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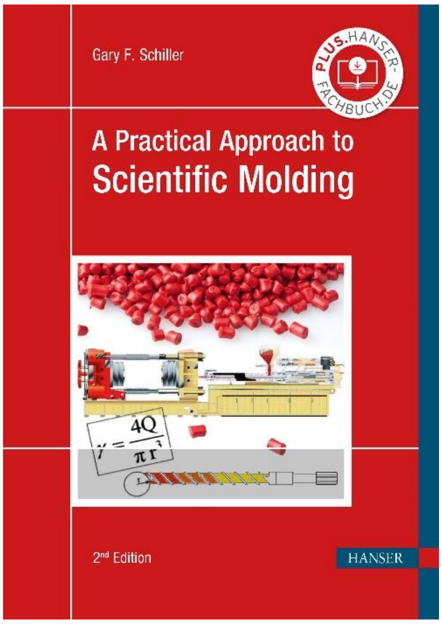

Sample Pages

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.

There is a new chapter in this second edition, Chapter 13, covering the effects of making specific changes to the process. This reviews the downstream effects of a process change and how it can and will affect the process overall. These changes can have a huge impact on part quality. This chapter was written to inform the engineer/technician of the potential side effects to the change being made.

The first edition was well received and has provided insight to many in establishing scientific molding processes. The new insights of this second edition will allow the user to be more informed as to the cause and effects of a process change.

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

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- 43 years in the plastics industry
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- 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

Contents

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.

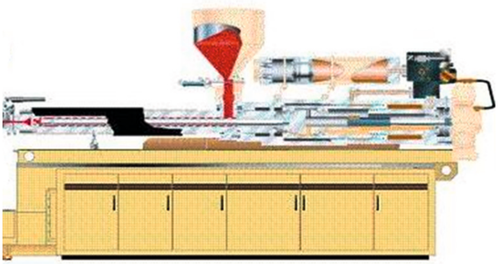

Figure 1.1 Injection unit

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.

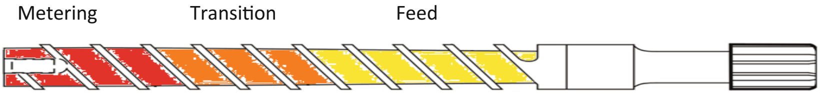

Figure 1.2 Reciprocating screw

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.

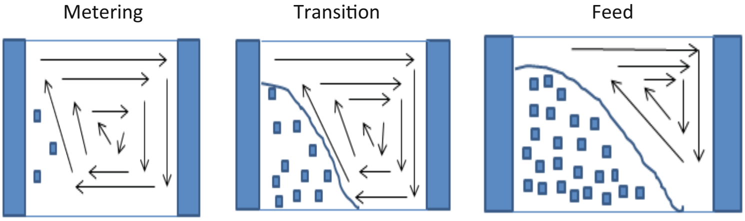

Figure 1.3 Melting of the plastic in different sections of the screw. Courtesy of AIM Institute

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.

1.3 Pressurizes the Melt

The non-return valve (check ring) is what pressurizes the melt. It creates a seal on the inside of the barrel through the use of a sliding check ring, ball-check screw tip, and/or poppet check ring. There are also plunger-style screws that inject the plastic into the molds: there are no moving parts to this design.

And as the plastic is pushed forward the non-return valve seals off, not allowing any plastic to return behind it. If it does there is either a worn non-return valve or possible wear in the barrel. This will be discussed later in the book.

1.4 Sections of the Screw

There are many different screw styles available today, with a multitude of materials available. The reciprocating screw provides the function of conveying the material, and compressing and heating it to prepare it for the next shot.

Figure 1.4 Sections of the screw

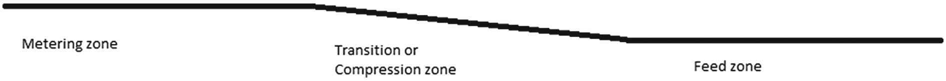

Figure 1.5 Root diameter changes in each sections of the screw

1.4.1 Feed Zone

The feed zone is used to convey the material from the feed throat and start the compaction process in the barrel. This section starts to compress the pellets within the flight and starts the friction process as the material rubs along the barrel wall as the screw rotates. Screws can have long or short feed sections depending on the material being run. Longer feed sections could be for shear sensitive materials or a material that melts easily with a low melt temperature.

1.4.2 Transition or Compression Zone

This is where the flight depth starts to get shallower. The material starts to receive greater compression and the friction or shearing of the material increases, contributing to the melting of the plastic. This is where most of the work is done on heating the material (see Figure 1.5).

1.4.3 Metering Zone

This zone has the shallowest flight depth. By the time the material gets to this point it should be melted, and ready to be conveyed past the non-return valve to position itself in front of the screw building the next shot.

1.5 L/D or Length/Diameter

Length (L) is measured from the front of the screw to the end of the flights. Diameter (D) is measured from the highest point on the flight of the screw to the corresponding other side (see Figure 1.6). Keep in mind the value of L/D for the screw in the press: too short of an L/D results on non-melted pellets, while too long of an L/D and the result is too much residence time, which can burn or degrade the plastic.

Figure 1.6 Where to measure length and diameter of screw

1.6 Compression Ratio

This refers to the depth of the feed section flight (Figure 1.8) divided by the depth of the metering section flight (Figure 1.7). If there is a 3 : 1 compression ratio screw this means that the depth of the feed section flight is three times the depth of the metering section flight. The measurement is taken from the root of the screw to the top of the flight.

Figure 1.7 Measuring flight depth in metering section

Figure 1.8 Measuring flight depth in feed section

Example:

The depth of the feed section is 0.450″ and the depth of the metering section is 0.150″. It is expressed as 0.450″ divided by 0.150″ = 3 or 3 : 1 compression ratio.

Compression ratios for materials:

- Low compression screws range from 1.5 : 1 to 2.5 : 1, and are for shear sensitive materials
- Medium compression screws range from 2.5 : 1 to 3 : 1, and are for general-purpose materials
- High compression screws range from 3 : 1 to 5 : 1, and are for crystalline materials

One way of determining whether the compression ratio is correct for the material is to check if the standard cycle creates black streaks or non-melts in the parts. If one of these two conditions exist, then the machine can have the wrong compression ratio screw for the application.

1.7 Profile

The profile of the screw refers to the number of flights in each section of the screw (see Figure 1.9). Some screws will have a profile of 10-5-5, which means that there are 5 flights in the metering section, 5 flights in the transition section, and 10 flights in the feed section. This would be representative of a general-purpose screw

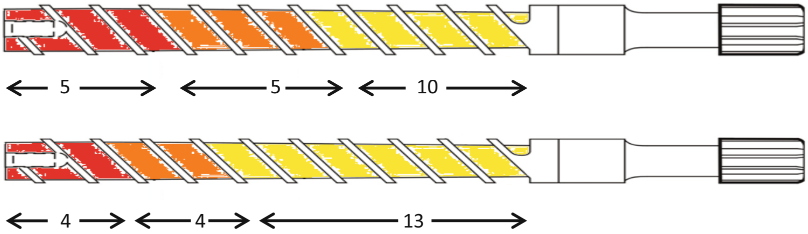

Figure 1.9 Different profiles of a screw

The 13-4-4 profile would possibly be used for a shear sensitive material, with the long feed section not allowing the material to heat up or be under compression or shear for as long with the shorter compression or transition zone.

1.8 Injection Pressure

Injection pressure is also known as boost pressure, fill pressure, or injection 1st stage pressure. Its purpose is to provide enough pressure (abundant pressure) so the process does not become pressure limited, which limits the filling velocity. If the fill pressure limits the velocity, the shear rates of the material can vary (when pressure limited you will not see the same velocity or flow rate in the plastic due to pressure controlling the filling phase and not velocity, which can reduce the temperature from under-shearing of the plastic; differental temperatures can cause differental shrinkage).

When establishing the injection pressure, start with abundant pressure and establish a 95% full part. After running the relative viscosity curve test (please see Chapter 6 for test and procedure) and selecting an optimum velocity, start coming down on the fill pressure until it affects the fill time. When the fill time starts to increase, that is when pressure is affecting the fill rate.

The set point should be 150–250 psi above transfer pressure to account for any viscosity variation that might be seen during normal operation.

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.

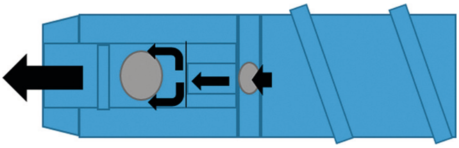

Figure 1.10 Flow through a ball non-return valve (cut-away)

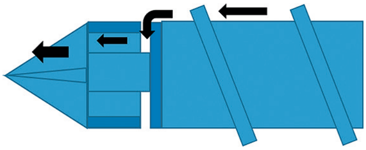

Figure 1.11 Flow through a sliding (3pc) non-return valve (cut-away)

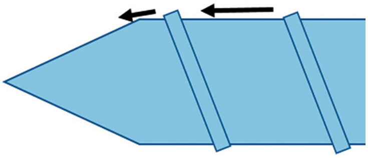

Figure 1.12 Flow along a smear tip or plunger tip

Figure 1.13 Flow through a poppet tip (cut away)

The smear tip (Figure 1.12) is a low shear tip, where the plastic is extruded in front of the screw and there are no moving components; this type of screw tip is used for shear sensitive materials such as PVC.

■ 1.13 Different Styles of Non-return Valves

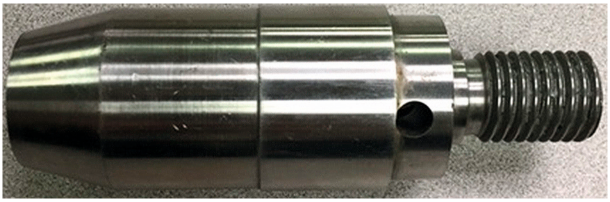

Figure 1.14 Ball check non-return valve

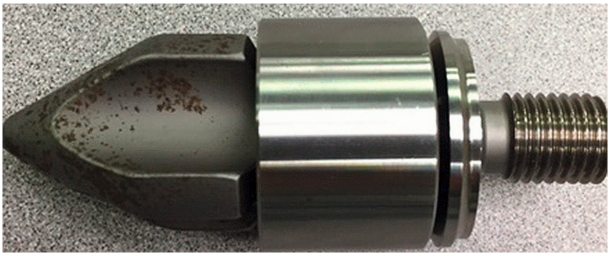

Figure 1.15 Sliding check ring (3 Pc)

1.14 Decompression/Pull Back/Suck Back

Decompression is used to relieve the pressure off the front of the screw, which in turn relieves the pressure off the hot manifold or a cold runner. When the screw sucks back it will create a vacuum effect inside the barrel and draw the melt backwards, creating a void in the nozzle. This will allow the pressure in the manifold system to relax into that void and take pressure off of the tip area, which helps avoid gate or nozzle drool. There are two different decompressions phases:

Pre-decompression is used in conjunction with a nozzle shut-off and to decompress the manifold before the nozzle shuts off completely and screw starts to rotate, again creating a void area for the pressurized plastic from the manifold to relax into.

Post decompression is used if there is no nozzle shut-off and suck back of the melt is needed to keep the material from drooling, out of either the nozzle or gates.

Post decompression can and should be used whether there is a nozzle shut off or not. This will create a slight gap in front of the screw. As the screw injects forward for the next cycle it gives room for the non-return valve to move back and seal properly.

The minimum distance to suck back or decompress is the movement of the sliding ring or the ball. As a reference we add 0.250″ or ¼″ as a starting point, but sometimes more decompression is required depending on how much the melt is compressed within the system. This movement or decompression will also help with shutting off the non-return valve upon injection or forward movement because it creates a small gap and as the screw moves forward the ring and/or ball will have time to seat or shut off before the plastic starts moving.

1.15 Screw Rotate Delay

A minimum of 0.5 second screw delay is needed before the machine starts to rotate. When the machine is done with the pack/hold phase of the cycle, the check ring seat and the check ring are pressed against each other tightly; if the screw rotates with no delay, the first movement is metal on metal, which can wear the check ring out prematurely.

If a screw rotate delay time is added after pack/hold, there is a chance for relaxation before rotation starts, minimizing the wear to the seal area.

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