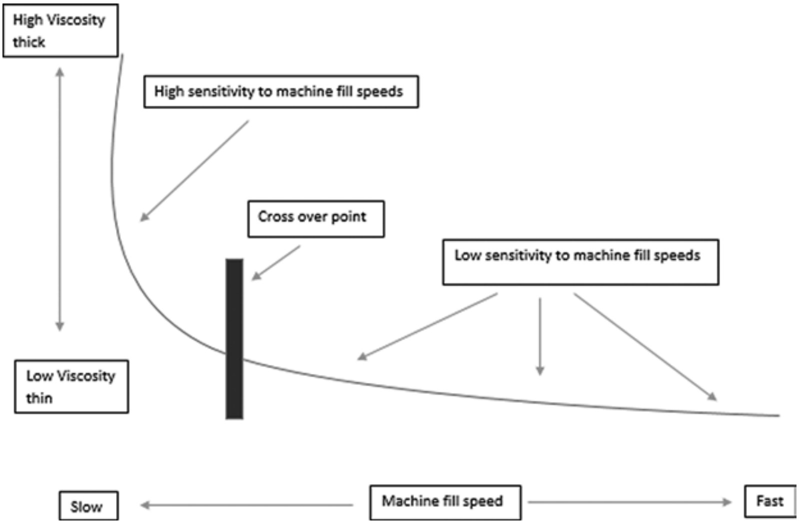


Figure 6.8 Rheology curve breakdown

Note that there are certain materials that do not like the fast injection velocities and must be run at slower velocities or closer to the crossover point (e. g., polycarbonate, PVC).

Let's look at the viscosity curve another way: it is all about managing variation within the process, and where on the curve is the smallest variation (Figure 6.9).

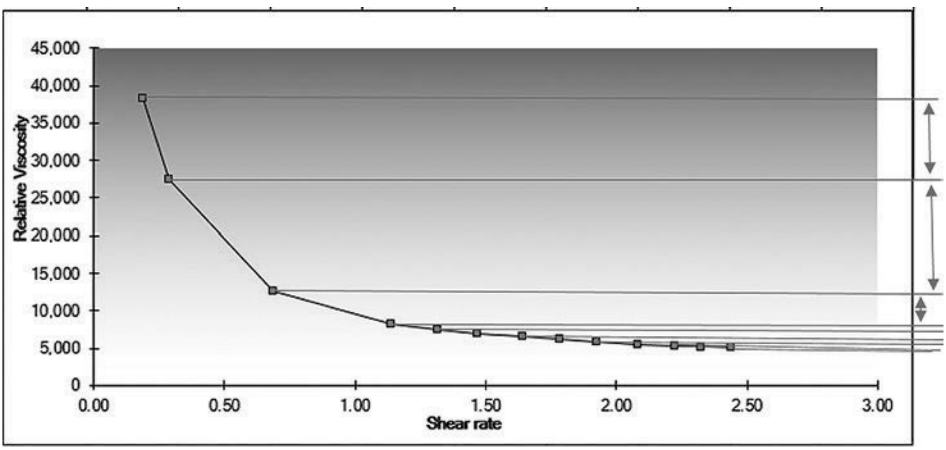


Figure 6.9 Rheology curve showing variation

6.4 Least Pressure Curve

The least pressure curve (Figure 6.10) is set up with the transfer pressure as the inputs and is designed to pick the least amount of pressure it takes to fill the cavity while still maintaining the proper shear rate. When running a viscosity test, the fastest plastic that is shot into the mold and the slowest plastic that is shot into the mold will usually be the highest pressures; this graph just tells where is the lowest pressure at transfer compared to the proper shear rate. The lower the pressure the easier the machine is working, minimizing wear.

Figure 6.10 Least pressure curve

6.5 Plastic Flow Rate (Qp)

This is the rate or speed at which the plastic flows into the mold and can be represented as Qp or flow rate of plastic. It is normally measured in cm^3/sec or in^3/sec.

As the plastic starts to flow into the cavity, it can become faster or slower depending on the part geometry. This is due to the area that the flow front is moving into. Keeping the flow channels as large as possible and having the same wall thicknesses will help prevent the changes in flow rate.

6.6 Shear Rates

Divide Q as needed as the plastic flows through the delivery system.

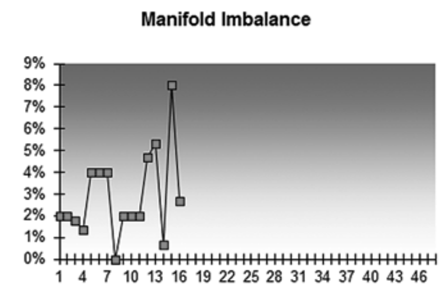
Qtotal is the total volume to be injected during fill or fill time. It refers to the total amount of plastic that is injected out of the nozzle (remember this is a certain amount of material at a specific point) and is the same as that observed in the sprue, as this would be handling the same amount of plastic as being injected out of the nozzle. As the material starts to go through different sections of the runner

MANIFOLD BALANCE TEST

PRODUCT:		PART No:	
JOB No:		MOLD No:	
PROJECT:		CAVITIES:	16
PRESS No:			

CAVITY	AVERAGE PART WT (GRAMS)	FILL SEQUENCE	AVERAGE % IMBALANCE		PARTWEIGHTS (GRAMS) SHOT 1	SHOT 2	SHOT 3	Analysis of Fill From Mean Weight
1	4.900	8	2%	0	4.90	4.91	4.89	-0.9%
2	4.900	8	2%	0	4.80	4.90	5.00	-0.9%
3	4.910	4	2%	0	4.90	4.93	4.90	-1.1%
4	4.933	3	1%	0	5.00	4.90	4.90	-1.6%
5	4.800	11	4%	0	4.80	4.80	4.80	1.1%
6	4.800	11	4%	0	4.80	4.80	4.80	1.1%
7	4.800	11	4%	0	4.80	4.80	4.80	1.1%
8	5.000	1	0%	0	5.00	5.00	5.00	-3.0%
9	4.900	5	2%	0	4.90	4.90	4.90	-0.9%
10	4.900	5	2%	0	4.90	4.90	4.90	-0.9%
11	4.900	5	2%	0	4.90	4.90	4.90	-0.9%
12	4.767	14	5%	0	4.80	4.80	4.70	1.8%
13	4.733	15	5%	0	4.70	4.80	4.70	2.5%
14	4.967	2	1%	0	5.00	5.00	4.90	-2.3%
15	4.600	16	8%	15	4.90	4.50	4.40	5.2%
16	4.867	10	3%	0	4.80	4.90	4.90	-0.2%
	4.855	= average		max =	5.00	5.00	5.00	
				min =	4.70	4.50	4.40	
	Cavity with most imbalance =		15	range =	0.3	0.5	0.6	
	Maximum imbalance =		8%	avg =	4.869	4.859	4.837	
	Average imbalance =		3%	pop std =	0.085	0.113	0.141	
	% range drop, shot 1 to 3 =		-100%					

1	Process should be running at equilibrium: mold & melt temperature, pressures stable
2	Consider mold's ability to run a short shot
3	Set process to run short shots whereby one part is full or nearly so; begin shot collection.
4	Collect three shots separated, weigh individual parts and record, calculate average
5	Review avg of three shots for significant decline in range: use only 1 shot if more than 10%
6	Restore process to normal.



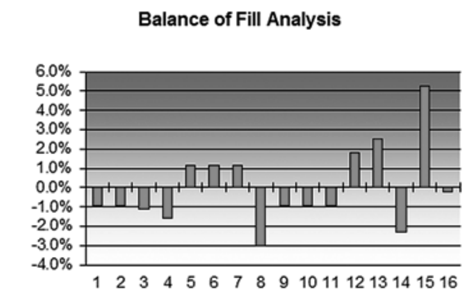


Figure 6.21 Manifold balance graph for 16-cavity mold

Figure 6.1 depicts the Excel spreadsheet with corresponding numbers and columns, to show where to use the formulas and how they play a role in setting up the spreadsheet. This will allow the graphing of the balance of a mold, along with the fill sequence, and finally how the balance compares to the average weight.

8.13 Runner Sizing

Below is one method for sizing the runner. One of the other methods is to keep the diameter the same all the way to the gate. At the end of the day we are trying to equalize the shear rate, minimize the pressure drop, and equalize velocity through each section of the runner for good part quality.

Dgate feed = 1.5 × wall thickness at gate (0.060″ at gate is used for this example)

Standard formulas:

Dfeed = Dbranch × $N^{1/3}$

Dfeed = 2 × $\sqrt{2}$ × area d-branch/π

Note: N is the number of branches that the feed runner is feeding.

Size the gate runner first and upsize if needed back to the sprue. Make the changes to keep the shear rate the same in each section.

Dgate feed = 1.5 × 0.060 = 0.090″

Dfeed 1 = 0.090″ × 1.26 = 0.113″

Dfeed 2 = 0.113″ × 1.26 = 0.142″

(If we take N to the ⅓ power and N is the number of branches (2) for each section in the Dfeed 1 and in Dfeed 2, then we get 1.26.)

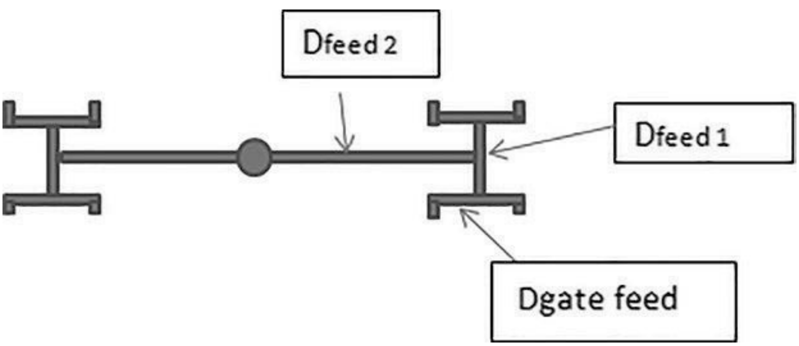


Figure 8.9 Sizing runner from gate back to sprue

structure less chance to form. Remember the larger the crystalline structure, the less light that will pass through and bounce off creating a cloudy appearance
- The same material with just different cooling rates (see Figure 12.6)

Figure 12.6 Same material, two different cooling rates (left: fast cooling rate; right: slow cooling rate)

12.7 Color Streaks

Color streaks happen when the material is contaminated or there is a mixing or degradation issue.

- Material contaminated
  - Pellets or liquid color from the previous job; review where the material is hanging up and eliminate
- Screw/barrel needs to be cleaned
  - Skin layer from previous runs or colors will be in the barrel and on the screw. If a new skin layer does not cover the previous skin layer it will constantly bleed out
- Nozzle needs to be cleaned
  - Dead spots may be present in a general purpose nozzle (Figure 12.7); it will need to be removed and cleaned to remove previous color or material

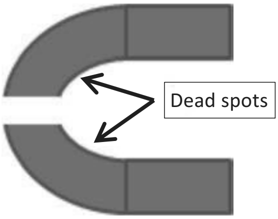


Figure 12.7 General purpose nozzle tip

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