Injection Molding Machines

A User's Guide

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Leseprobe

3 General Design and Function

An injection molding machine may be defined as a “machine that discontinuously produces shaped objects from mostly macromolecular materials.” Shaping is performed under pressure by injecting the plasticated material in the machine through a channel into the mold cavity. The essential components of an injection molding machine are the injection unit and the clamping unit [1 to 4].

Nowadays, prospective buyers of an injection molding machine can choose from a wide variety of machine types, sizes, and models. The selection process is less confusing when the equipment has been thoroughly studied and the operating principles are understood.

Figure 3.1 shows the basic concept of an injection molding machine; the injection unit is on the right side of the support, and the clamping unit is on the left. The majority of machines are horizontally built; however, equipment with vertical clamping or injection units is frequently used, and some machines can be converted from horizontal to vertical operation. Such special designs are becoming more important as the need grows to integrate different processing steps into one machine.

For many years, the control unit was housed in a separate, free-standing cabinet, but nowadays it is attached to the stationary machine platen.

The molding equipment essentially consists of an injection molding machine, an injection mold, and a unit (heat exchanger) for controlling the mold temperature. These three components interact with one another through three processing parameters: pressure, temperature, and speed. Before starting the production of a new molded part, decisions concerning the raw material to be used, the geometry (design) of the molded part, and the mold design must be made at the earliest planning stage. The development and design departments bear the responsibility for the final costs of a molded part (Fig. 3.2). CAE methods are available to help the engineer navigate these stages. Economic success of a product and its production also depends on a good deal of ancillary equipment that has to be synchronized with the

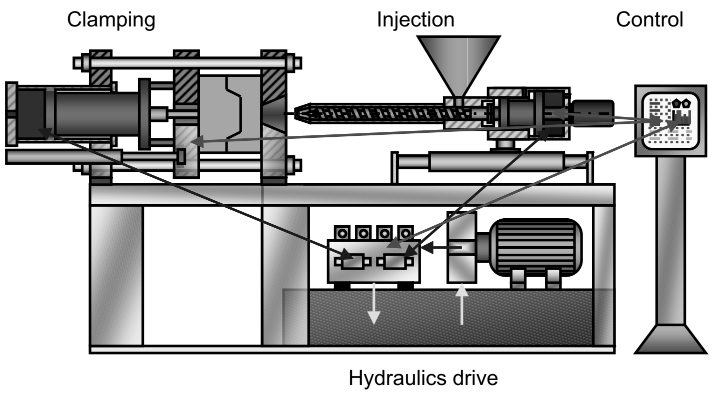

Figure 3.1: Schematic of an injection molding machine, hydraulically operated [1]

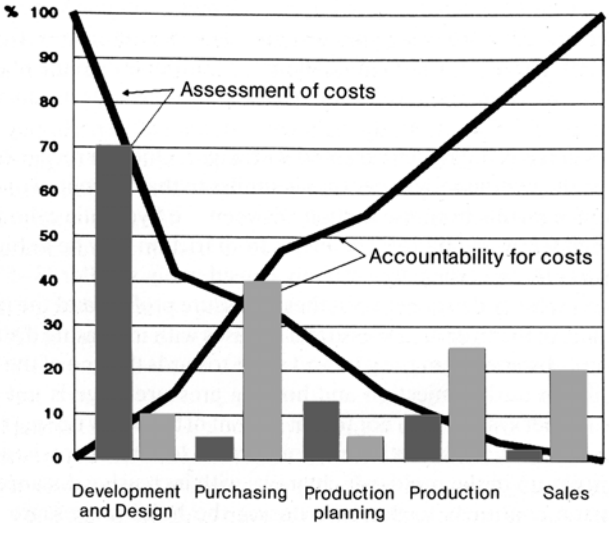

Figure 3.2: Assessment of costs and accountability for costs

machine so that the process can be automated. Operations here include drying, transporting, and mixing the plastic material as well as the separation, removal, and post-machining of the moldings. Together, the various items of ancillary equipment constitute an extension of the workplace of an injection molding machine. Some of them will be discussed in later chapters.

The raw material is supplied to the injection molding machine through the feed hopper, which is located on top of the injection unit. Thermoplastics are usually fed in the form of pellets; thermosets and, more recently, rubbers are often used in powder form. Good free flow is needed in all cases. Often it is necessary to blend the material (left hopper in Fig. 3.3) to keep moisture-sensitive polymers dry by hot air heating (center hopper), or to prevent "bridging" inside the hopper by using systems with stirrers or screw conveyers (right hopper). In any event, the angle of the hopper must be optimized to prevent flow stagnation.

Rubber is frequently supplied in ribbon form. Glass-reinforced polyester may be used either in ribbon form or as a paste, which is usually pressure-fed to the screw through a cylinder by a piston or fed in by an additional screw.

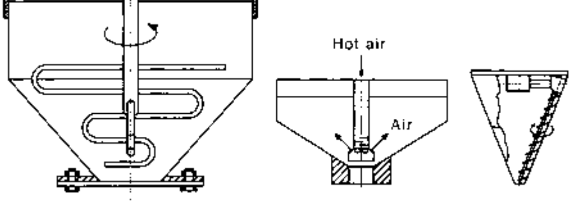

Figure 3.3: Commercial hoppers featuring stirrers, hot-air heating, and screw conveyers [3]

3.1 Characterization of the Injection Molding Process

The injection process can be characterized in several ways, for example, in terms of functions, time-cycles, or physical parameters related to the process (pressure, temperature, speed).

3.1.1 Functional Process Steps

The basic injection molding process, shown in Fig. 3.4, can be divided into several partly overlapping phases. The cycle begins when the mold closes. At this stage, the nozzle has been pushed against the mold's sprue bushing, which connects the nozzle to the mold. Then, a controlled pressure surge in the hydraulic cylinder pushes the screw forward and pumps the melt into the mold cavity. After a pressure-holding phase, the molding cools down to the mold temperature, while the screw takes in new plastic material directly from the feed hopper and conveys it to the screw tip. On its way, the plastic passes through heated barrel zones, with the rotation of the screw causing the plastic particles in the flights to be continuously rearranged. As a result of both shear and heat transfer from the barrel wall, the material experiences largely homogeneous heating ($\Delta T \pm 5$–20 °C) [1, 2]. The conveying action of the screw leads to a build-up of pressure in front of the screw tip. This pressure pushes the screw backward. As soon as the space between the tip and the nozzle contains enough melt for one shot, the screw stops rotating. Meanwhile, the part in the mold has been cooled and solidified under a temporary, usually decreasing, pressure, so the mold opens and the molding can be ejected. Then the mold closes again and a new cycle starts.

Generally, the mold is designed such that, during opening, the molding remains in the mold half mounted on the movable platen. The molding is ejected by a mechanical or hydraulic

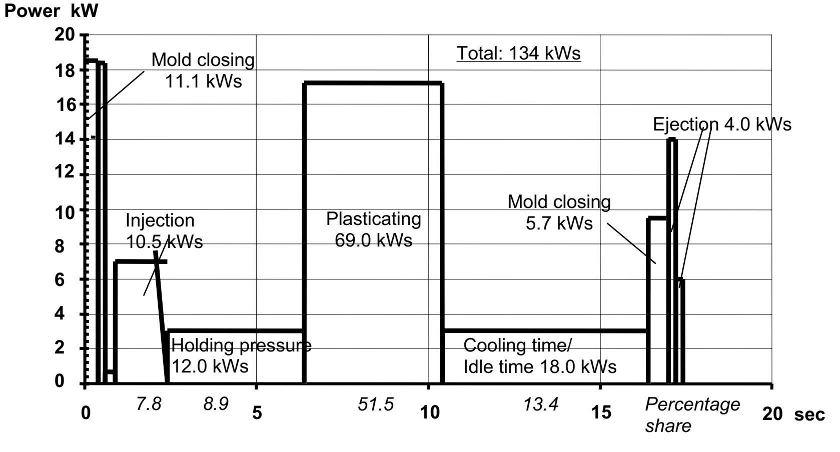

Figure 3.4: The stages of injection molding showing the energy consumption during the different processing steps

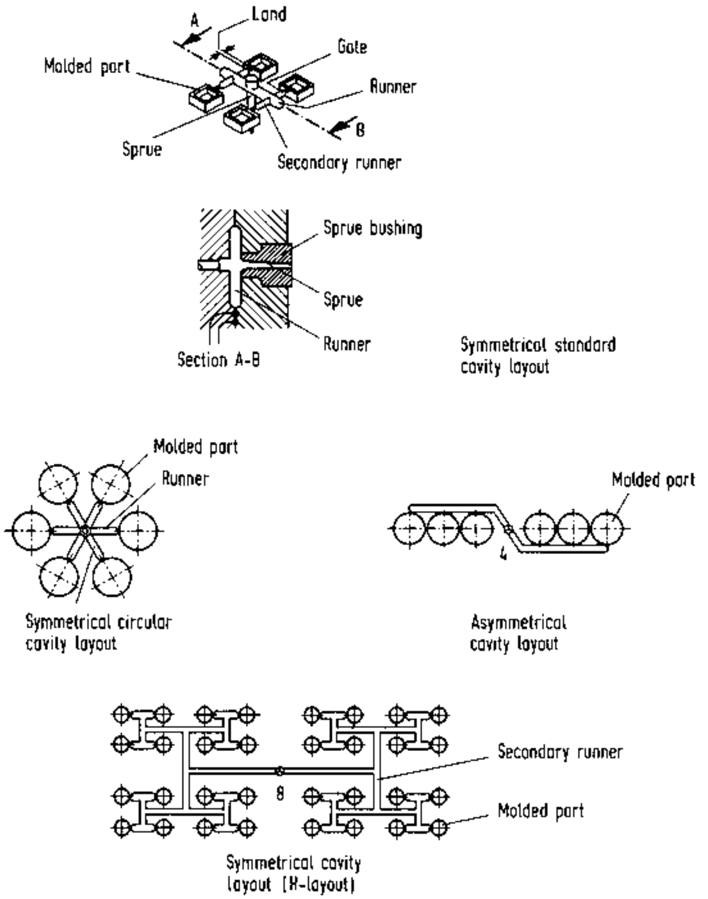

Figure 3.5: Basic runner systems for injection molds

ejector at an adjustable distance from the stationary platen, or it can be taken out by a robot. The molding may consist of one or more parts together with the runner system (Fig. 3.5).

The dynamics of the process are shown in Fig. 3.6. It can be seen that the pressure profile in the hydraulic cylinder (p_H) is similar to that in front of the screw tip (p_{SC}). The difference results from friction between the hydraulic cylinder and its piston and between the screw and the barrel. Pressure losses due to friction may be as high as 10 %. At high pressure, though, the loss is certainly considerably smaller (3 to 5 %).

There is little correspondence between these pressure profiles and the pressure inside the mold (cavity pressure). The hydraulic pressure (p_H) decreases with increasing distance from the nozzle. At some distance from the gate, and more so toward the end of the flow path, pressure build-up during injection and the holding-pressure stage is not similar to either that in the runner system (p_{C1}) or that in front of the screw tip (p_{SC}). There is a time lag in the pressure

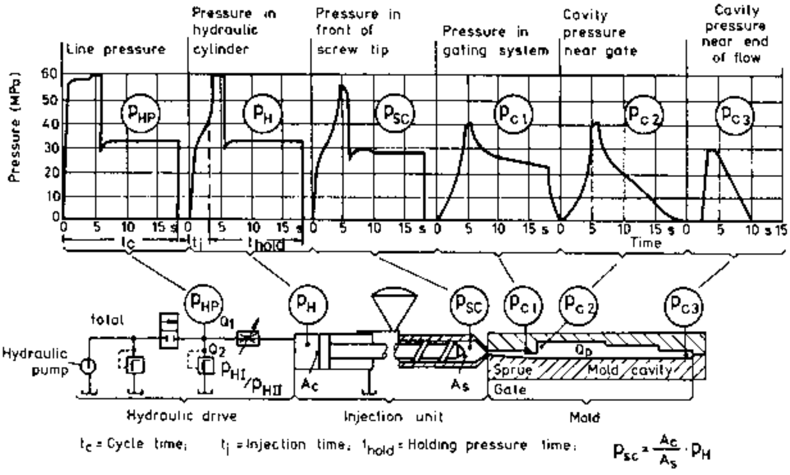

Figure 3.6: Change in pressure over time at various locations in the injection molding system

build-up in the cavity (p_{C2}), which grows with increasing distance from the sprue (p_{C3}). The pressure continues to decrease during the holding-pressure stage and reaches zero before the end of this stage. The pressure drop, in contrast to the pressure in front of the screw tip, begins as soon as the melt starts to solidify in the runner system and/or cavity. This prevents any further pressure transmission into the cavity.

This demonstrates that the material solidifies under different localized pressure conditions. The melt and mold temperatures are also non-uniform. The melt leaves the nozzle with a temperature profile that varies with time and location. During injection and the holding-pressure stage, pressure and temperature variations within the melt are present. Both parameters are even interdependent. Both the surroundings and the process itself have an effect. Machines and machine components exhibit distinct idiosyncrasies from one to the next, as well as hysteresis, where, for example, hydraulic components are concerned.

Every molder should have a mental picture of temperature and pressure differences and variations during the molding process so as not to misinterpret such terms as homogeneity of the melt, constant temperature, constant dimensions, and reproducibility.

3.1.2 Injection Molding Cycle

Another way to look at the molding process is to consider the injection molding cycle illustrated in Fig. 3.7. As may be seen, the total cycle time is dominated by the cooling of the part in the cavity. The total cycle time can be calculated as

$$t_{cycle} = t_{closing} + t_{cooling} + t_{ejection}$$

The closing and the ejection times can last from a fraction of a second to a few seconds. The size of the machine and, to a lesser extent, of the mold and its design determine when the mold

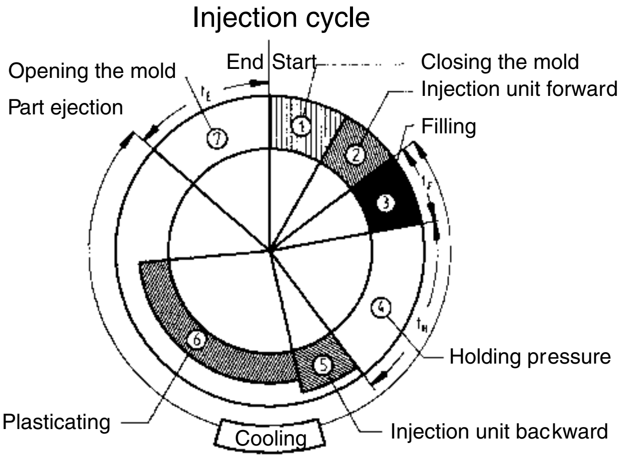

Figure 3.7: Injection molding cycle

can be opened. The cooling time depends mostly on the wall thickness and can take from half a second to several minutes.

3.1.3 Significance of Pressure

Various kinds of pressure are in action during the injection molding process. They are differentiated according to place and time of action. Localized differences have already been pointed out in Fig. 3.6.

3.1.3.1 Hydraulic Pressure on the Injection Side

Hydraulic pressure has to be supplied by the drive unit of the machine to overcome the flow resistance of the material in the nozzle, in the runner system, and in the cavity. Its characteristic is much the same as the pressure of the melt in front of the screw tip. It generally rises within a short time from barometric pressure (or the lowest possible pressure in the system) to a magnitude that corresponds to the flow resistance of the melt from nozzle to cavity.

Readings of the hydraulic pressure, however, do not allow conclusions to be drawn about the holding-pressure stage and the pressure profile in the cavity. This is illustrated schematically in Fig. 3.8 by the curves for the hydraulic and the cavity pressure. Figure 3.8 indicates the influence of flow resistance in the nozzle and runner system ($t_0 - t_1$). One can also recognize the onset of cavity filling (seen as a small drop in pressure) and the moment of completed volumetric filling (seen as a sudden, steep increase in pressure). However, this holds true only if the hydraulic pressure has not been switched over to holding pressure beforehand. From the compression stage (t_3) on, the hydraulic pressure provides only incomplete information about the process. In general, cavity pressure very rarely corresponds to hydraulic pressure.

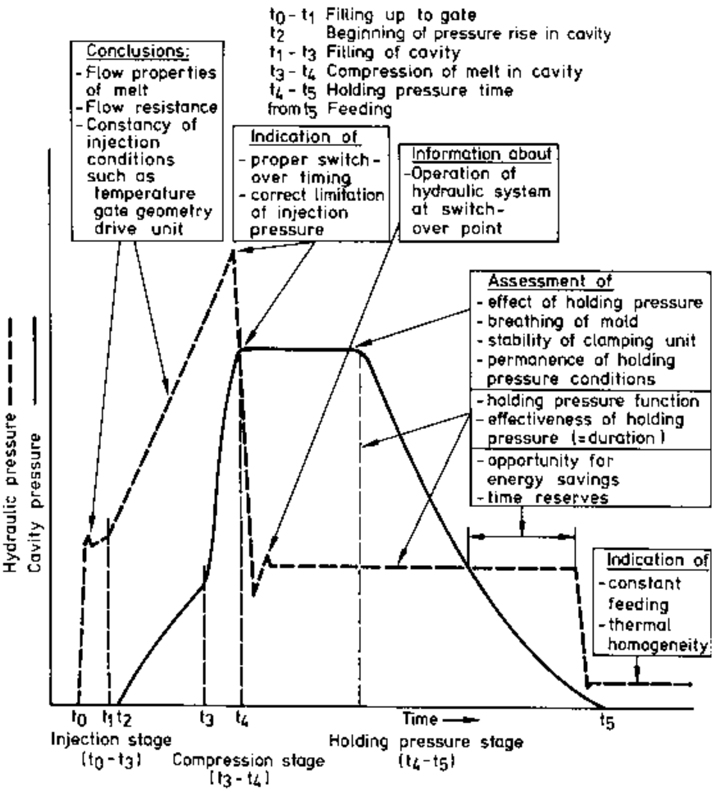

Figure 3.8: Information yielded by cavity pressure and hydraulic pressure during the injection cycle

High resistance to the melt flow from the nozzle to the cavity leads to a rapid build-up of high pressure. This effect makes it difficult to notice the onset of compression after volumetric filling of the cavity (Fig. 3.9, top). On the other hand, this onset is usually easily noticed if the flow resistance is low (Fig. 3.9, center). The bottom graph in Fig. 3.9 shows the pressure changes resulting from varying cross-sections found in extensive runner systems. The amount of pressure required to compensate their flow resistance may be considerably higher than the pressure drop in the cavity and will depend on the geometry of the runner systems.

Other factors and their effects on the hydraulic pressure are detailed in Fig. 3.10. While the influence of the axial screw speed is widely known, the effects of hydraulic oil and melt temperatures are frequently underrated. The viscosity of the hydraulic fluid, which is temperature-dependent, exerts an influence on the pressure. Most molders are aware of this correlation, as it often affects the consistency of production, particularly during start-up with cold oil. More often neglected is the effect of the mold temperature. Since the hydraulic-pressure profile may be affected by the cooling process in the mold as shown in Fig. 3.10 (bottom), injection time will be markedly affected if operation of the injection unit is viscosity-dependent. This influences the production result, too.

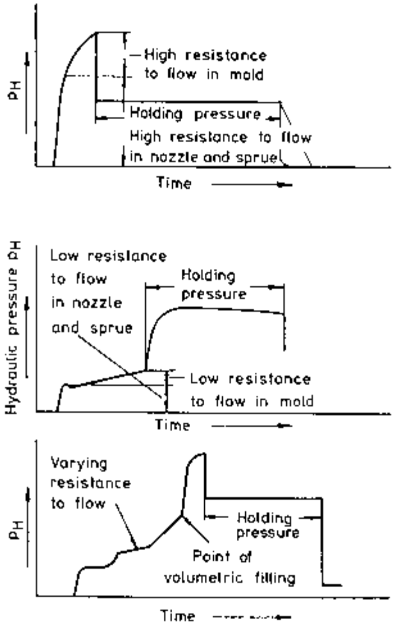

Figure 3.9: Effects of resistance to flow on the pressure in the hydraulic cylinder; top: point of volumetric filling not noticeable due to high resistance to flow; center and bottom: point of volumetric filling visible due to low resistance in nozzle and runner system

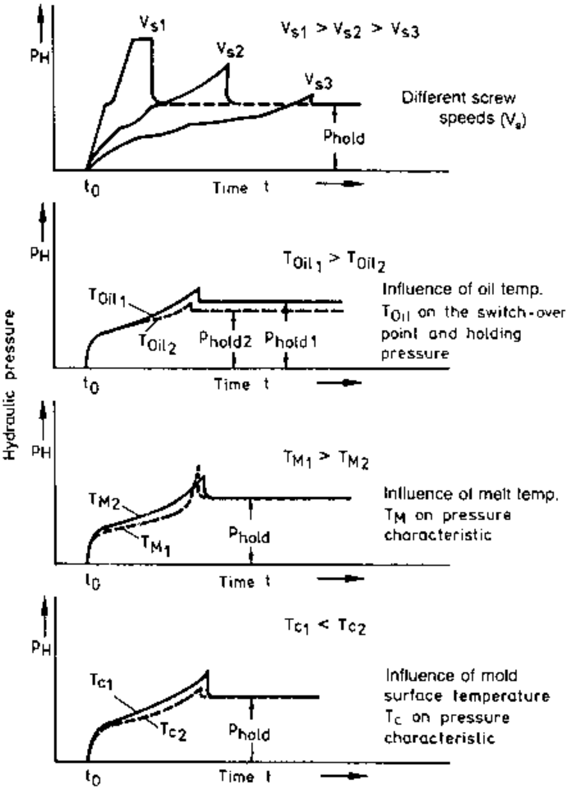

Figure 3.10: Pressure profiles of hydraulic cylinders; influence of various parameters on the hydraulic pressure

Some other characteristic variations in the hydraulic-pressure profile can be fairly reliable indicators of irregularities during injection. Jetting or sticking of the melt to the cavity surface can result in irregular pulsation of the hydraulic pressure (Fig. 3.11, top). Less frequent is a pulsating hydraulic pressure after an abrupt pressure switch-over (Fig. 3.11, center). A pressure profile of this kind shows how reliably the machine's hydraulic system operates. Fluctuations in hydraulic pressure during feeding are signs of feeding irregularities (Fig. 3.11, bottom). These would show up even more clearly in a recording of the pressure of a hydraulic screw drive or the amperage of an electric motor.

Measurements and continuous recordings of the hydraulic pressure are recommended because they are simple to carry out and provide important information about the injection and feeding stages. The reward for such a small effort is the ability to reliably control the plasticating unit during processing stages.

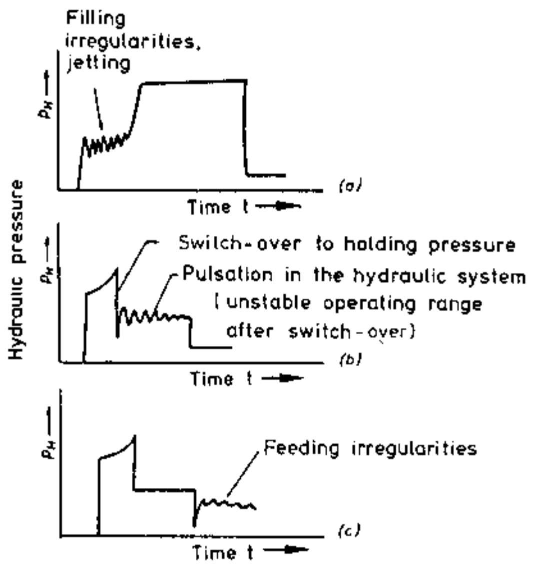

Figure 3.11: Causes of pulsating hydraulic pressure

3.1.3.2 Pressure in Front of the Screw Tip

The pressure in front of the screw tip varies in much the same way as the hydraulic pressure, except it occurs during the holding-pressure stage (Fig. 3.6). The ratio of the cross-section of the hydraulic piston to that of the screw normally yields a sufficiently accurate conversion for determining the pressure in front of the screw tip. A frictional loss of about 5 % in the operating range should be assumed.

At very low pressure, this loss can rise to 10 %. Measuring the hydraulic pressure is preferable to reading the pressure of the hot melt, which cannot be reliably done during continuous operation. It also allows conclusions to be drawn about the rise in melt temperature on caused by friction.

3.1.3.3 Cavity Pressure

Analyses of the injection molding process have made substantial contributions to advances in process control. Recording the cavity pressure plays a central role in ensuring constant molding quality. Pressure recording is now at a high standard thanks to the use of pressure transducers based on strain gages or piezoelectric crystals. Provided certain requirements are met, recording can be done under harsh production conditions.

The information obtainable from a typical cavity pressure curve recorded during the molding cycle is illustrated in Fig. 3.12. It is possible to identify three fundamental stages:

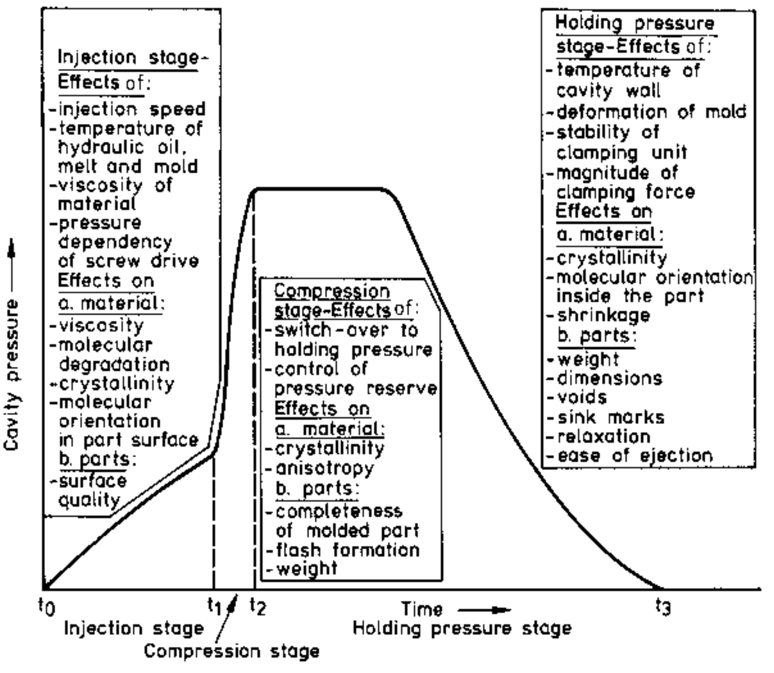

Figure 3.12: Change in cavity pressure over time and information obtainable from recording the pressure

- Filling of the cavity (injection stage)
- Compression of the melt (compression stage)
- Holding of the solidifying material under pressure (holding-pressure stage)

These three stages can be associated with specific effects and quality criteria. The injection stage primarily affects the appearance of the molded part, while the holding pressure mostly controls the dimensions. The graph illustrates the relative significance of the injection pressure (Fig. 3.12). While the injection pressure is needed to overcome flow resistance from the nozzle to the cavity, it has mostly little bearing otherwise on the quality of the part. The compression and holding-pressure stages are usually much more important and useful in this regard.

The pressure profile also provides information about typical flaws in the process technology. A high pressure peak in the compression stage resulting from a switch-over to lower holding pressure that is either incorrectly set or unreliable can produce flash or, even worse, a packed mold. This leads not only to considerable fluctuations in the weight of the molded parts but also in their dimensions, primarily in the direction of mold opening. The pressure peak cannot be reliably controlled and must be avoided by carefully choosing the switch-over point. Further negative effects are treated in the following section, which will discuss the switch-over point and holding-pressure time in more depth because of their particular importance.

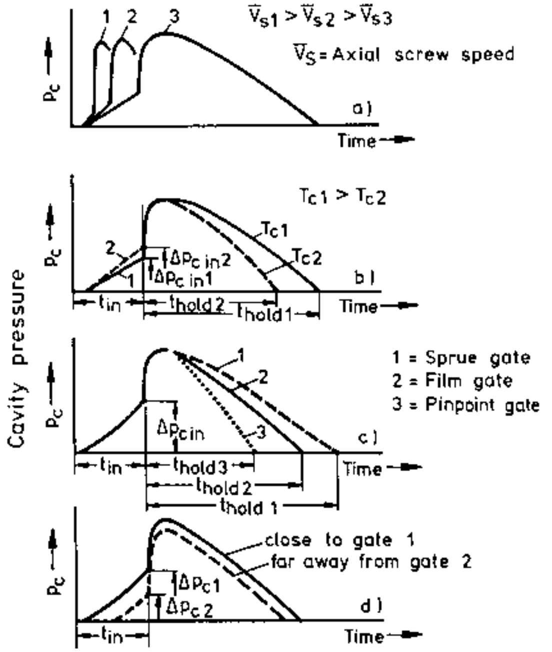

Figure 3.13: Cavity pressure profile as a function of (a) axial speed $(v)_S$), (b) mold temperature (T), (c) gate geometry, and (d) distance of the pressure sensor from the gate

Figure 3.13 demonstrates typical effects of various processing parameters on the cavity pressure. Different axial screw speeds lead to noticeable changes in the build-up of pressure during the compression stage (Fig. 3.13a). A high mold temperature improves pressure propagation in the mold (Fig. 3.13b). The gate design has a significant influence on the holding pressure during the cooling stage (Fig. 3.13c). There is also a pressure drop in the cavity between those areas close to the gate and those close to the end of the flow path (Fig. 13d). Some of these effects will be treated in detail later.

3.1.3.4 Switch-Over from Injection to Holding Pressure

Since reliable information about the pressure in the cavity is generally not available, it often happens that a wrong point is chosen for the switch-over from injection to holding pressure. Figure 3.14 demonstrates four basic possibilities [2]:

- Injection without switch-over
- Injection with late switch-over
- Injection with premature switch-over
- Injection with optimum switch-over