1 The Injection Molding Process

1.1 Process Flow

Injection molding is a process for manufacturing plastic articles in which plastic pellets are melted (*step 1: plasticizing*) and then injected into the cavity of a mold (*step 4: injection*). For most plastics, the plastic melt solidifies in the cavity by solidifying (*step 5: cooling*) so that the injected part can be removed from the mold (*step 6: demolding*).

Injection molding is a cyclical process

The process shown in Figure 1.1 represents a repetitive cycle. In the first step, the plastic pellets are fed to the screw via the feed hopper. The rotary motion of the screw carries the material forward. The resulting frictional heat and the electrical heating of the barrel cause the pellets to melt (plasticize). As long as the nozzle on the side of the barrel close to the mold is closed, the melt collects in front of the screw tip (screw antechamber) and pushes the screw back. The melting process is improved at high levels of friction. For this purpose, a hydraulic counter-pressure (back pressure) is built up in the drive barrel (injection barrel), which slows down the backward movement of the screw and is thus responsible for a longer metering time. The melt volume required for the injection molding process is metered during plasticizing in the screw antechamber. With the aid of a displacement measuring system, the metering volume is determined from the return travel of the screw.

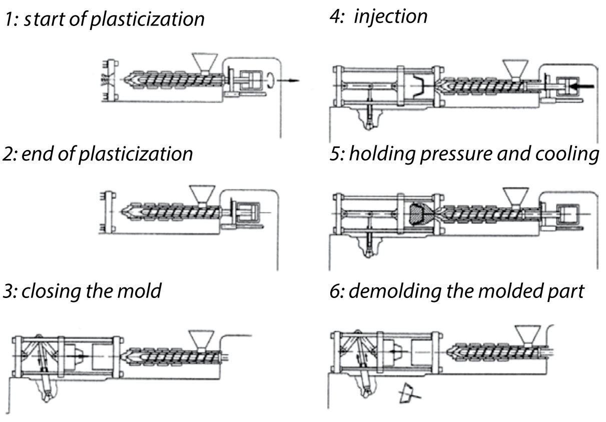

Figure 1.1 Basic process sequence for injection molding (source: Pötsch G., Michaeli W.: Injection Molding, p. 2, Figure 2.34, Hanser Verlag, 1995)

Injection molding

Before a molded part can be injected, the mold is closed with high force (clamping force) and the injection unit with the nozzle is moved to the sprue bushing of the mold. The melt is injected into the mold cavity at a predetermined injection speed by the screw. During this process, the pressure (injection pressure) increases steadily. In most injection molding machines today, the injection speed is controlled. An injection pressure set by the machine operator is merely a limiting pressure that should not be exceeded by the machine's drive system.

Holding pressure to compensate for shrinkage

The injection process is complete when the cavity is almost completely filled with melt. From now on, further melt must be pressed in (under holding pressure) to compensate for the material shrinkage of the molded part during cooling. The holding pressure is significantly lower than the injection pressure, so that the force acting in the cavity does not exceed the clamping force of the machine. Otherwise, flashing will occur. The switchover from injection to holding pressure usually takes place when the screw reaches a predefined stroke point during its forward movement (switchover position). When the molded part has cooled down and is sufficiently stable, the mold can be opened, and the molded part removed from the mold by means of an ejector integrated in the mold.

Settings, specific and machine-related

The machine settings (parameter speeds, paths, and pressures) can be specific or machine-related. Both specifications can be converted into each other with the screw diameter *D* (Table 1.1). Specific data are independent of the screw diameter and allow easy transfer of a machine setting to another machine. In the following, specific data are always used as a basis. Today, it is still common to additionally specify machine-related values. Many machine control systems offer a conversion and optional display of these specifications.

Table 1.1 Conversion of Specific to Machine-related Settings During Injection Molding

Process Flow	Settings		Conversion
	Specific	Machine-Related	
Metering	Peripheral speed: v	Rotational speed: n	$u = \pi n D_{screw}$
Injection Holding pressure	Pressure of the screw: $p_{spec.}$	Hydraulic pressure of the machine: $p_{hydr.}$	$p_{hydr.} = \left(\frac{D_{screw}}{D_{hydr.plunger}}\right)^2$
	Volume in front of the screw: V	Screw stroke: s	$V = s\frac{\pi}{4}D^2{}_{screw}$
	Volume per unit time: $\dot{V}$	Screw advance speed: v_{screw}	$\dot{V} = v_{screw}\frac{\pi}{4}D^2_{screw}$

D_{screw}: Screw diameter
$D_{hydr.}$: Diameter of the hydraulic piston of the injection side

Consistent quality is contingent on cycles that are as uniform as possible

For consistently good quality injection molded products, the cycles of the injection molding process must be as uniform as possible (Figure 1.1). This can only be achieved with continuous and trouble-free operation, because large temperature changes occur in each cycle. The mold is heated to a temperature below the melt temperature in the case of thermoplastics (these become soft/viscous at high temperatures). Additional heat is added to the mold from the melt, which begins an oscillation around the set mold temperature. With each interruption of production, there will inevitably be a different (not the same) starting situation for the next cycle.

1.2 The Machine and Plant Technology

The machine technology required for the process includes the machine, the tool and the periphery. In the following brief overview, the significance for a uniform process is considered in each case. In Chapter 2 “Technical Jargon”, selected details are explained in more detail.

The machine itself is composed of four main assemblies:

- clamping unit
- injection unit
- drive unit
- control unit

1.2.1 Clamping Unit

Task and size designation

The task of the clamping unit is to open and close the mold. It requires a very high force to keep the mold closed. The melt, injected under very high pressure, must not push the mold open and must not enter the parting line area. The clamping force is so significant that it is used to describe the size of injection molding machines.

Protection against mold damage

Another important task is protection of the mold. This includes the most parallel possible guidance and exact centering of the opened mold halves during the closing movement. Insufficiently parallel guidance leads to wear of the parting lines, since the closing mold halves initially touch each other at only a few points. The buildup of force places particular stress on these areas, and there continues to be a very slight relative movement of the two mold halves until the parting line is fully closed. This causes wear, which can lead to the formation of flash. This is a molded part defect that can only be corrected by reworking the mold.

Three typical types of clamping units are distinguished by their drive technology and overall length.

Hydraulic Systems

Several hydraulic barrels are necessary for functionality

The hydraulic systems are moved by barrel-piston systems. Small pistons are used for the higher movement speeds during travel, the clamping force is built up with a larger piston (Figure 1.2). This two-piece system provides good mold protection. If an injection molded part has not been completely demolded and is still partially in the mold during the next closing process, the machine cannot close the mold completely under the low force of the small travel barrels and can easily detect this fault. Before the part is crushed in the parting line under clamping force and causes major damage, the machine switches to fault mode.

Mechanical Systems

Movement and strength buildup by means of a movement

The mechanical systems are moved by a toggle lever system. Depending on the position of the lever, these systems have either a high possible movement speed or a large clamping force. A single hydraulic barrel enables both the travel movement and the force buildup (Figure 1.3). As a result, these systems are faster. Because the lever system is almost stretched shortly before the closed position, the closing speed here automatically becomes very small and the clamping force increasingly large. Protection of the mold is only possible with a high outlay on force sensors. Toggle systems are basically more complex in design and are more likely to have small clamping forces. The development of electric motor drives made a mechanical system mandatory.

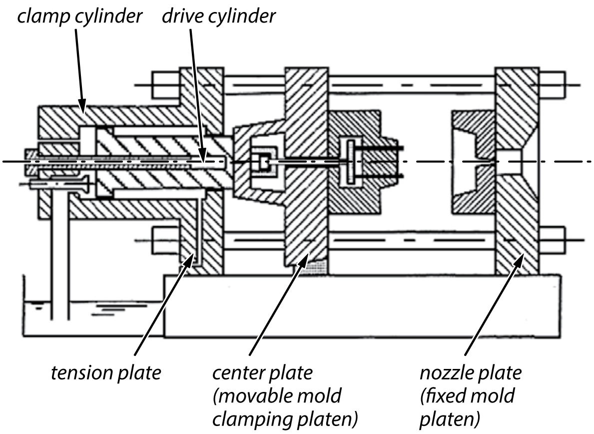

Figure 1.2 Structure of a fully hydraulic clamping unit

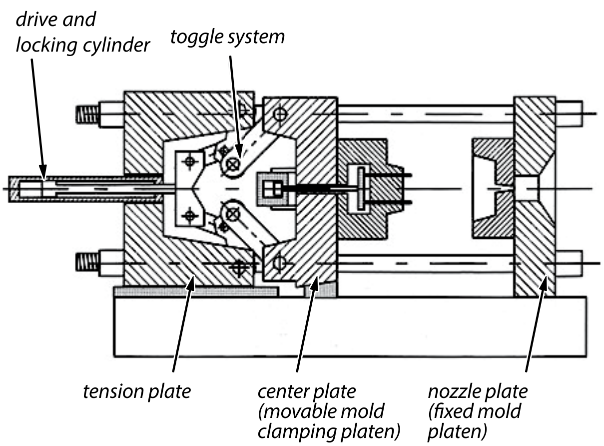

Figure 1.3 Structure of a mechanical locking system

Overall Length of the Clamping Unit

> Short overall lengths due to two-platen design

The overall length of the clamping unit can be kept small in a two-platen design. The hydraulic and mechanical systems have a fixed frame consisting of the mold platen and the tie-bars/columns. The motion and force unit is located in between. The two-platen machines do not have a rigid frame, the movement and force unit pulls the mold-fixing platens together at the columns (Figure 1.4). Often the plates can be completely decoupled in that the columns can be unlocked at one plate and travel with the moving half. After relocking, the force can be applied via the moving or fixed half. These systems are used especially for large clamping forces, because a reduction in the overall length is particularly important here. It should be noted that the effort required for exact parallel guidance is high for a completely separable system.

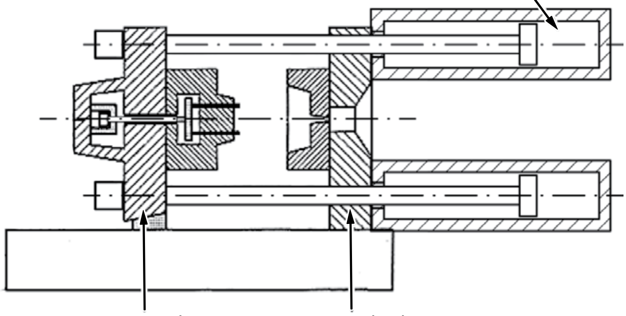

Figure 1.4 Structure of a two-platen system

1.2.2 Injection Unit

Heat for melting plastic

The task of the injection unit is to melt and meter the plastic and inject it into the mold. Approx. 30% of the heat for melting is generated by electric band heaters and approx. 70% by the rotary motion of the screw. The rotary motion conveys the plastic from the hopper towards themold. The molten plastic that collects here pushes the screw back. The volume of melt required for the next cycle can be metered via the return path of the screw.

1.2.3 Drive

The injection molding machine has at least five movement axes, driven either hydraulically or by electric motors:

- injection
- metering
- mold movement

- ejector movement
- injection unit movement

Parallel drives enable simultaneous movements

Except for the metering process, all movements are linear and can be easily performed with hydraulic barrels. The hydraulic drive has the advantage that hydraulic oil can be fed under pressure to different movement axes. It only becomes complicated if several axes are to be moved simultaneously. In the case of a parallel drive, the pressures and volume flows must each be independent of one another.

Electrical Systems

High efficiency ensures low energy requirements

Electric motors have been used since around 1995. Their advantage is their greater efficiency, which is why electrically driven machines have lower energy requirements. Another advantage is that each axis of motion needs its own drive motor and thus parallel drives are possible due to the system. The disadvantage of these drives is inevitably the higher price.

Hybrid drives

Another disadvantage of electric drives is that the motors become particularly large and expensive when the desired power is high. For this reason, many modern machines are only partially equipped with electric drives, in which case they are also referred to as hybrid drives.

With regard to the process, electric motor drives seem to have somewhat higher repeatability. In principle, however, there is no compelling reason to prefer one system over another.

1.2.4 Controls

Interface between man and machine

The control system is divided into two parts. The operator essentially has to deal with the input terminal. A screen enables process settings to be made and current production values to be viewed. The second part of the machine control is invisible to the operator; this part processes all sensor signals and regulates all movements. The operator should know that a time delay on the display screen is not an indication of slow control. The speed of response to an emergency stop signal, for example, is not detectable by the operator.

Common injection molding machines differ to a large extent in the operator interface for the operator. Basically, there is no compelling reason to prefer any machine on the basis of the control system.

2 Technical Jargon

Injection molders have their own jargon. However, the expressions are often not uniform, especially in company jargon, which is why the “correct” terms are used as far as possible in the following text. The 19-page DIN 24450:1987-02 is not reproduced here, but the essential technical terms are listed, with the aid of some sketches for explanation and introduction.

2.1 Injection Molding Machine

EJECTOR The ejector is an axially movable bolt that is moved through the center of the moving platen. It actuates the ejector system integrated in the mold so that the molded parts can be demolded after the mold opens. On machines with a small clamping force, a single central ejector is usually provided; on larger machines, the ejector movement is carried out by an ejector crossbar to prevent jamming. An ejector crossbar is an additional plate behind the moving mold fixing platen, by means of which several ejector bolts can be actuated at the same time (Figure 2.1).

EJECTOR COUPLING The ejector coupling enables precise control of the reverse movement. In many cases, the reverse movement of the mold ejector takes place:

- with a return spiral spring or
- with pushback pins projecting through the parting plane in the direction of the nozzle side.

The mold ejector system is coupled with the machine ejector by means of a:

- screw
- spring-actuated coupling
- pneumatically actuated coupling

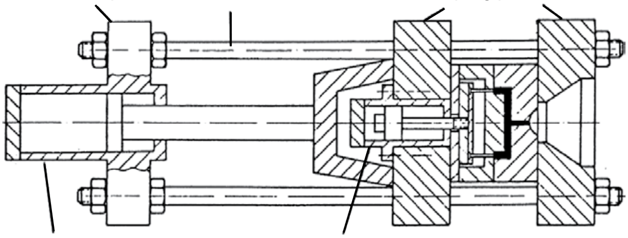

Figure 2.1 Ejector

NOZZLE The nozzle is the attachment of the plasticizing barrel to the mold (Figure 2.2). For adaptation, its radius is slightly smaller than that of the sprue bushing, and the melt outlet hole is also slightly smaller to enable the plastic cooling in the sprue bushing to be easily demolded. Shut-off nozzles are used for special applications.

USER INTERFACE Input screen on the injection molding machine.

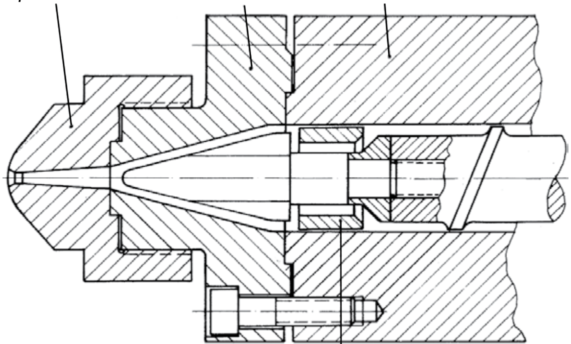

Figure 2.2 Nozzle, open

INJECTION BARREL Hydraulic cylinder, behind the screw, that enables the forward movement of the screw.

PLASTICIZING UNIT The plasticizing unit consists of (plasticizing) barrel with band heaters, internal screw with non-return valve and nozzle plasticizing unit (Figure 2.3). The hopper is not necessarily a part of this unit. In many cases, special drying hoppers are used anyway, or the material is fed directly to the feed zone of the screw from a central material supply.

NON-RETURN (CHECK) VALVE Mechanical closure element on the screw tip (Figure 2.4). It consists of the screw tip, the axially movable locking ring, and the thrust ring. The non-return valve closes during injection if the locking ring is not moved and the screw moves against the locking ring in its forward motion. During plasticizing, the melt flowing in from behind pushes the locking ring forward so that it rests against the flights of the tip. The melt can flow between the flights of the tip. The shot weight accuracy of the injection molding machine is largely determined by the closing behavior of the non-return valve; without the effect of holding pressure, there is a fluctuation in shot weight of approx. 2% over several cycles. With holding pressure, the shot weight variation is reduced to approx. 0.2%. To improve accuracy, the stroke of the locking ring can be modified, if necessary, by milling off the thrust ring contact surface at the tip. This allows the tip to be screwed further into the leading end of the screw, thereby shortening the stroke of the locking ring to close the lock. The non-return valve is a wearing part and may have to be replaced if the shot weight variation increases. The cause is the relative movement between the screw tip, which rotates during plasticizing, and the thrust ring, which is dragged along by the melt at a lower speed and rests against the tip during plasticizing.

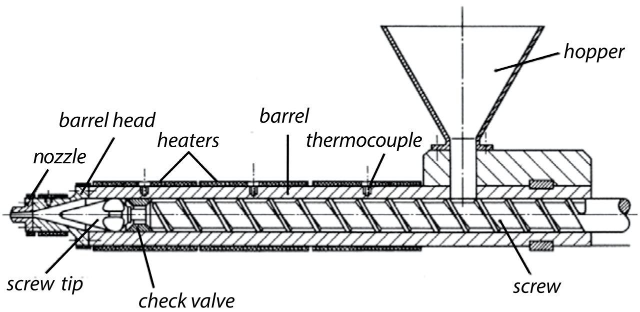

Figure 2.3 Plasticizing unit

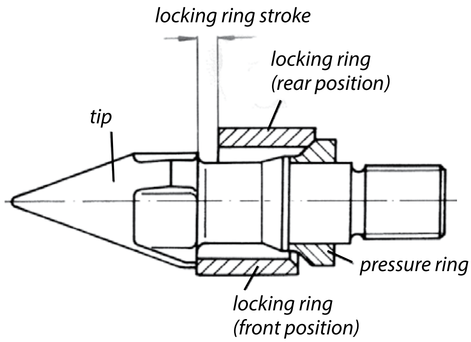

Figure 2.4 Non-return valve

SCREW CHAMBER The volume in the plasticizing barrel between the nozzle and the screw tip.

CLAMPING UNIT The clamping unit, also known as the clamp in operating jargon, carries the mold and can open and close it. One important function is to keep the mold closed even at high injection pressures. The clamping force can be applied either mechanically with a toggle lever, (Figure 2.5a) hydraulically with a hydraulic piston system (Figure 2.5b) or with a hydromechanical system. Each system has its advantages and disadvantages. For the injection molding process, the differences between them are not critical.

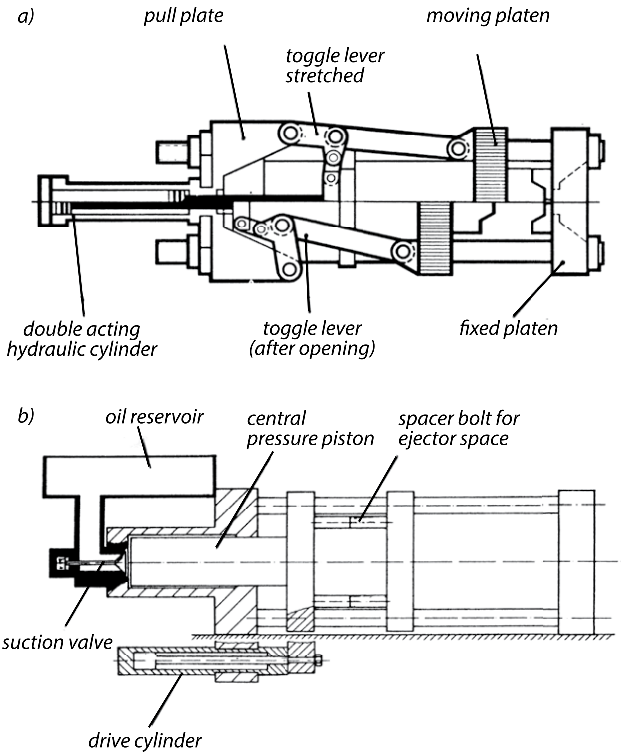

Figure 2.5 Clamping units; a: toggle lever, b: fully hydraulic

SCREW The screw is located inside the plasticizing unit. It has six tasks:

1. feed pellets from the hopper
2. convey
3. compact
4. melt
5. homogenize and
6. inject

The screw is a wearing part; especially when filled materials are used, abrasive wear must be expected, in which the screw flights are ground away. This can significantly impair plasticizing performance.

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