

6 Design of Gates

6.1 The Sprue Gate

The sprue gate is the simplest and oldest kind of gate. It has a circular cross-section, is slightly tapered, and merges with its largest cross-section into the part.

The sprue gate should always be placed at the thickest section of the molded part. Provided proper size, the holding pressure can thus remain effective during the entire time the molded part solidifies, and the volume contraction during cooling is compensated by additional material forced into the cavity. No formation of voids or sink marks can occur. The diameter of the sprue gate depends on the location at the molded part. It has to be a little larger than the section thickness of the molded part so that the melt in the sprue solidifies last. The following holds (Figure 5.9):

$$d_F \geq S_{\max} + 1.0 \text{ (mm)}. \quad (6.1)$$

It should not be thicker, though, because it then the melt solidifies too late and extends the cooling time unnecessarily.

To demold the sprue without trouble it should taper off towards the orifice on the side of the nozzle. The taper is

$$\alpha \geq 1-4^\circ. \quad (6.2)$$

American standard sprue bushings have a uniform taper of 1/2 inch per foot, which is equivalent to about 2.4° .

The orifice towards the nozzle has to be wider than the corresponding orifice of the nozzle. Therefore

$$d_A \geq d_D + 1.5 \text{ mm} \quad (6.3)$$

(Refer to Figure 5.9 for explanation of symbols)

If these requirements are not met, undercuts at the upper end are formed (Figure 5.8).

Very long sprues, that is if the mold platens are very thick, call for a check on the taper. Possibly another nozzle has to be used in the injection molding machine.

To a large degree the release properties of the sprue also depend on the surface finish of the tapered hole. Scores from grinding or finishing perpendicular to the direction of demolding have to be avoided by all means. Material would stick in such scores and prevent the demolding. As a rule the interior of sprue bushings is highly polished.

A radius r_2 (Figure 5.9) at the base of the sprue is recommended to create a sharp notch between sprue and molding and to permit the material to swell into the mold during injection.

To its disadvantage, the sprue always has to be machined off. Even with the most careful postoperation, this spot remains visible. This is annoying in some cases, and one could try to position the sprue at a location that will be covered after assembly of the article. Since this is often impractical, the sprue can be provided with a turnaround so

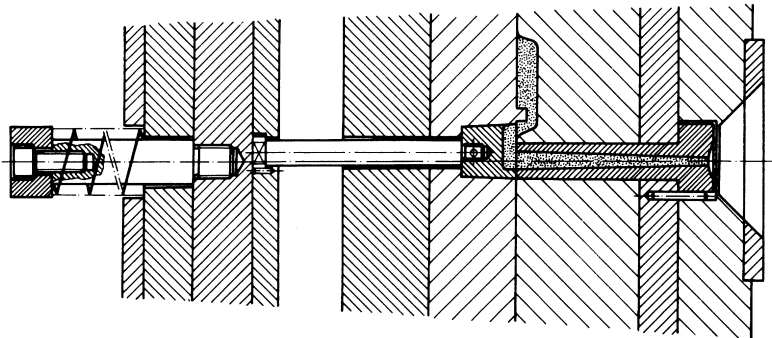


Figure 6.1 Sprue with turnaround [6.1] (also called “overlap gate”)

that it reaches the molded part from the inside or at a point not noticeable later on (Figure 6.1). The additional advantage of such redirected sprues is the prevention of jetting. The material hits the opposite wall first and begins to fill the cavity from there [6.2]. Machining as a way of sprue removal is also needed here.

Another interesting variant of a sprue gate is shown in Figure 6.2. It is a curved sprue, which permits lateral gating of the part. It is used to achieve a balanced position of the molded part in the mold, which is now loaded in the center. This is only possible, however, for certain materials, such as thermoplastic elastomers.

6.2 The Edge or Fan Gate

An edge gate is primarily used for molding parts with large surfaces and thin walls. It has the following advantages:

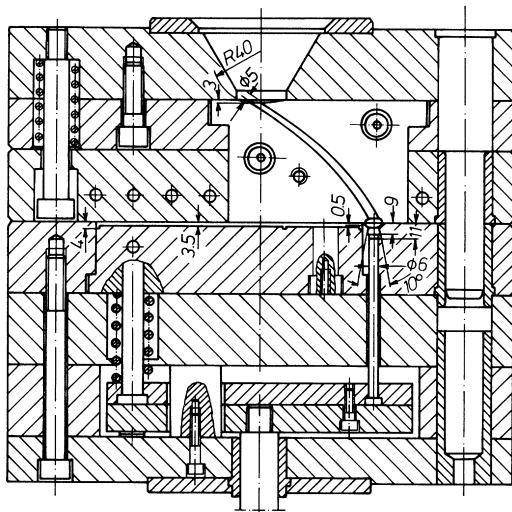


Figure 6.2 Curved sprue [6.3]

- parallel orientation across the whole width (important for optical parts),
- in each case uniform shrinkage in the direction of flow and transverse (important for crystalline materials),
- no inconvenient gate mark on the surface.

The material leaving the sprue first enters an extended distributor channel, which connects the cavity through a narrow land with the runner system (Figure 6.3). The narrow cross-section of the land acts as a throttle during mold filling. Thus, the channel is filled with melt before the material can enter the cavity through the land. Such a throttle has to be modified in its width if the viscosity changes considerably.

The distributor channel has usually a circular cross-section. The relationship of Figure 6.3 generally determines its dimensions. They are comparable with the corresponding dimensions of a ring gate, of which it may be considered a variant.

Besides the circular channel, a fishtail-shaped channel is sometimes met (Figure 6.4). This shape requires more work and consumes more material, but it results in excellent part quality due to a parallel flow of the plastic into the cavity.

Dimensioning was mostly done empirically so far. Today it can be accomplished with the help of rheological software packages such as CADMOULD, MOLDFLOW, etc. (see Chapter 14).

Figure 6.3 Edge gate with circular distributor channel [6.1, 6.4]

$D = s$ to $4/3 s + k$,
 $k = 2$ mm for short flow lengths and thick sections,
 $k = 4$ mm for long flow lengths and thin sections,
 $L = (0.5 \text{ to } 2.0)$ mm,
 $H = (0.2 \text{ to } 0.7) s$.

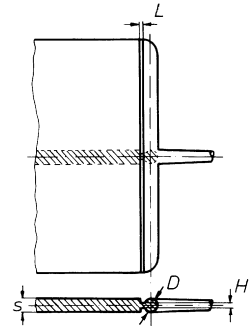
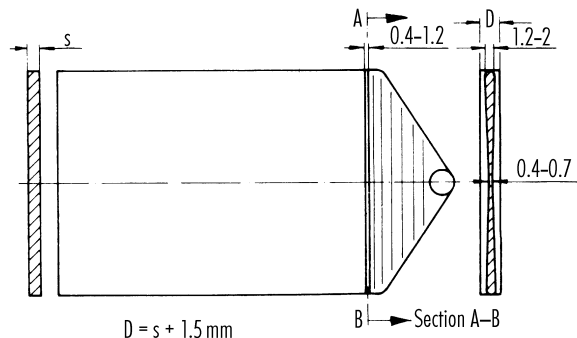


Figure 6.4 Edge gate with adjusted cross section resulting in uniform speed of flow front [6.5]



6.3 The Disk Gate

The disk gate allows the uniform filling of the whole cross-section of cylindrical, sleeve-like moldings, which need a mounting of the core at both ends. The disk can be of a plane circular shape (Figure 6.8) or a cone usually with 90° taper (“umbrella” gate) (Figure 6.5) and distributes the melt uniformly onto the larger diameter of the molded part. This has the advantage that knit lines are eliminated. They would be inevitable if the parts were gated at one or several points. Besides this, a possible distortion can be avoided. With proper dimensions there is no risk of a core shifting from one-sided loading either. As a rule of thumb, the ratio between the length of the core and its diameter should be smaller than

$$\frac{L_{\text{core}}}{D_{\text{core}}} < \frac{5}{1} \quad (6.4)$$

[6.5] (see also Chapter 11: Shifting of Cores).

If the core is longer, it has to be supported on the injection side to prevent shifting caused by a pressure differential in the entering melt. In such cases a ring gate should be employed (Section 6.4). A design like the one in Figure 6.6 is poor because it results again in knit lines with all their shortcomings.

The “umbrella” gate can be connected to the part in two different ways; either directly (Figure 6.5) or with a land (Figure 6.7). Which kind is selected depends primarily on the wall thickness of the molded part.

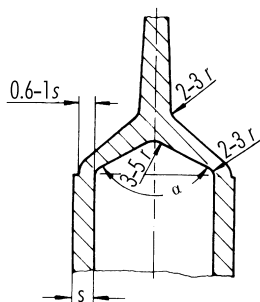


Figure 6.5 Disk gate [6.5] 90° taper

There is another type of umbrella gate known as a disk gate [6.5, 6.6]. A disk gate permits the molding of cylindrical parts with undercuts in a simple mold without slides or split cavities (Figure 6.8, left).

6.4 The Ring Gate

A ring gate is employed for cylindrical parts, which require the core to be supported at both ends because of its length.

The melt passes through the sprue first into an annular channel, which is connected with the part by a land (Figure 6.9). The land with its narrow cross-section acts as a throttle during filling. Thus, first the annular gate is filled with material, which then

Figure 6.6 Conical disk gate with openings for core support [6.5]

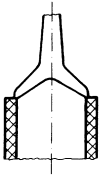
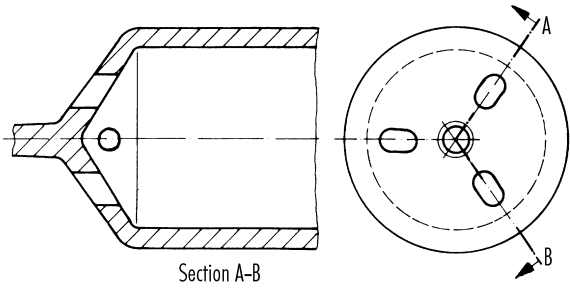


Figure 6.7 Disk gate

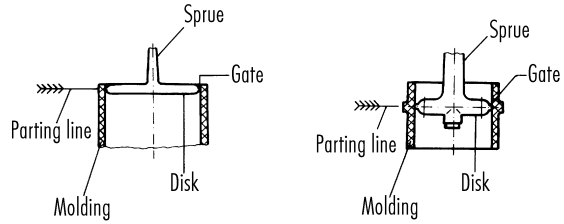


Figure 6.8 Disk gates [6.5, 6.6]

enters the cavity through the land. Although there is a weld line in the ring gate, its effect is compensated by the restriction in the land and it is not visible, or only slightly visible.

The special advantage of this gate lies in the feasibility of supporting the core at both ends. This permits the molding of relatively long cylindrical parts (length-over-diameter ratio greater than 5/1) with equal wall thickness. The ring gate is also utilized for cylindrical parts in multi-cavity molds (Figure 6.9). Although similar in design, a disk gate does not permit this or a core support at both ends.

The dimensions of a ring gate depend on the types of plastics to be molded, the weight and dimensions of the molded part, and the flow length. Figure 6.10 presents the data for channels with circular cross-section generally found in the literature.

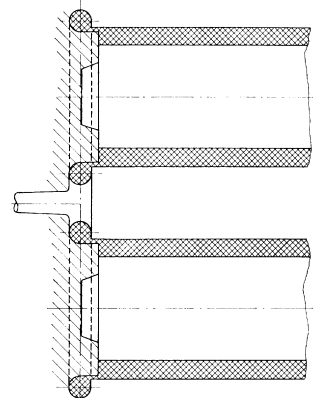


Figure 6.9 Sleeves with ring gates and interlocks for core support [6.1]

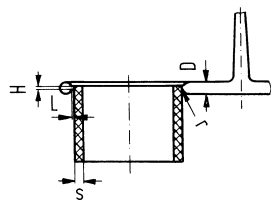


Figure 6.10 Ring gate with circular cross-section [6.4, 6.5]
 $D = s + 1.5 \text{ mm to } 4/3 s + k$,
 $L = 0.5 \text{ to } 1.5 \text{ mm}$,
 $H = 2/3 s \text{ to } 1 \text{ to } 2 \text{ mm}$,
 $r = 0.2 s$,
 $k = 2 \text{ mm for short flow lengths and thick sections,}$
 $k = 4 \text{ mm for long flow lengths and thick sections.}$

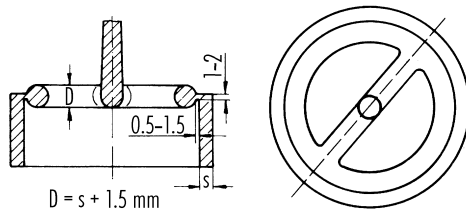


Figure 6.11 Internal ring gate [6.5]

The gates in Figures 6.9 and 6.10 are called external ring gates in the literature [6.5]. Consequently, a design according to Figure 6.11 is called internal ring gate. It exhibits the adverse feature of two weld lines, is more expensive to machine, and complicates the core support at both ends.

A design variation of the common ring gate can be found in the literature. Since it is basically the usual ring gate with only a relocated land (Figure 6.12), a separate designation for this does not seem to be justified.

6.5 The Tunnel Gate (Submarine Gate)

The tunnel gate is primarily used in multi-cavity molds for the production of small parts which can be gated laterally. It is considered the only self-separating gating system with one parting line, which can be operated automatically.

Part and runner are in the same plane through the parting line. The runners are carried to a point close to the cavities where they are angled. They end with a tapered hole, which is connected with the cavities through the land. The tunnel-like hole which is milled into the cavity wall in an oblique angle forms a sharp edge between cavity and tunnel. This edge shears off the part from the runner system [6.7].

There are two design options for the tunnel (Figures 6.13a and 6.13b). The tunnel hole can be pointed or shaped like a truncated cone. In the first case the transition to the molded part is punctate, in the second it is elliptical. The latter form freezes more slowly

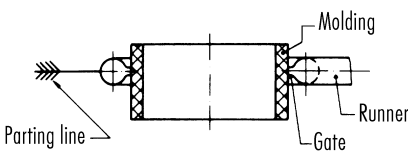


Figure 6.12 External ring gate (rim gate) [6.6]

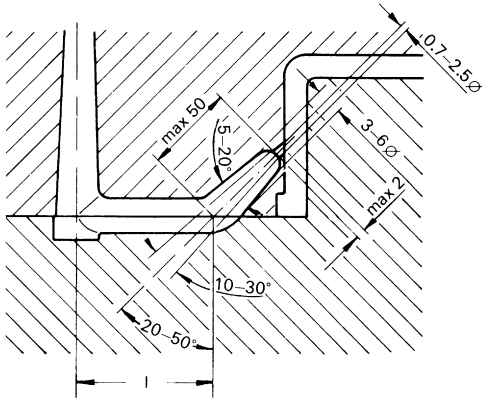


Figure 6.13a Tunnel gate with pointed tapered tunnel [6.5]

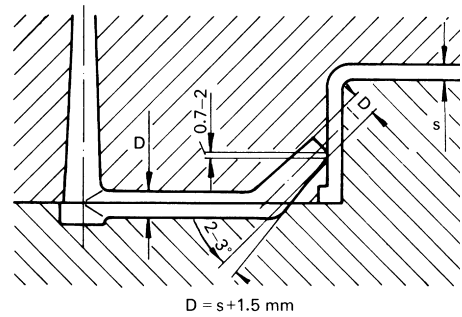


Figure 6.13b Tunnel gate with truncated tapered tunnel [6.5]

and permits longer holding pressure time. Machining is especially inexpensive because it can be done with an end-mill cutter in one pass.

For ejection, part and runner system must be kept in the movable mold half. This can be done by means of undercuts at the part and the runner system. If an undercut at the part is inconvenient, a mold temperature differential may keep the molded part on the core in the movable mold half as can be done with cup-shaped parts.

The system works troublefree if ductile materials are processed. With brittle materials there is the risk of breaking the runner since it is inevitably bent during mold opening. It is recommended therefore, to make the runner system heavier so that it remains warmer and hence softer and more elastic at the time of ejection.

In the designs presented so far, the part was gated laterally on the outside. The tunnel is machined into the stationary mold half and the molded part is separated from the runner during mold opening. With the design of Figure 6.14 the part, a cylindrical cover,

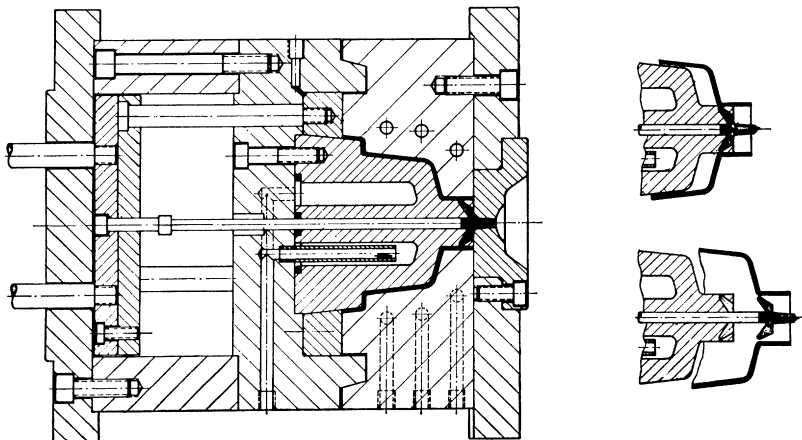


Figure 6.14 Mold with tunnel gates for molding covers [6.8]

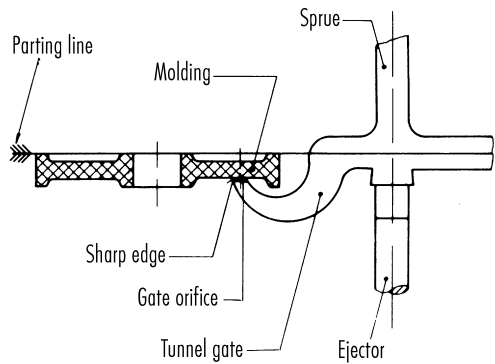


Figure 6.15 Curved tunnel gate [6.6]

is gated on the inside. The tunnel is machined into the core in the movable mold half. The separation of gate and part occurs after the mold is opened by the movement of the ejector system. The curved tunnel gate (Figure 6.15) functions according to the same system.

6.6 The Pinpoint Gate in Three-Platen Molds

In a three-platen mold, part and gate are associated with two different parting lines. The stationary and the movable mold half are separated by a floating platen, which provides for a second parting line during the opening movement of the mold (Figure 6.16). Figures 6.17 and 6.18 show the gate area in detail.

This system is primarily employed in multi-cavity molds for parts that should be gated in the center without undue marks and post-operation. This is particularly the case with cylindrical parts where a lateral gate would shift the core and cause distortion.

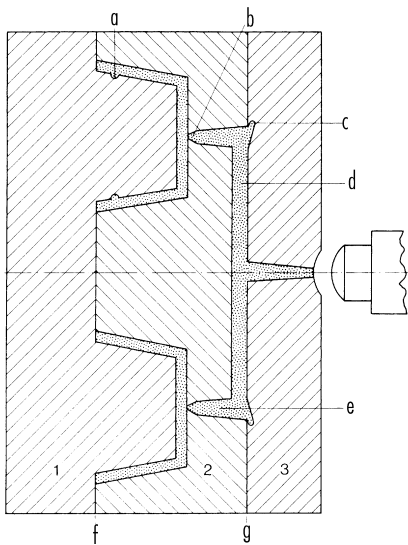


Figure 6.16 Three plate mold [6.9]
1 Movable mold half, 2 Floating plate,
3 Stationary mold half,
a Undercut in core, b Gate, c Undercut,
d Runner, e Sprue core, f Parting line 1,
g Parting line 2.

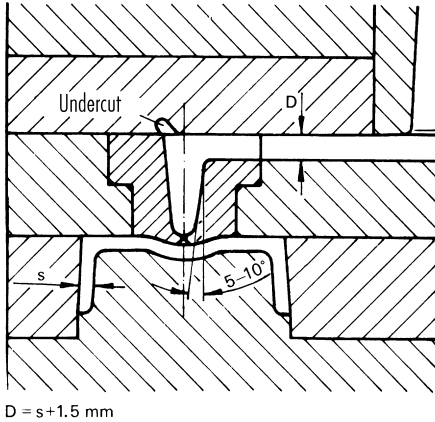


Figure 6.17 Pinpoint gate in three-plate mold [6.5]

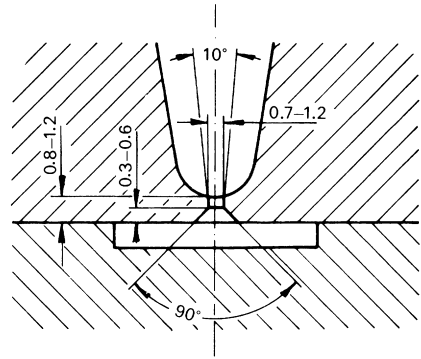


Figure 6.18 Dimensions for pin point gate [6.6]

Thin-walled parts with large surface areas are also molded in such a way in single cavity molds. Multiple gating (Figure 6.19) is feasible, too, if the flow length-over-thickness ratio should call for this solution. In this case special attention has to be paid to knit lines as well as to venting.

The opening movement of a three-platen mold and the ejection procedure separate part and runner system including the gate. Thus, this mold provides a self-separating,

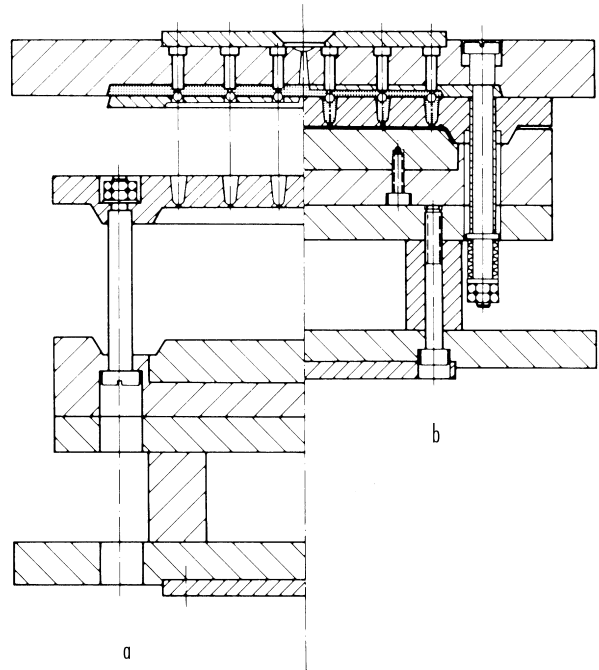


Figure 6.19 Three plate mold for multiple gating in series [6.10]
a Open, b Closed.

automatic operation. The mold is opened first at one and then at the other parting line, thus separating moldings and runner system.

6.7 Reversed Sprue with Pinpoint Gate

The reversed sprue is frequently enlarged to a “pocket” machined into the stationary mold half. It is connected with the cavity by a gate channel with reversed taper.

During operation the sprue is sealed by the machine nozzle and fully filled with plastic during the first shot. With short cycle times the material in the sprue remains fluid, and the next shot can penetrate it. The nozzle, of course, cannot be retracted each time.

The principle of operation of a reversed-sprue gate is demonstrated in Figure 6.20. The hot core in the center, through which fresh material is shot, is insulated by the frozen plastic at the wall of the sprue bushing. Air gaps along the circumference of the bushing obstruct heat transfer from the hot bushing to the cooled mold. The solution shown in Figure 6.20 functions reliably if materials have a large softening range such as LDPE, and the molding sequence does not fall short of 4 to 5 shots per minute [6.11].

If these shorter cycle times are impractical, additional heat has to be supplied to the sprue bushing. This can be done rather simply by a nozzle extension made of a material with high thermal conductivity. Such materials are preferably copper and its alloys. The design is presented in Figure 6.21. The tip of the nozzle is intentionally kept smaller than the inside of the sprue bushing. With the first shot the gap is filled with plastic, which protects the tip from heat loss to the cool mold later on.

Major dimensions for a reversed-sprue design can be taken from Figure 6.22.

The gate diameter like that of all other gates depends on the section thickness of the part and the processed plastic material and is independent of the system. One can generally state that smaller cross-sections facilitate the break-off. Therefore, as high a melt temperature as possible is used in order to keep the gate as small as possible.

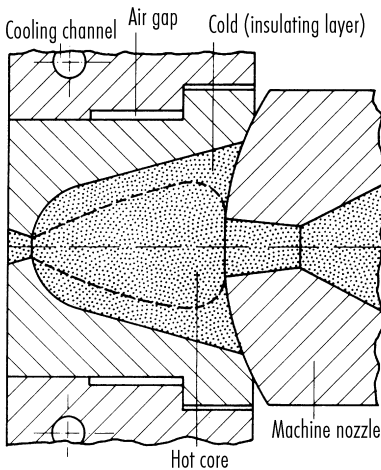


Figure 6.20 Bushing for reversed sprue [6.9]

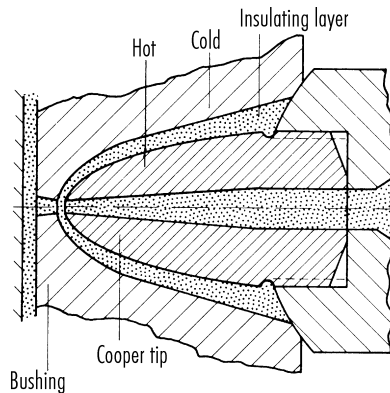
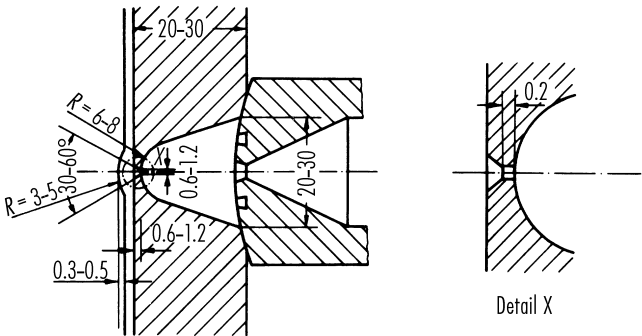


Figure 6.21 Reversed sprue heated by nozzle point [6.9]

Figure 6.22 Reversed sprue with pinpoint gate and wall thickening opposite gate for better distribution of material [6.11] right: Detail X (Dimensions in mm)

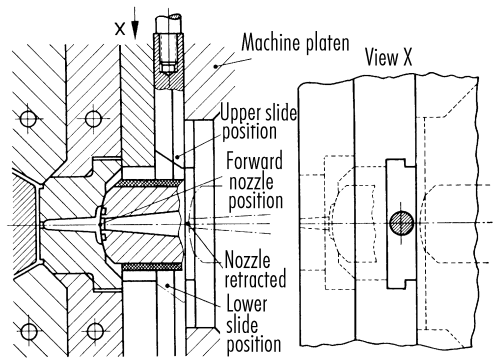


A tapered end of the pinpoint gate is needed, even with its short length of 0.6 to 1.2 mm, so that the little plug of frozen plastic is easily removed during demolding and the orifice opened for the next shot.

Some plastics (polystyrene) have a tendency to form strings under those conditions. In such cases a small gate is better than a large one. Large gates promote stringing and impede demolding.

It is practical to equip the nozzle with small undercuts (Figure 6.22), which help in pulling a solidified sprue out of the bushing. The sprue can then be knocked off manually or with a special device (Figure 6.23).

Figure 6.23 Sprue strike-off slide in a guide plate between mold and machine platen [6.12]



A more elegant way of removing the sprue from the bushing is shown in Figure 6.24. The reversed sprue is pneumatically ejected. An undercut holds the sprue until the nozzle has been retracted from the mold. Then an annular piston is moved towards the nozzle by compressed air. In this example it moves a distance of about 5 mm. After a stroke of 3 mm the air impinges on the flange of the sprue and blows it off [6.12].

6.8 Runnerless Molding

For runnerless molding the nozzle is extended forward to the molded part. The material is injected through a pinpoint gate. Figure 6.25 presents a nozzle for runnerless molding.

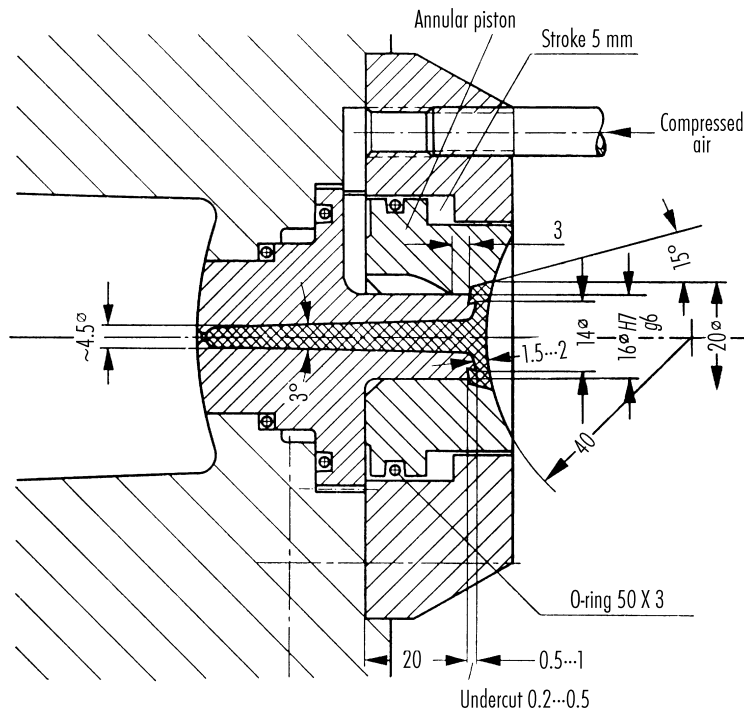


Figure 6.24 Reversed sprue with pinpoint gate and pneumatic sprue ejector [6.12] Dimensions in mm

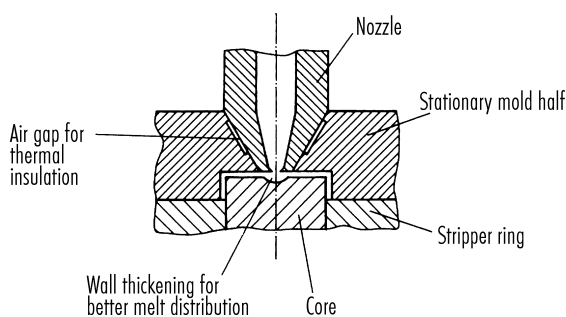


Figure 6.25 Sprueless gating

The face of the nozzle is part of the cavity surface. This causes pronounced gate marks (mat appearance and rippled surface) of course. Therefore, one has to keep the nozzle as small as possible. It is suggested that a diameter of 6 to 12 mm not be exceeded. Because the nozzle is in contact with the cooler mold during injection- and holding-pressure time, this process is applicable only for producing thin-walled parts with a rapid sequence of cycles. This sequence should not be less than 3 shots per minute to avoid a freezing of the nozzle, which is only heated by conduction. The applicability of this procedure is limited and it is used for inexpensive packaging items.

The principle is successfully employed when the material is further distributed through runners as in a three-platen mold.

6.9 Molds with Insulated Runners

Properly designed insulated runners, i.e., with thermally controlled gate, offer several advantages over hot runners. These are:

- Thanks to the lack of dead spots and to the smooth channel, insulated runners are dependable, provided that fairly well stabilized materials are used. But all common thermoplastic materials nowadays meet this condition.
- Since the thermal insulation arises itself through melt deposited at the wall, the temperature distribution of the melt will always be very uniform.
- Insulated runners are always economical if constant operation with uniform cycles is guaranteed. It is not suitable, however, for extended interruptions.
- The higher the throughput, i.e., the greater the shot weight at normal wall thickness, the more dependable are insulated runners.
- Because insulated runners are very easy and quick to clean, they are particularly recommended when frequent color changes have to be made or when recycled material is used for which it cannot be guaranteed that entrained impurities will not lead to blockage or unclean, patchy surfaces.
- Properly designed insulated runners are both cheaper to buy and to maintain than hot runners.

A distinguishing feature of a well designed insulated runner is that it has minimal heat loss. This means that thermal equilibrium will be reached pretty quickly with low energy input on startup or after interruptions. Good design requires the following measures:

- good insulation effect through thick, outer insulation (generous channel cross-section),
- an isolated air gap (a chimney effect must not occur in the air gap),
- minimal contact areas between channel block and mold,
- carefully calculated installation of cartridge heaters in the channel block to compensate for losses at critical points during long cycle times.

It is always advisable – and absolutely vital for heat-sensitive plastics such as POM, PC, PBT, etc. – that the gate area be carefully designed. Neither the critical shear rate may be exceeded nor may material that is too cold be transported into the mold. Furthermore, material that is too hot must not remain there to decompose. The following measures will produce an ideal temperature profile in the gate area:

An internally heated needle (Figure 6.26) serving as the energy supply element in the transition area to the cavity must have a temperature profile well adjusted to the plastic for processing. This means that the tip of the needle must keep the melt precisely at its ideal processing temperature, while it must not overheat the melt along its shaft, and in the area of the guide bushing the temperature of the plastic should just about be that of freezing.

For some years now, three standard types of tried and proven modules have been available in two sizes for materials such as PS, ABS, PC, PE, PP, PA, POM and PBT (see Figures 6.27 and 6.28) (e.g., supplied by KBC System, Bellanger, 1271 Givirns, Switzerland):

- for gate diameters in the range: 0.6 to 2.5 mm: MIDI,
- for gate diameters in the range 2.0 to 5 mm: MAXI.

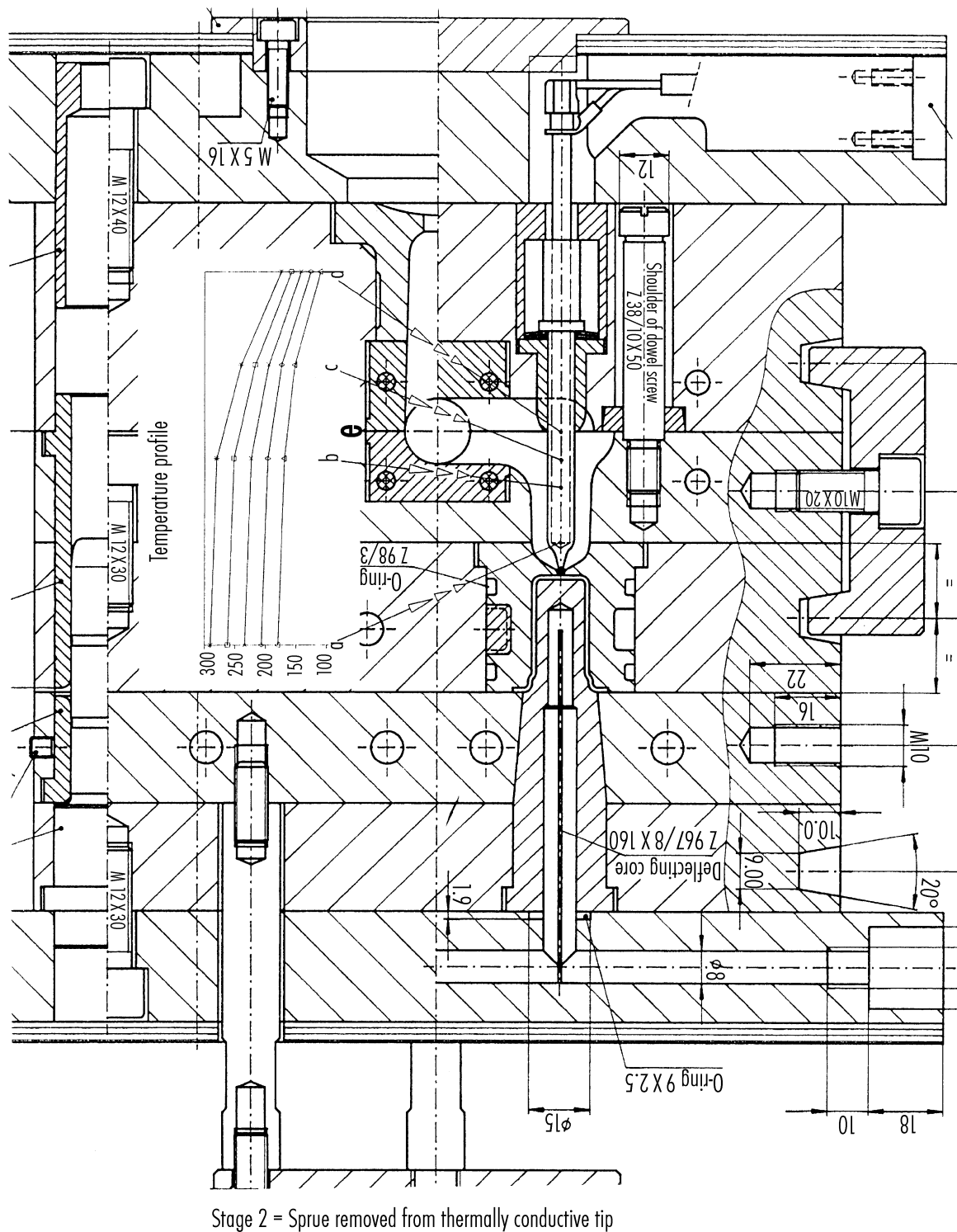


Figure 6.26 Insulated runner mold with internally heated needle

Application Areas

PE moldings weighing 0.15 g can still be produced at a rate of 8 shots/minute with insulated runners, although the heat input into the system is correspondingly low for small shot weights. In these cases, more energy must be fed to the runner by means of cartridge heaters. Nevertheless, the insulated runners require barely one fourth of the

Figure 6.27 Internally heated needles

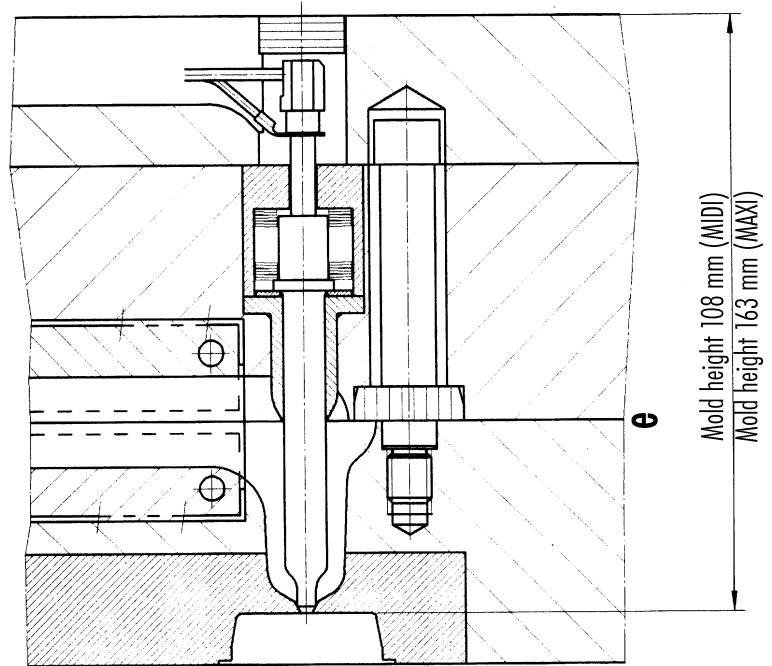
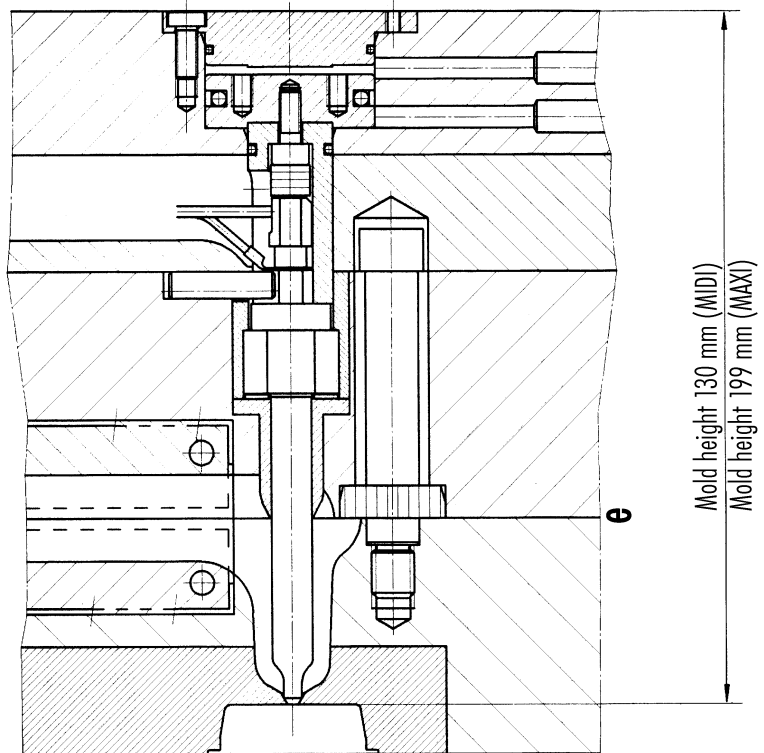


Figure 6.28 Internally heated needles



electric energy required by hot runners. It may generally be assumed that the size and weight of the producible molded parts are governed only by the rheological limits of the plastic melts used, i.e. the shear rate at the gate.

Practical Experience Gained with Insulated Runners

Thanks to its simple construction, clear functionality and self-sealing capability, the insulated runner is easy to operate. There are few practiced operatives who consider the freezing of the insulated runner during protracted production breaks to be a serious disadvantage. Quite the opposite is true. They appreciate the fact that the second parting line is easy and quick to open by simply moving two retaining clamps and that the frozen material can be removed in one movement (Figure 6.29). The mold is then ready for production again after two to three cycles. This is quite advantageous because, when disruptions occur in the case of hot runners, these are by far more complicated to dismantle and clean. Furthermore, protracted disruptions with hot runners cause problems because the material degrades if the heating is not turned off. An insulated runner can be completely cleaned within a few minutes, whereas production has to be stopped for hours when this happens to hot runners.

6.10 Temperature-Controlled Runner Systems – Hot Runners

Runner systems in conventional molds have the same temperature level as the rest of the mold because they are in the same mold block. If, however, the runner system is located in a special manifold that is heated to the temperature of the melt, all the advantages listed below accrue. Runner manifolds heated to melt temperature have the task of distributing the melt as far as the gates without damage. They are used for all injection-molded thermoplastics as well as for crosslinking plastics, such as elastomers and thermosets.

In the case of thermoplastics, these manifolds are usually referred to as the hot-runner system, the hot manifold, or simply as hot runners. For crosslinking plastics, they are known as cold runners.

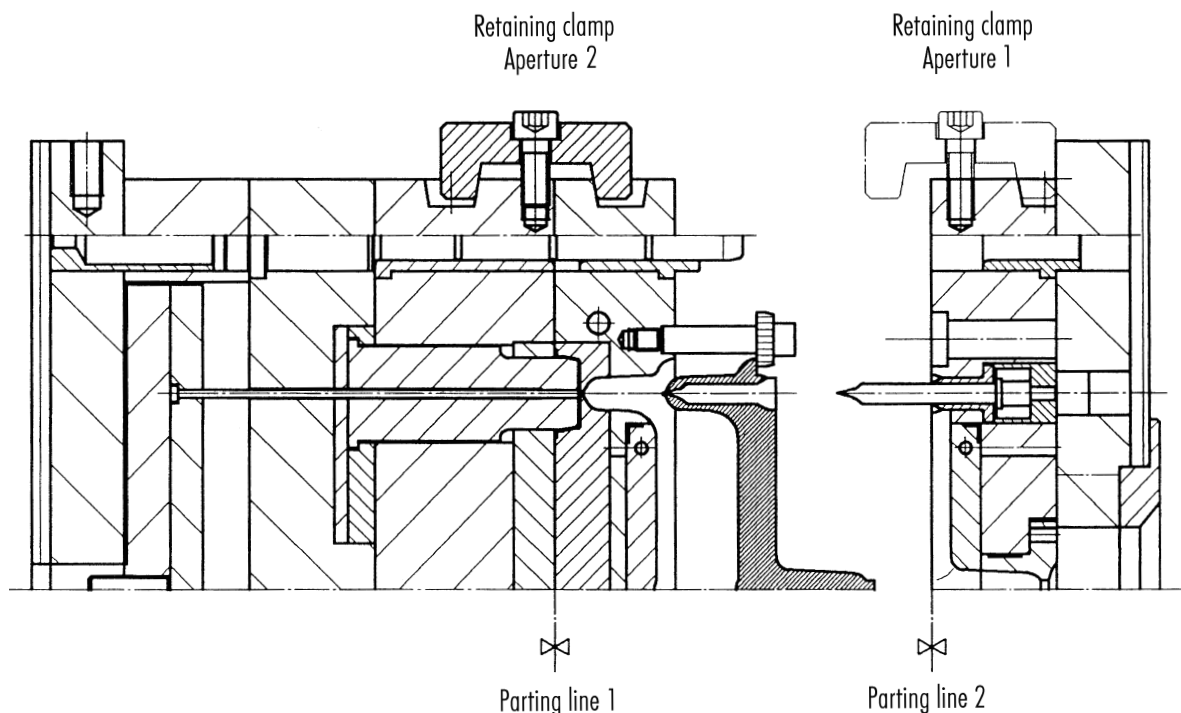


Figure 6.29 Retaining clamps make insulated runners easier to clean

6.10.1 Hot-Runner Systems

Hot-runner systems have more or less become established for highly-automated production of molded thermoplastic parts that are produced in large numbers. The decision to use them is almost always based on economics, i.e. production size. Quality considerations, which played a major role in the past, are very rare now because thermoplastics employed today are almost all so stable that they can be processed without difficulty with hot-runner systems that have been adapted accordingly.

Hot-runner systems are available as standard units and it is hardly worthwhile having them made. The relevant suppliers offer not only proven parts but also complete systems tailored to specific needs. The choice of individual parts is large.

Table 6.1 Hot runner systems suppliers in North America (selection) (see also Table 17.2)

D-M-E Company	Madison Heights, MI/USA
Dynisco HotRunners	Gloucester, MA/USA
Eurotool	Gloucester, MA/USA
Ewicon Hotrunner Systems	East Dundee, IL/USA
Gunther Hot Runner Systems	Buffalo Grove, IL/USA
Hasco-Internorm	Chatsworth, CA/USA
Husky	Bolton, Ontario/Canada
Incoe	Troy, MI/USA
Manner International	Tucker, GA/USA
Mold-Masters	Georgetown, Ontario/Canada
Thermodyne HotRunner Systems	Beverly, MA/USA

6.10.1.1 Economic Advantages and Disadvantages of Hot-Runner Systems

Economic Advantages:

- **Savings in materials** and costs for regrind.
- **Shorter cycles**; cooling time no longer determined by the slowly solidifying runners; no nozzle retraction required.
- **Machines can be smaller** because the shot volume – around the runners – is reduced, and the clamping forces are smaller because the runners do not generate reactive forces since the blocks and the manifold block are closed.

Economic Disadvantages:

- Much more complicated and considerably more expensive.
- More work involved in running the mold for the first time.
- More susceptible to breakdowns, higher maintenance costs (leakage, failure of heating elements, and wear caused by filled materials).

Technological Advantages:

- Process can be automated (demolding) because runners do not need to be demolded.
- **Gates at the best position**; thanks to uniform, precisely controlled cooling of the gate system, long flow paths are possible.
- **Pressure losses minimized**, since the diameter of the runners is not restricted.
- **Artificial balancing of the gate system**; balancing can be performed during running production by means of temperature control or special mechanical system (e.g. adjustment of the gap in a ring-shaped die or use of plates in flow channel). (Natural balancing is better!)

- **Selective influencing of mold filling;** needle valve nozzles and selective actuation of them pave the way for new technology (cascade gate system: avoidance of flow lines, in-mold decoration).
- **Shorter opening stroke** needed compared with competing, conventional three-platen molds.
- **Longer holding pressure**, which leads to less shrinkage.

Technological Disadvantages:

- Risk of thermal damage to **sensitive** materials because of long flow paths and dwell times, especially on long cycles.
- Elaborate temperature control required because non-uniform temperature control would cause different melt temperatures and thus non-uniform filling.

6.10.1.2 Hot Runners for Various Applications and New Possibilities

Figure 6.30 shows the basic possibilities that are available.

Hot-runner systems are almost always used when large series have to be made in highly automated production. However, they also permit new technological variants based on the possibility of positioning the gates so as to yield the best quality molded parts. They are primarily connected to needle valve nozzles, which are actuated with precise timing.

Cascade gating (Figure 6.31): needle valve nozzles that – depending on the filling – are opened and closed so that the flow front is always fed by the last nozzle to have been passed [6.14, 6.15].

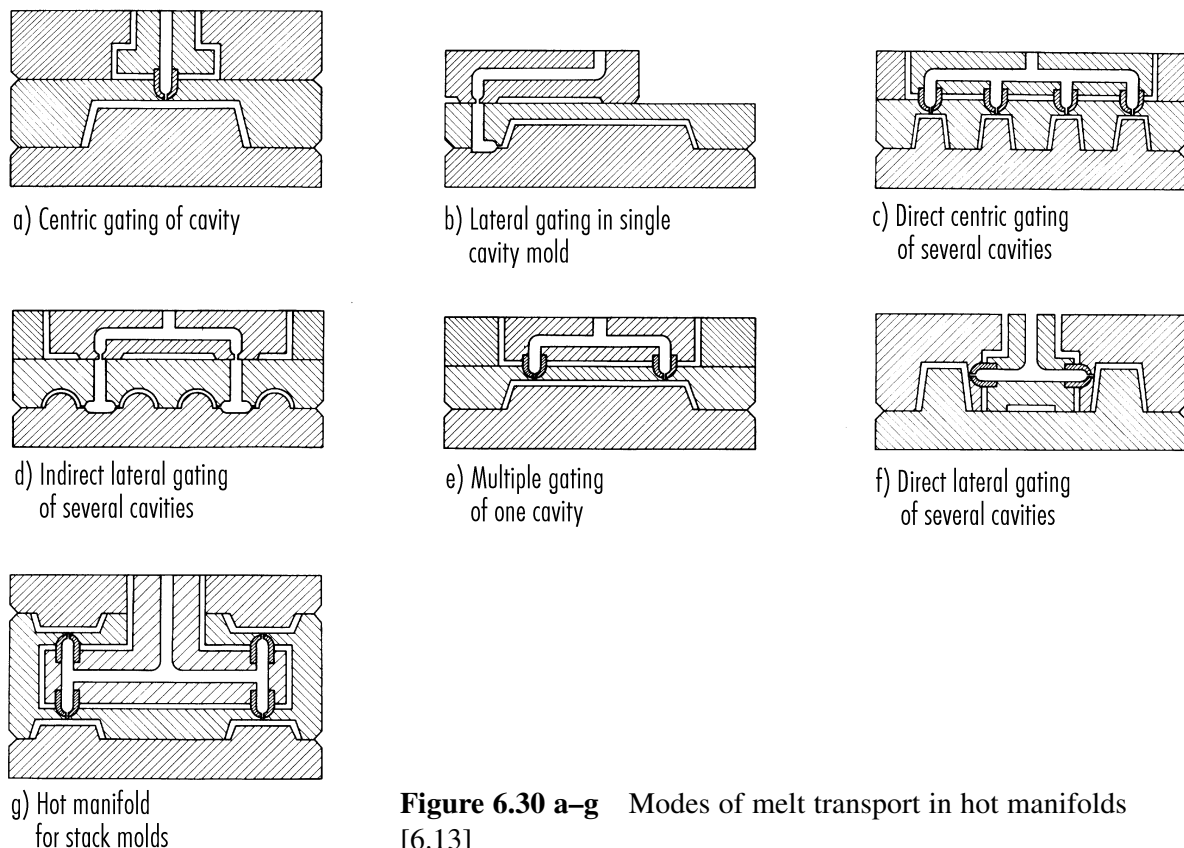
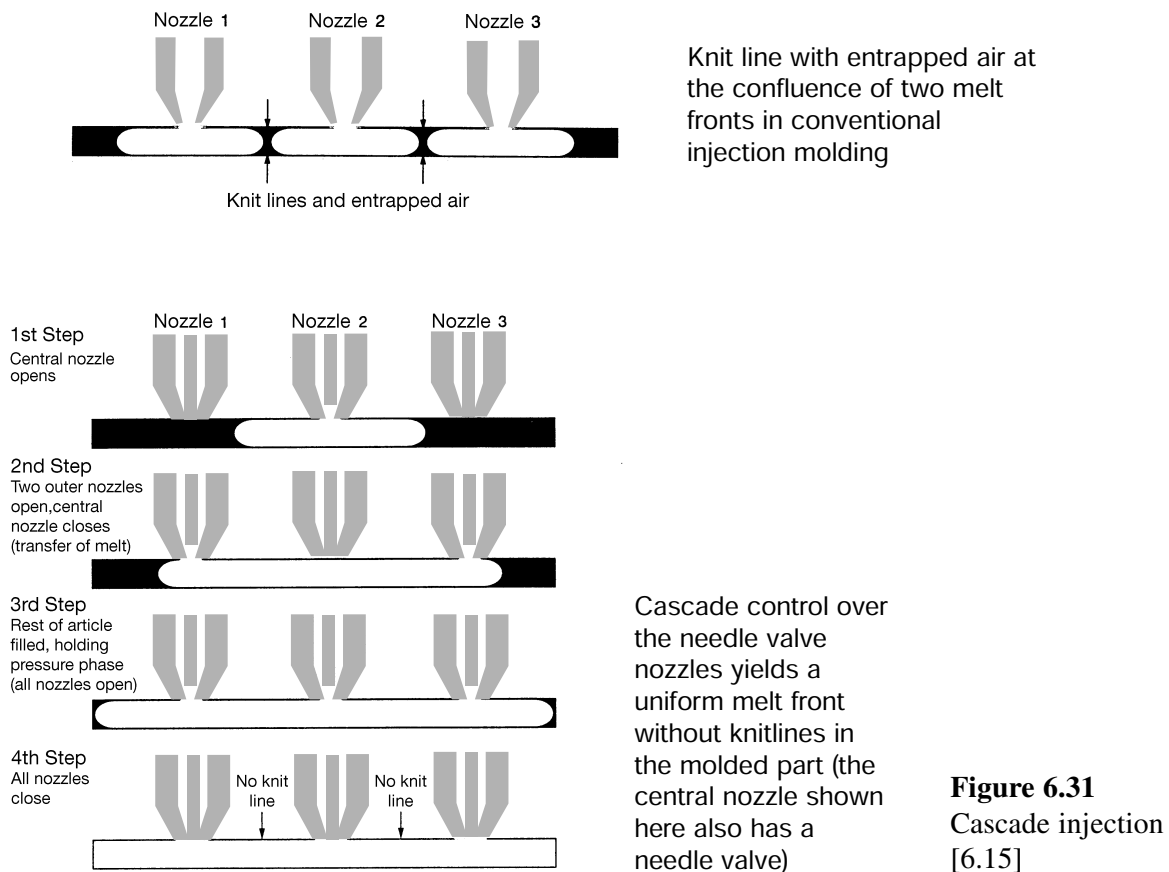


Figure 6.30 a–g Modes of melt transport in hot manifolds [6.13]



This allows:

- **Avoidance of weld lines** (e.g. requirement for vehicle body exterior parts). These large-surface parts require gates. This would normally give rise to weld lines. The cascade gating technique pushes the flow front forward in relays, whereby each nozzle opens only after the front has just passed it and the previous nozzle closes at the same time.
- **In-mold decoration** (integrated lamination with textiles or film) has become possible because the lower pressures no longer displace the inserted textile, and so no folds or other flaws occur. This method works on the principle of avoiding weld lines.
- **Multi-cavity mold** with cavities of different geometry and volume. Also known as family molds because parts of different volume that belong together are produced simultaneously in one mold by one shot.
- **Since injection pressure and holding pressure** may be actuated independently of each other, opening and closing can be adjusted to the conditions of each cavity.
- **Controlled volume balancing** means that a weld line can be shifted into a non-critical area of the molded part.
- **Stack molds**, i.e. doubling or quadrupling of production in the same time scale thanks to two or more mold platens and parting lines.

6.10.1.3 Design of a Hot-Runner System and its Components

Hot-runner molds are ambitious systems in a technological sense that involve high technical and financial outlay for meeting their main function of conveying melt to the gate without damage to the material. Such a design is demonstrated in Figure 6.32.

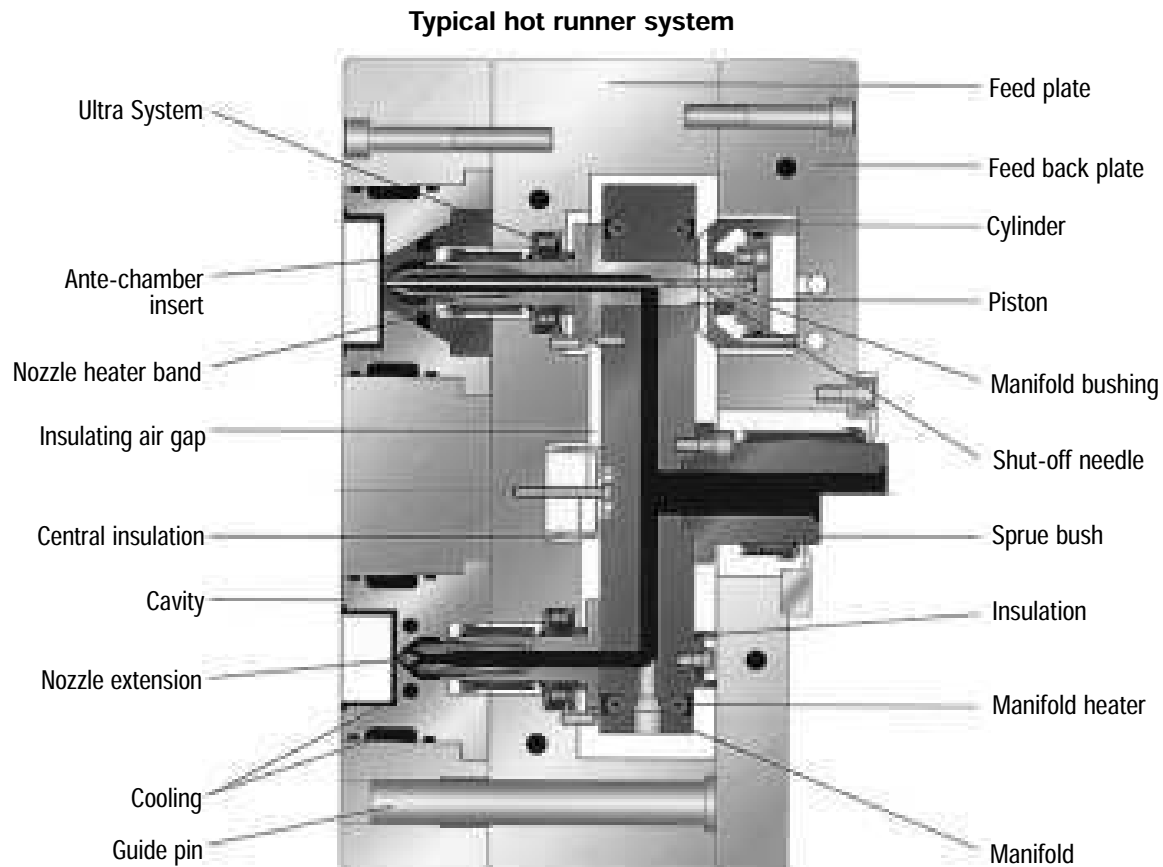


Figure 6.32 View through an externally heated manifold block. Typical hot runner system with two different gate nozzles. Top: A needle valve nozzle with pneumatic actuation; bottom: an open nozzle point for a small mold mark, of the kind used for thermoplastics. Manifold is heated with tubular heaters [6.16]. (Husky)

Hot runners are classified according as they are heated:

- insulated-runner systems (see Section 6.9) and
- genuine hot-runner systems.

The latter can be further sub-classified according to the type of heating (see Figure 6.35 [6.17]):

- internal heating, and
- external heating.

Heating is basically performed electrically by cartridge heaters, heating rods, band heaters, heating pipes and coils, etc. To ensure uniform flow and distribution of the melt, usually a relatively elaborate control system comprising several heating circuits and an appropriate number of sensors is needed. The operating voltage is usually 220 to 240 V, but small nozzles frequently have a low voltage of 5 V, and also 15 V and 24 V operating voltage.

Externally/Internally Heated Systems

The two possibilities are shown schematically in Figure 6.33, while Figure 6.34 shows the flow conditions and the resultant temperature distributions in the melt for both types

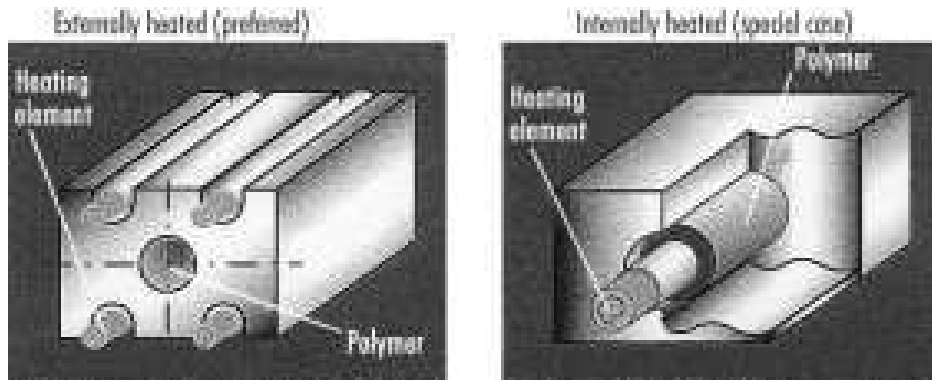


Figure 6.33
Cross-sections of
the flow-channel
in the manifold
Source:
DuPont [6.17]

of heating. For the sake of completeness, it should be mentioned that this distinction between internal and external heating applies only to the manifold blocks because it is common practice to heat, for instance, the blocks externally and the nozzles internally.

The major advantages and disadvantages of the two types are immediately apparent from Figure 6.34.

Externally Heated System:

Advantage:

Large flow channels cause low flow rate and uniform temperature distribution.

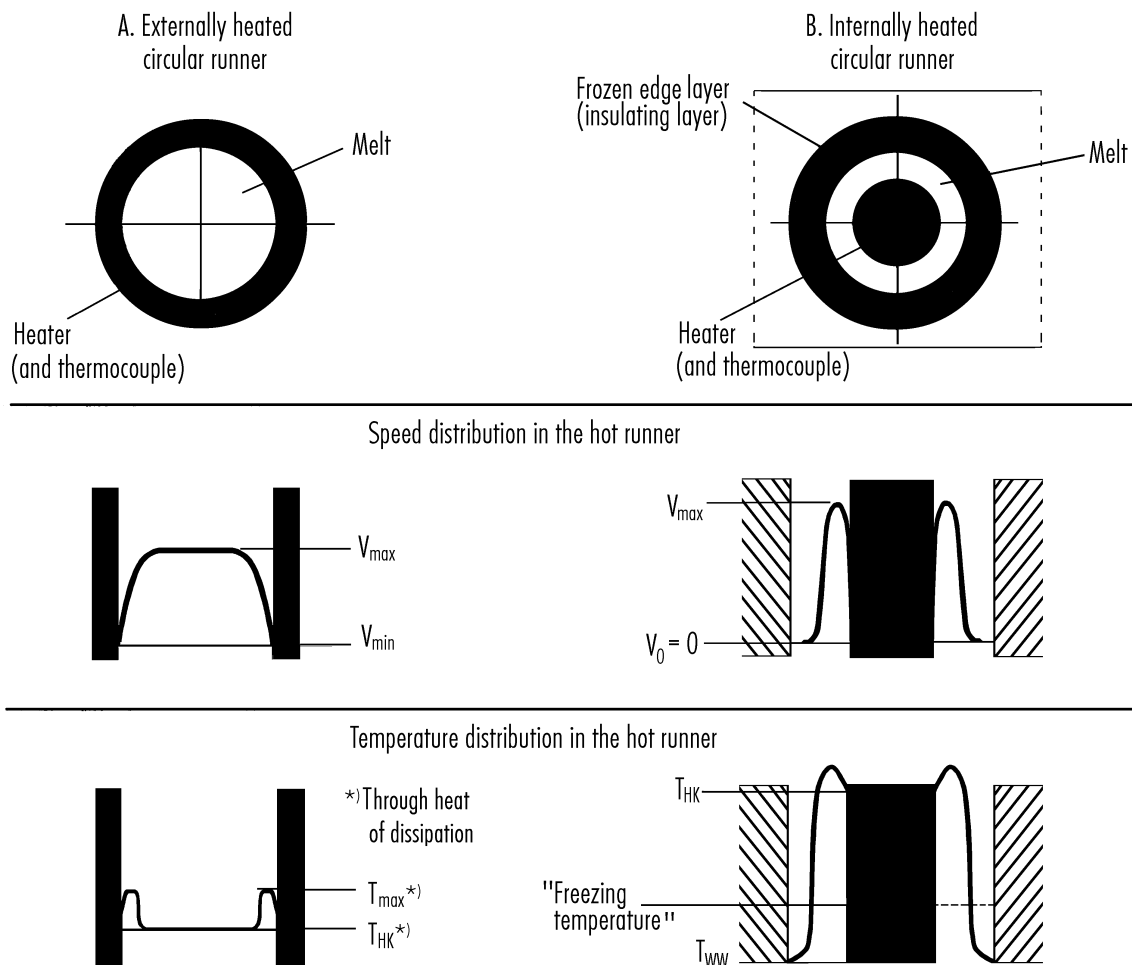


Figure 6.34 Hot runner systems. Comparison of internally and externally heated systems [6.18]

Disadvantage:

The temperatures required for external heating have to be very much higher (see Figure 6.35 [6.19] for PA 66). Here, the mold temperature is approximately 100 °C and the manifold temperature is at least 270 °C; this means there is a temperature difference of approximately 170 °C from the mold block, which means:

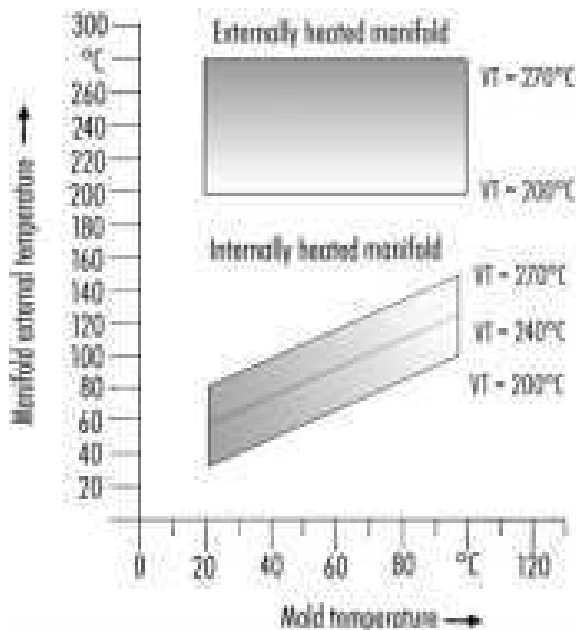


Figure 6.35 External temperatures of manifold systems as a function of mold temperature [6.19]

- special measures required for fixing the hot-runner nozzles to the gates because of the considerable thermal expansion,
- risk of disruption if this is not adequately resolved,
- higher heating power (over 500 W per 100 mm line for a typical cross-section measuring 40 · 7 mm²),
- insulation from the mold block,
- large, unsupported areas and therefore, with large-surface molds, risk of bowing of the mold platen on the feed side if this has not been designed thick enough and thus, as a direct consequence, the mold becomes very heavy.

Internally Heated System

A frozen layer of plastic forms on the inner surface of the channel and functions as an insulation layer.

- The heat requirement of the system is much lower (roughly 55 W per 100 mm length of inside tube).
- The temperature differences between mold and manifold blocks are negligible; therefore measures that would have been necessary for large heat expansion are not needed.
- The hot manifold of an internally heated system is a compact block that is bolted tightly to the mold. Consequently, the mold is very rigid and no measures are required for centering the nozzles and gates. This also allows the plate on the machine side to be manufactured as one block consisting of fixed mold with in-built manifold and corresponding rigidity [6.20] (Figure 6.36).

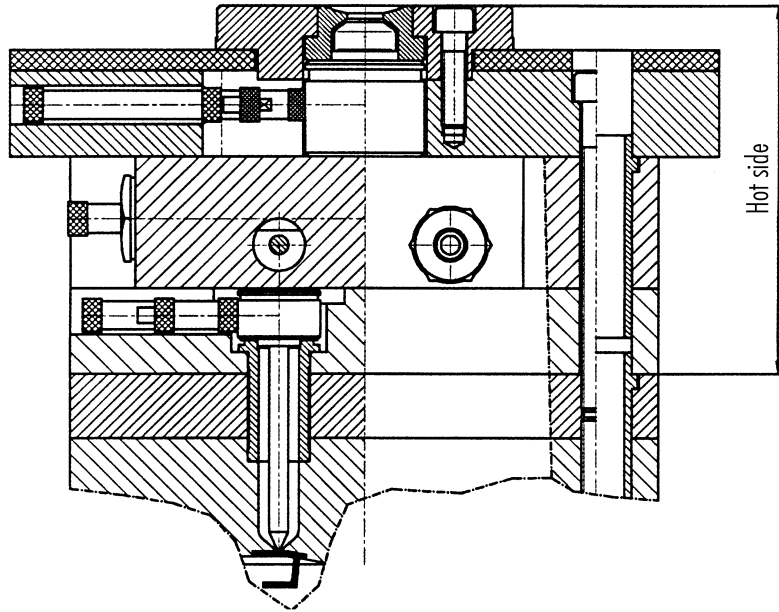


Figure 6.36 Cross-section through a mold with hot side [6.20]

The melt volume is small and so the dwell times of the flowing melt are short. On the other hand, the flow rates are very much greater and this can damage the material.

It is not advisable to use internally heated systems for sensitive materials.

When deciding on a certain system, advice can be obtained from suppliers. All of the major ones supply more than one system [6.19, 6.21].

6.10.1.3.1 Sprue Bushing

The sprue bushing serves to transfer the melt from the machine into the manifold. In order to satisfy the basic requirement of uniform melt temperature, this spot must also be carefully heated and must therefore generally be fitted with its own heating circuit and temperature sensors. If the temperature in this area is too low for thermoplastics sensitive to high temperatures, there may be complaints about the surface quality of the finished parts because there may be a temperature difference of 20 to 30 °C in the melt on account of the large lengths of sprue bushings of 30 to 50 mm [6.21]. They must therefore be heated.

Since the plastic melt is shot through the hot runner into the injection mold under high pressure, a high nozzle contact pressure is necessary in order to achieve a permanent and melt-tight connection to the hot runner. Naturally the same conditions apply here as for any other sprue bushing. Since, with hot runners, the distance between machine nozzle and mold is often large – e.g., if clamping systems are required on the feed side in the mold – extended, heated nozzles are required in such cases (Figure 6.37).

Since there are no temperature differences between machine and manifold, it is not necessary to detach the machine nozzle from the sprue bushing. So-called extended nozzles and extended bushings have become commonplace (Figure 6.38) because they ensure that no melt escapes either into the cavity or out of the bushing and also that decompression can be readily performed.

Decompression is an established method of preventing melt drooling from a hot runner gate into the empty cavity after demolding, thereby leading to lower quality and disrupting operations. It is generally performed by retracting the screw in the cylinder but may also be effected by retracting the extended nozzle in the extended bushing.

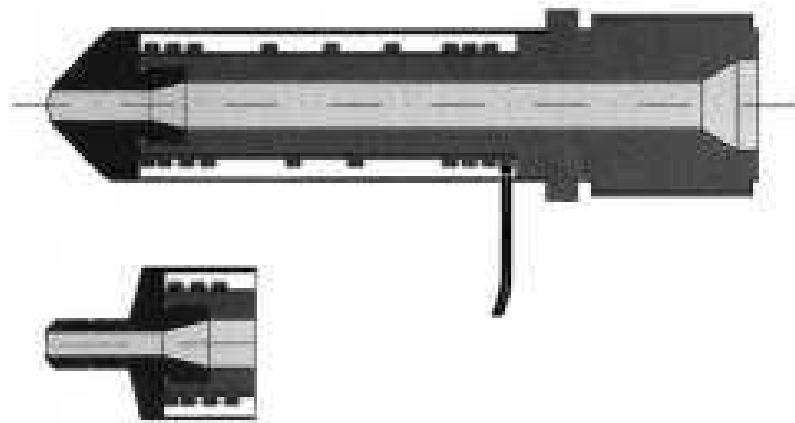


Figure 6.37 Machine nozzle with integrated heater [6.22]

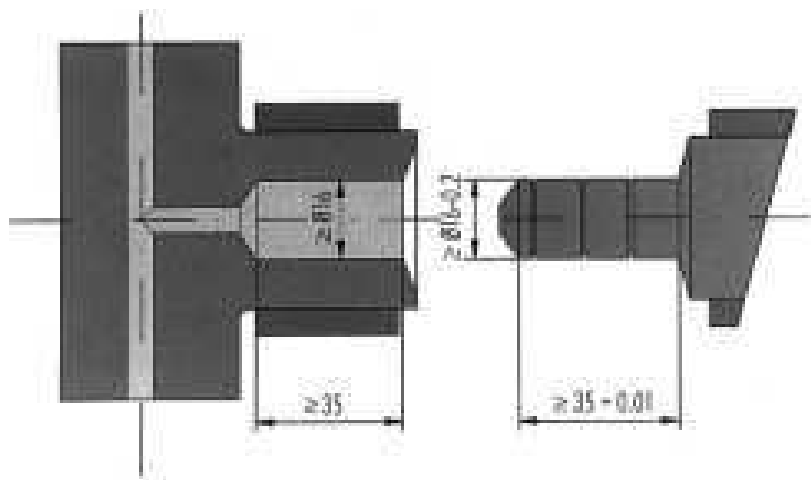


Figure 6.38 Dipping nozzle (extended) [6.22]

Nozzles and bushings are available as standard parts and it is not worthwhile having them made.

6.10.1.3.2 Melt Filters

As a result of blockages in the hot runners, particularly in the narrow cross-sections of the gate nozzles, which are caused by melt that is not totally clean, it is very common to install filters nowadays (Figure 6.39). Roßbach [6.23] always recommends this precaution, not just when virgin material is being processed or when the machines have a clamping force of less than 5000 kN (larger machines have molds whose gates are so large that common impurities do not become trapped). In all cases, actually, it is necessary to know the pressure losses in order to be able to estimate whether mold filling will still be accomplished without error. The pressure loss is usually $< 30\%$ of the standard pressure of a nozzle without filter.

A filter cannot be installed on the mold if decompression is employed. In this case, the filter should be installed in the nozzle of the machine as shown in Figure 6.40.

6.10.1.3.3 Manifold Blocks

6.10.1.3.3.1 Single-Cavity Molds

There are several reasons for installing a heated sprue in the case of single-cavity molds, e.g., when a prototype has to be produced under exactly the same conditions as parts

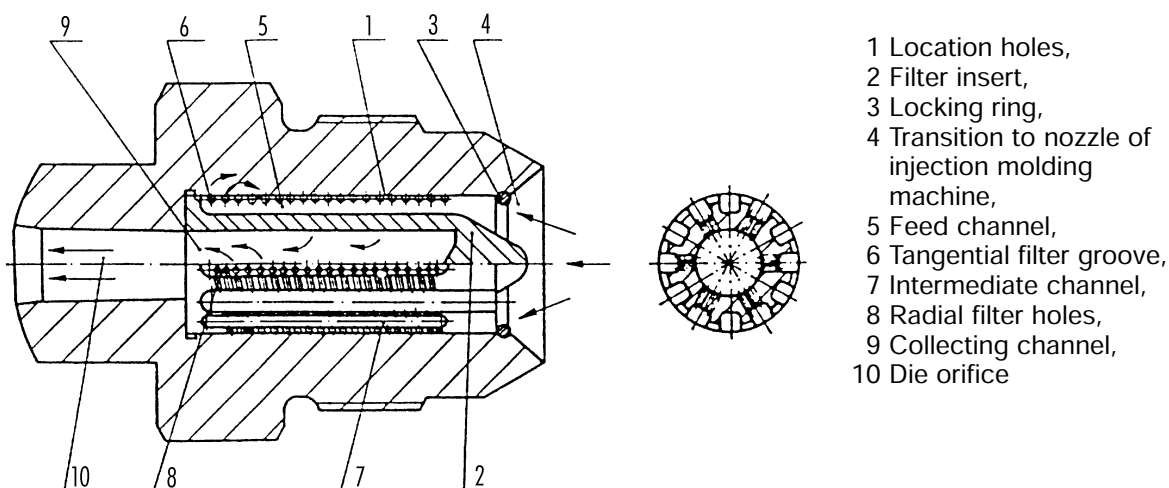


Figure 6.39 Filter insert with radial holes and tangential grooves [6.23]

from a later series to be made in a multi-cavity mold. Only in such cases is the same holding pressure and thus the same shrinkage adjustable. Figure 6.41 shows a needle valve nozzle and a nozzle with thermal valve for simple applications.

6.10.1.3.4 *Manifold Beams*

6.10.1.3.4.1 *Multi-Cavity Molds*

The melt is fed from the screw bushing via the runners to the gate nozzles. With identical cavities, natural balancing is preferred, i.e., the cross-sections and distances to every sprue bushing have the same dimensions (see Section 5.6). However, as discussed in Section 5.6, it is possible, with the same means, to compensate for different lengths by changing the channel cross-sections, i.e., to balance artificially. As already briefly mentioned, apart from needle valve nozzles, there are other mechanical or thermal (usually more simple) ways of controlling the flow rate to the various cavities.

In contrast to internally heated manifolds, with externally heated manifolds, manifold beams are used instead of manifold blocks (Figure 6.42). This is so enough space remains for installing the support pillars, which have to prevent unpermissible bending of the platen on the fixed mold half when the cavities are being filled.

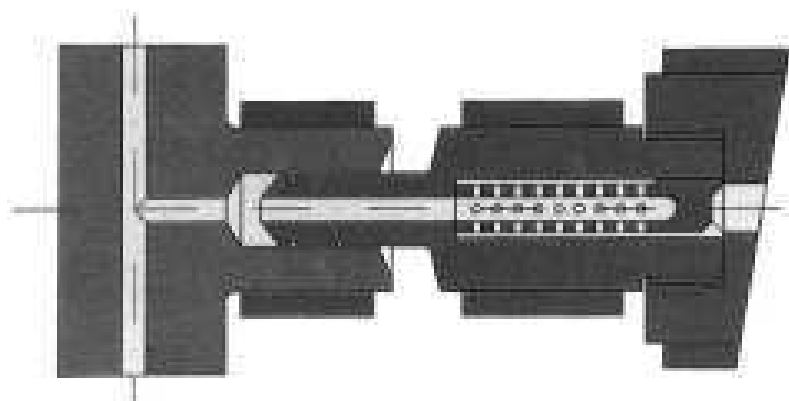
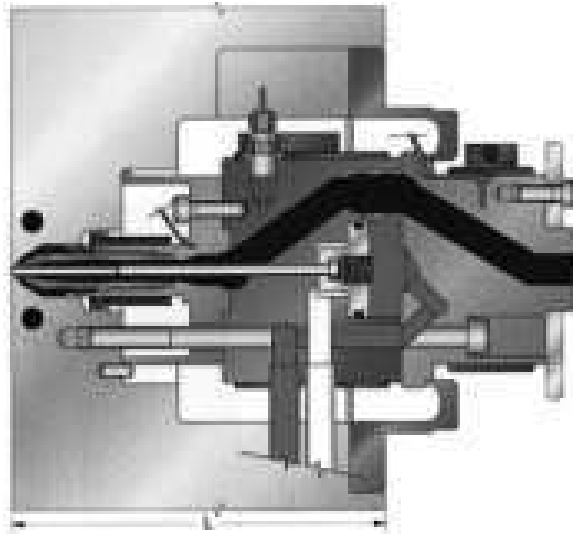
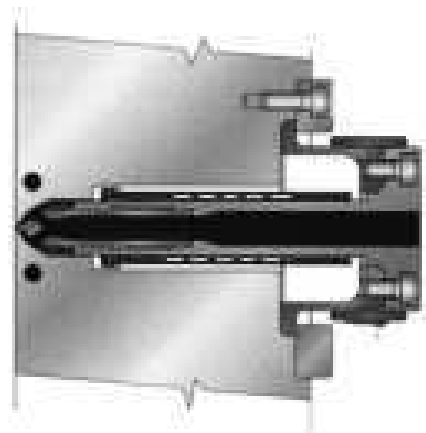


Figure 6.40 Pressure relief with an dipping nozzle using a melt filter



Needle valve for simple applications with length L of 80 to 155 mm

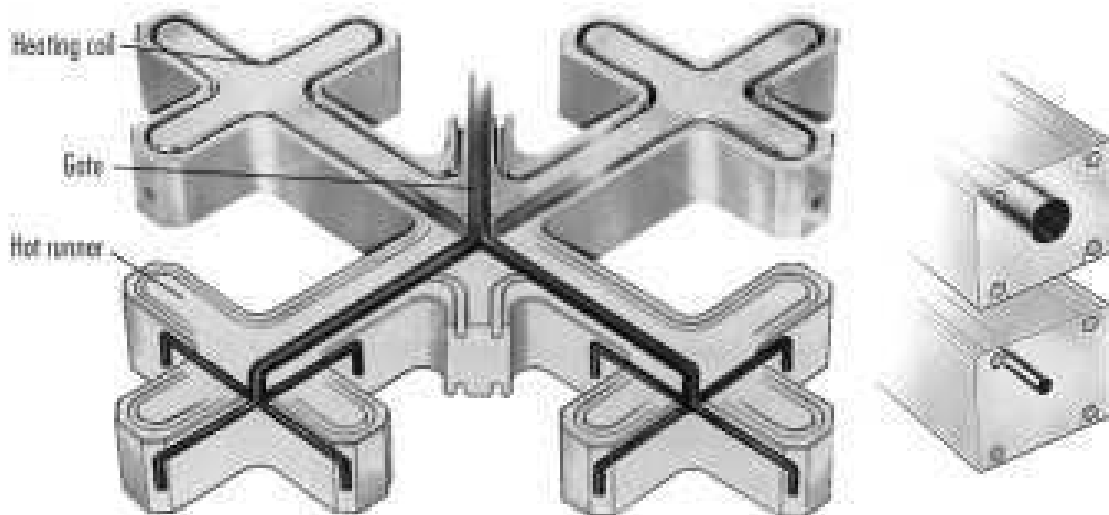


Gating with a thermal shut-off nozzle is the most common way of eliminating the cold sprue

Figure 6.41 Hot runner for simple (single-cavity) molds. Left, with needle valve; right, with thermal closure [6.16] (Husky)

Melt flow

Flow channels on the same plane should be equally long and have the same diameter in order to ensure that the melt undergoes the same drop in pressure and experiences the same shear on its way from the machine to all cavities.



Optimum flow channel contours

Each application imposes specific demands on molded part weight, filling time, material type and processing conditions. Flow studies ensure that hot runner systems are optimally designed. Smaller channel diameters increase shear and pressure drop to the benefits of faster color changes and shorter dwell times. Larger diameters are chosen for shear-sensitive polymers and applications involving pressure restrictions.

Figure 6.42 Manifold block for feeding 16 gate nozzles [6.16] (Husky)

The melt runners should naturally be as smooth as possible in order that no melt may get trapped. In addition, the design of all turnarounds must promote flow, i.e. large radii are required, sharp corners are forbidden. In the less expensive runners, the channels are bored and honed. For the corners, turnaround pieces are required that fit into the channel (see Figure 6.43). They are held in place by special sealing elements. There is no hiding the fact that these channels can be better cleaned.

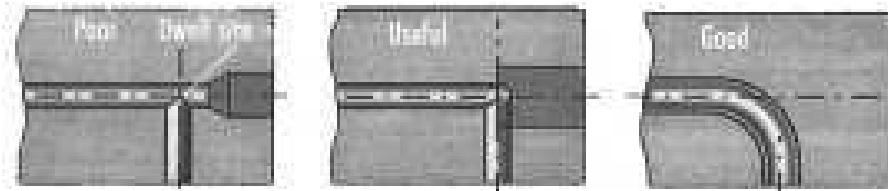


Figure 6.43
Turnarounds in
the manifold
[6.17]
Source: DuPont

Details on heating hot runners are provided in Section 6.10.1.6.

In order to minimize the number of heating circuits and controls and to be able to utilize failsafe, inexpensive tubular heaters, various hot runner system manufacturers offer manifold beams with heat-conduction tubes (see Chapter 17). These failsafe, maintenance-free tube-like bodies ensure uniform heat distribution even at those points where a heat gradient is present, such as in spacers, centering pieces and mounting pieces. This results in a relatively inexpensive, failsafe and, when properly designed, virtually isothermal hot manifold.

The bores are generally chosen such that acceptable flow rates are obtained on the one hand and tolerably long dwell times on the other. Diameters of 6 to 8 mm are chosen for medium throughputs.

There have also been trials [6.24] to bolt together the manifold from high-pressure hydraulic pipes and fittings. They are then surrounded with a band heater and insulated individually. Particular advantages are:

- the mass to be heated up is very much smaller than in manifold beams,
- thermal expansion is easily compensated by bending the tubes,
- more space is available for the supporting columns of the mold platens and these can be distributed better,
- easy to clean and disassemble,
- inexpensive.

A good example is the production of multi-component moldings with a hot runner system that consists of such tubes bolted together because the two requisite distribution systems would take up a great deal of space if they were made from manifold blocks. Separate temperature control is also easier to ensure.

Insulation of the external heated runners, in as far as the rigidity of the mold platens allows this, are usually of an air pocket with spacers consisting of poorly conducting metal, e.g., titanium and ceramic (Figure 6.32).

6.10.1.4 Nozzles for Hot-Runner Molds

The nozzle forms the connection between hot manifold and cavity. The essential requirements imposed are:

- Transport of as homogeneous and isothermal a melt as possible to the mold.



Figure 6.44 Hot runner system for a car fender [6.16].

Hot runner systems for injection molding of large automotive parts such as bodywork components and fender trim require injection on the moving mold half and “Class A” surfaces.

Encapsulated, premounted, and prewired manifold systems are available for large molds whose core or cavity takes up the entire mold half. This simplifies installation and maintenance. Pre-mounted hot runner system with five nozzles, two of which are parallel, for injection at the rear of the fender trim.

- Thermal separation between hot manifold and cooled mold. The mold should not experience an undue temperature rise in the gate area (dull, wavy regions) and the gate should not cool to the extent that it freezes.
- Clean, reproducible separation between the fluid content of the runner and the solidifying part during demolding (no forming of strings and no drooling).

It can be seen that, relative to normal molds, the demands imposed on the nozzles have undergone little change. However, a large number of new variants have come into existence.

The advantages of the various types of nozzles may be described as follows:

Open Nozzles (Figure 6.45): Offer flow advantages and are used in conventional molds where such requirements have to be met. They are also used for filled, abrasive molding compounds on account of their relatively high insensitivity. Finally, there are sometimes spatial reasons for resorting to these gates, which require a certain amount of machining for removing the sprue.

Nozzles with Tips (Figure 6.46): The tips are hot due to the very good thermal conduction of their mounting, e.g. in the nozzle platen, because they must carry the heat into the melt at the gate that is at risk of freezing. They are, therefore made of highly conducting materials, usually copper or copper-beryllium. They thereby, and function as flow aids. It is particularly important for the sprue to tear off cleanly, which is precisely why these nozzles come in a variety of designs to suit the material for processing. This applies particularly to hot-edge nozzles. Very high-quality nozzles feature soldered-in heating wires that are controlled by their own control loop, which utilizes a dedicated

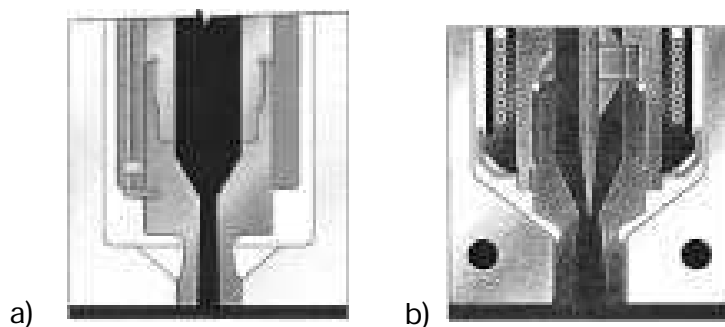


Figure 6.45 Hot runner gate nozzle with sprue (indirect gating), particularly recommended for abrasive melts [6.16] (Husky)

a) Thermal seal (TS) nozzles:

Tapered gate, open nozzle tip, large, free gate

b) Thermal seal nozzle with torpedo:

Thermal seal nozzles require a balance of conditions in the gate area in order that the material may tear off readily. The additional torpedo extends the processing window by minimizing the consequences of cycle interruptions and possible forming of strings. Thermal seal nozzles are ideal for the gate of cold runners or gating onto molded-part surfaces when a small sprue is not problematic. The nozzles have an extended tip that forms a part of the shape-giving cavity surface and whose contours can be adapted. The design also simplifies the installation of the nozzle tip. A negative nozzle taper ensures that the material tears off at the tip of the cone. The corresponding height of the sprue depends on the gate diameter and the plastic being processed. The swappable, thermal seal nozzles of hardened steel are suitable for a wide range of amorphous and crystalline polymers and offer long service lives, even when abrasive materials are used.

sensor installed there. Many of these nozzles do not have pinpoint gates but rather ring gates as, due to similar or sometimes superior optical design, the flow speed is much smaller than in the pinpoint gate on account of the relatively large surface area. They, therefore, come in a variety of designs to suit the material for processing.

Needle Valve Nozzles (Figure 6.47): These are increasingly being used where injection is performed segment-wise, e.g., with a cascade gate. Actuation is usually performed pneumatically, but there are hydraulically actuated nozzles available. The latter are mainly used for large molds since they require less space. Hydraulically actuated nozzles still suffer from the reputation of leaking at precisely the wrong moment.

Whereas hot runners may be heated with 220 V, the small, narrow, and closely arranged nozzles have necessitated the development of 5 V, 15 V and 24 V heaters. Due to their close spatial arrangement of down to 11 mm, wiring of the individually heated, loop-controlled nozzles presents a problem [6.21]. In all cases that do not require the narrowest temperatures, indirect heating is preferred; it is maintenance-free and less expensive. For this reason, the heat-conducting elements, which are enveloped by the melt, are made of highly heat-conducting materials (usually copper-beryllium) or else heat pipes are used.

More details of the various nozzles are to be found in the text accompanying the diagrams.

A particular problem of externally heated distributors is sealing off of the nozzles against the mold. A good solution to this problem seems to be that afforded by Husky, called ultra-sealing technology. The seal is effected by disk springs and is described in Figure 6.48.

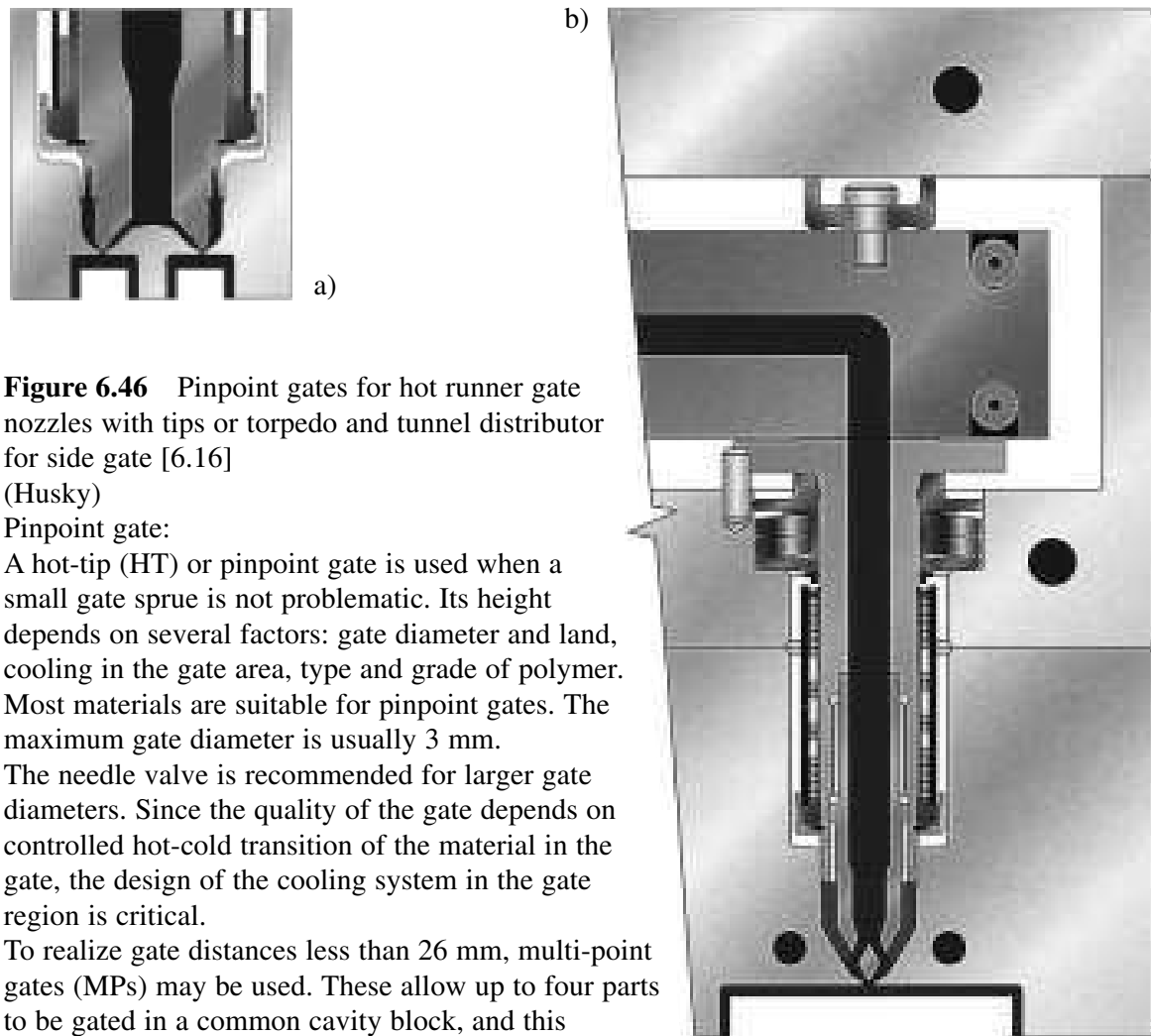


Figure 6.46 Pinpoint gates for hot runner gate nozzles with tips or torpedo and tunnel distributor for side gate [6.16]

(Husky)

Pinpoint gate:

A hot-tip (HT) or pinpoint gate is used when a small gate sprue is not problematic. Its height depends on several factors: gate diameter and land, cooling in the gate area, type and grade of polymer. Most materials are suitable for pinpoint gates. The maximum gate diameter is usually 3 mm.

The needle valve is recommended for larger gate diameters. Since the quality of the gate depends on controlled hot-cold transition of the material in the gate, the design of the cooling system in the gate region is critical.

To realize gate distances less than 26 mm, multi-point gates (MPs) may be used. These allow up to four parts to be gated in a common cavity block, and this reduces the size of the mold and the investment costs.

a) MP nozzles. These allow up to four parts to be gated via the same nozzle housing. The possible distances between the gates range from 7 mm to 30 mm.

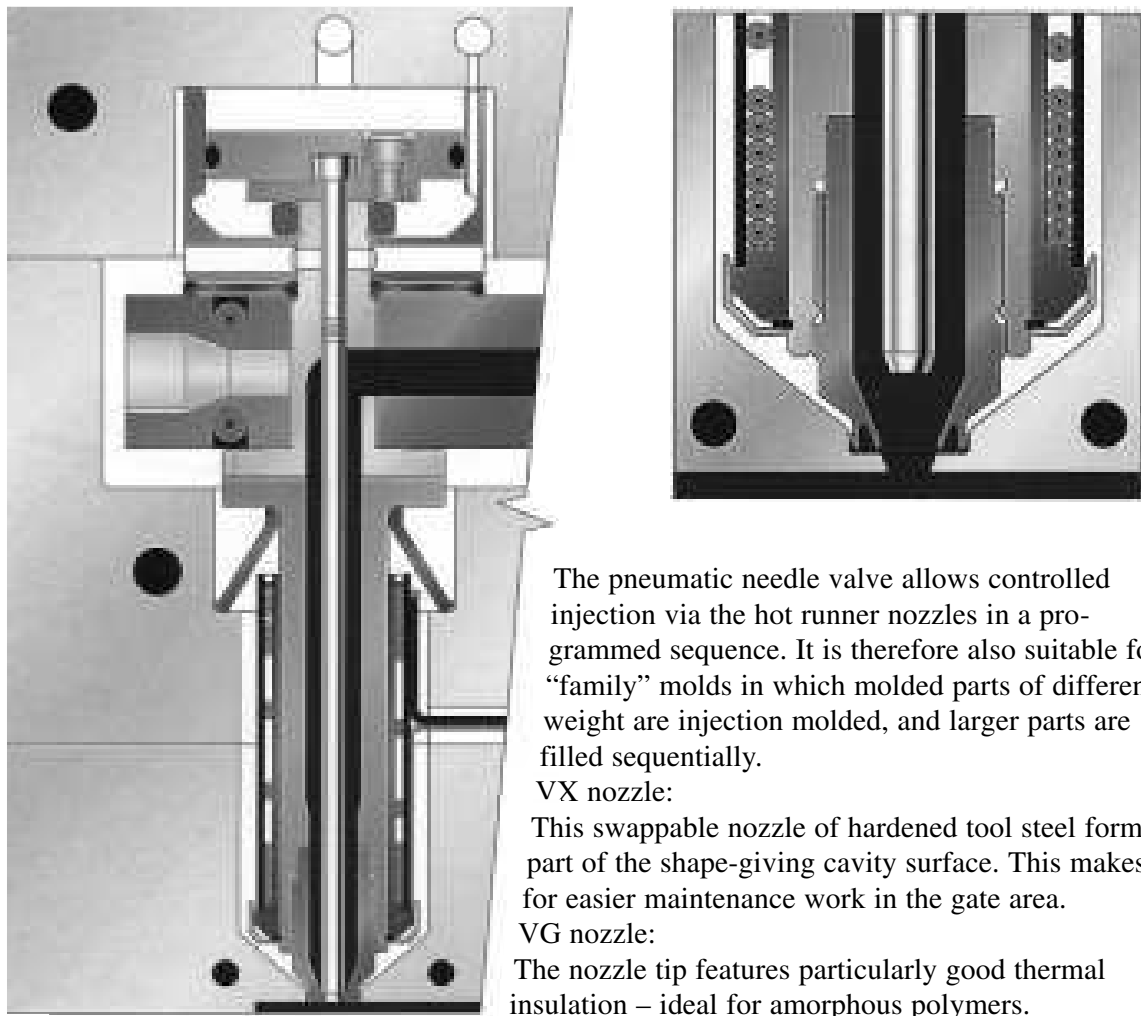
b) HT nozzles. An exchangeable insulating cap reduces the amount of insulating plastic film that coats the nozzle tip. This speeds up color change and enables heat-sensitive plastics to be processed.

6.10.1.5 Data Concerning the Design of Hot Runner Manifolds

Although hot runner manifolds are rarely made in-house nowadays, some dimensional data are provided below.

6.10.1.5.1 *Manifold Beams*

The material should be a C 60 or higher-grade steel. The diameters of the channels may be chosen from Table 6.2. When shot weights are low and the channels are shorter than 200 mm, the shot weights alone determine the diameters in this table. If the channels are longer, the channel diameters must be enlarged in order to reduce pressure losses and thus to keep shear heating to a minimum.



The pneumatic needle valve allows controlled injection via the hot runner nozzles in a programmed sequence. It is therefore also suitable for “family” molds in which molded parts of different weight are injection molded, and larger parts are filled sequentially.

VX nozzle:

This swappable nozzle of hardened tool steel forms part of the shape-giving cavity surface. This makes for easier maintenance work in the gate area.

VG nozzle:

The nozzle tip features particularly good thermal insulation – ideal for amorphous polymers.

Figure 6.47 Hot-runner gate nozzles with needle valve. Left: for semicrystalline plastics; right: amorphous plastics [6.16] (Husky)

The turnarounds would be made of corner pieces with fits of, e.g., H 7, n 6 and mounted with sealing plugs. The turnarounds naturally would have to be secured against twisting; no undercuts must form in the channel (compare Figure 6.43).

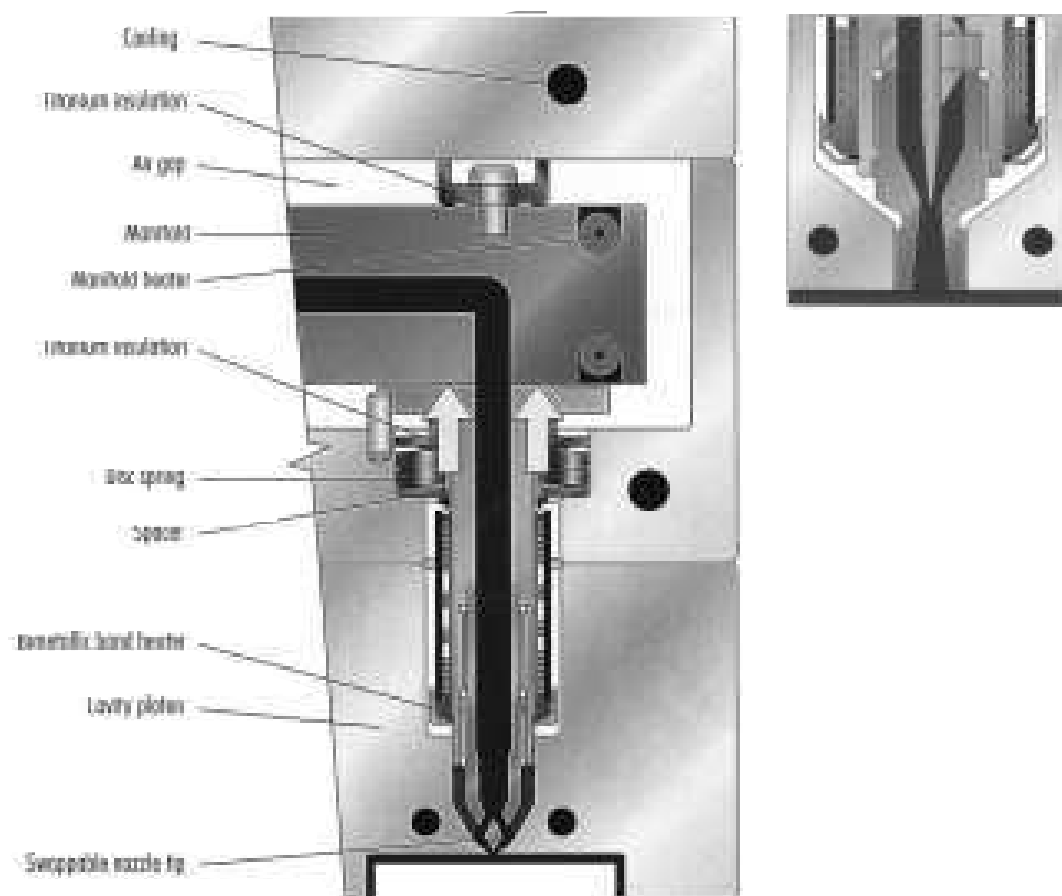
In in-house production, the manifold would be made of high-pressure pipes and fittings (see Figure 6.49) or manifold beams.

The robust tubular heaters would normally be used for the heating elements. They are inserted into milled grooves with a thermally conducting cement (Figure 6.49). The grooves should approximate the isotherms that can be determined and printed out with the aid of an appropriate heat-calculation program.

For insulation purposes, an air gap of 3 to 5 mm is left all around the manifold. The insulation can be improved by inserting crumpled aluminum foil. Spacers can be made of titanium.

Table 6.2 Guidelines for dimensioning channels in hot runner molds [6.13, 6.28]

Channel diameter (mm)	Channel length (mm)	Shot weight/cavity (g)
5		Up to approx. 25
6		50
8		100
6 to 8	Up to 200	
8 to 10	200 to 400	
10 to 14	Over 400	

**Figure 6.48** Hot runner gate nozzle with the Husky patented sealing system featuring disc springs [6.16] (Husky)

The patented ultra-sealing system facilitates hot runner operation. The design prevents potential damage by cold-start leakage or the failure of overheated components. A disc spring unit presses the nozzle housing during assembly against the hot runner manifold, thereby bringing the preliminary load to bear that is necessary for dependably sealing the system while the temperature is still below the flow temperature of the material. While the manifold is warming up, the disc springs absorb the thermal expansion, even in the case of excessive overheating temperatures. The wide processing window of $\pm 100^\circ\text{C}$ allows the same hot runner to process a number of different plastics using the same channel dimensions and gates.

Table 6.3 Guide values for dimensioning pinpoint gates [6.29]

Shot weight (g)	Pinpoint gate ϕ (mm)	Shot weight (g)	Pinpoint gate ϕ (mm)
to 10	0.4 to 0.8	40 to 150	1.2 to 2.5
10 to 20	0.8 to 1.2	150 to 300	1.5 to 2.6
20 to 40	1.0 to 1.8	300 to 500	1.8 to 2.8

It is therefore advisable, when having a hot runner made in-house, to use appropriate software (e.g. CADMOULD) to calculate both its rheological and its thermal behavior. Clues about the thermal performance to be installed are provided in Section 6.10.1.6.1. This information can be resorted to, however, if the power output is to be measured very accurately, it may also be calculated with the aid of a thermal design program (e.g. from CADMOULD). However, 25 to 30% must be added on to the result in order to cover mainly radiation losses.

All nozzles must be fitted with a thermocouple and their heating system must have its own control loop. This is the only way to ensure that the nozzles can be synchronized. Controllers with a PID structure are best [6.27]. The controllers should be connected to the machine control such that the temperatures are automatically adjusted to lower levels during breaks in operation or longer stoppages in order that no degradation, or even decomposition, may occur in the manifold area.

6.10.1.5.3 Notes on Operating Hot Runners

When heating hot runners with external heaters, it is advisable not to cool the molds themselves at first. Even better is to keep them as warm as possible with hot water, instead of with the cooling water, in order that the manifolds may attain their set values faster.

Color changes can take a very long time and be expensive on material. For medium-sized to large molds, between 50 and 100 shots must be allowed for. It is therefore best to avoid color changes if at all possible but, where this cannot be helped, to clean the hot runner prior to using the next color. This is relatively easily accomplished in drilled channels in the manifold by removing the stoppers and then heating until the plastic remaining in the channels melts at the edges so that the rest can be pushed out. Insulated runner manifolds definitely have an advantage in this respect.

6.10.1.6 Heating of Hot Runner Systems

6.10.1.6.1 Heating of Nozzles

There are three ways to heat nozzles in hot manifolds. One distinguishes:

- indirectly heated nozzles,
- internally heated nozzles,
- externally heated nozzles.

With indirectly heated nozzles heat is conducted from the manifold through heat-conducting nozzles or probes to the gate. To control the temperature of the individual nozzles independently of one another, the corresponding sections of the manifold have to be heated separately. This is usually done with paired heater cartridges along the runner in the nozzle area. Indirect heating of nozzles has the disadvantage that for small temperature changes at the gate, required for proper filling or smooth gate separation, a

far greater change of the manifold temperature is needed. This leads inevitably to changes in the melt temperature in the runner, too. This undesirable change in melt temperature can produce an adverse effect on the quality of the parts. It is better to control the nozzle temperature independently of the manifold. This can be done with directly heated nozzles.

For *internally heated nozzles*, diameter and length of cartridge heaters are determined by the dimensions of the nozzle. One should strive for a cartridge diameter as large as possible to have a low watt density.

Table 6.4 lists recommended watt densities according to [6.28]. Cartridges with a length of more than 75 mm should have an apportioned power output. A suitable variation in the winding provides more heat at the generally cooler end and less in the center, which is normally too hot.

Table 6.4 Dimensioning of cartridge heaters [6.28]

Cartridge "	Length (mm)	Watt density (W/cm ²)
$\frac{1}{4}$	30	35
	75	23
$\frac{3}{8}$	30	27
	200	13
$\frac{1}{2}$	50	20
	200	13

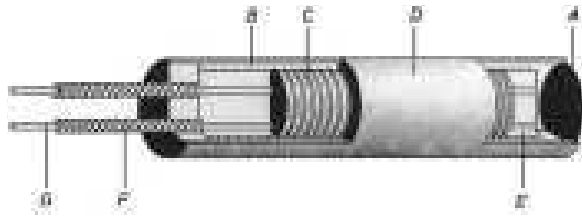
Hot-manifold nozzles with external heating are heated by band heaters, tubular heater cartridges or helical tubular heaters. Because of the large size but low power output of 4 W/cm², the use of band heaters is rather limited.

6.10.1.6.2 Heating of Manifolds

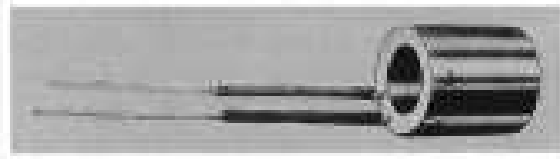
Hot manifolds with indirectly heated nozzles are heated with cartridge heaters. They permit heating of the individual nozzle areas separately, in contrast to tubular heaters, which are discussed later on. The cartridges are arranged on both sides of the runners. The distance from the runner is about equal to the cartridge diameter. The positioning in longitudinal direction has to be optimized by measuring the temperature distribution.

Tubular heaters can be recommended for manifolds with directly heated nozzles. These sturdy heating elements make a very uniform heating of manifolds possible; the probability of failure is small. The tubing is bent and inserted into milled grooves along the manifold and around nozzles from top and bottom. The grooves are milled with a slightly excessive dimension, e.g., 8.6 mm for an 8.2 mm heater diameter. When the tubing is inserted, it is embedded with heat-conducting cement and covered with steel sheet. The distance of the heaters from the runner should be somewhat larger than the tubing diameter.

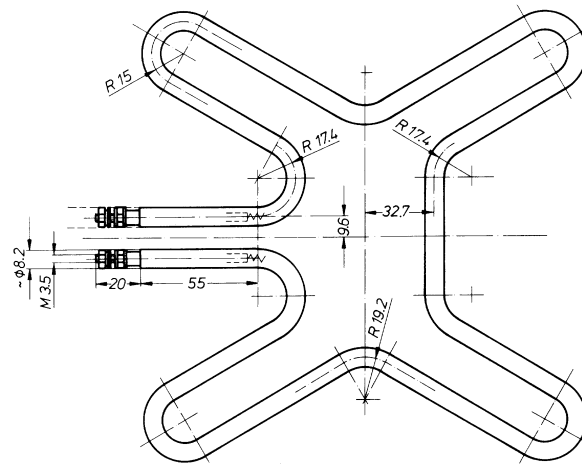
The most important elements for heating of the hot runners are summarized in Figure 6.51. Their use depends primarily on the requisite heating power and space considerations. The maximum heating power in the smallest space is attained with high-performance heater cartridges. However, the problems grow as the Watt density increases. Aside from the high failure rate, there is the risk of local overheating of the hot runner or its elements. For this and control reasons, the heating elements should not



a) High density heater cartridge, Watt density 10 to 130 W/cm²:
A Bottom welded airtight, B Insulator: highly compressed, pure magnesium oxide, C Filament, D Shell, E Ceramic body, F Glass fiber insulation, G Temperature resistant



b) Tubular heater, Watt density up to about 30 W/cm²



c) Tubular heater, Watt density about 8 W/cm²



d) Helical tubular heater

Figure 6.51 Heating elements for hot manifolds [6.29, 6.30]

be oversized. The Watt density should not exceed 20 W/cm², where possible. The most important precondition for acceptable service life of the heating cartridges is good thermal transfer to the heated object. For this, the requisite roughed fit demanded by the heater cartridge manufacturers must be observed strictly. Nevertheless, replacement of heater cartridges will remain unavoidable, and so simple assembly is crucial.

Insufficiently insulated hot-runner molds lose energy from radiation. With reflector sheets of aluminum mounted between manifold and platens, energy savings of up to 35% can be achieved [6.31].

6.10.1.6.3 Computing of Power Output

The power output to be installed can be calculated with the equation:

$$P = \frac{m \cdot c \cdot \Delta T}{t \cdot \eta_{\text{tot}}} \quad (6.5)$$

m Mass of the manifold (kg),

- c Specific heat of steel = 0.48 kJ/(kg · K),
 ΔT Temperature differential between desired melt temperature and manifold temperature at the onset of heating,
t Heating-up time (s),
 η_{tot} Total efficiency (electric-thermal) (ca. 0.4 to 0.7, mostly 0.6).

6.10.1.6.4 Temperature Control in Hot Manifolds

Hot-runner molds are extremely sensitive to temperature variations in nozzle and gate area. Even a temperature change of a few degrees can result in rejects. Exact temperature control is, therefore, an important precondition for a well functioning and automatically operating hot-runner mold. In principle, each nozzle should be controlled separately, because only then can the melt flow through each nozzle be influenced individually.

The control of the manifold itself is less critical. One measuring and control point is sufficient for smaller manifolds with tubular heaters. Thus, a four-cavity mold with directly heated nozzles requires at least 5 temperature-control circuits.

6.10.1.6.5 Placement of Thermocouples

There are two critical places in the nozzle area. One is the gate, the temperature of which is important for ease of flow and holding pressure; the other one is the point of greatest heat output, usually the middle of the cartridge heater where the material is in danger of thermally degrading. The best compromise is measuring the temperature between these two points. A proven method for externally heated nozzles is presented in Figure 6.52. Heaters with built-in thermocouples are often used for heated probes. Then the thermocouple should be at the end of the cartridge close to the tip of the probe. If the probe is sufficiently thick, miniature thermocouples of 0.8 mm diameter can be brought to the tip of the probe in a small groove.

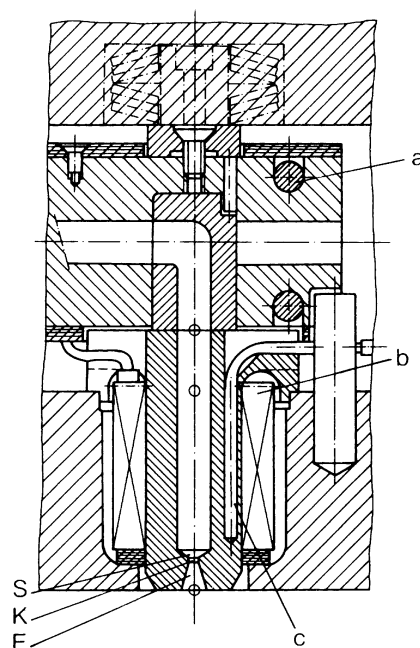


Figure 6.52 Heated nozzles for indirect gating [6.13]
S Restriction slit, K Cross section constriction at the nozzle outlet, E Expansion part, a Tubular heater, b Enclosed cylindrical heater, c Temperature sensor

Similar considerations apply to the manifold. Thermocouples should never be installed at the relatively cool ends of the manifold. This could pose the risk of overheating in the center. They should be located between the runner and the hottest spot of the cartridge. It is also obvious that the vicinity of a spacer or dowel would give a wrong temperature reading. With tubular heaters the thermocouple is positioned in the area of highest temperature, that is in the center close to the sprue bushing. For good reproducibility all thermocouples should be securely installed in the mold because thermocouples and kind of mounting can cause a considerable error in measuring. Only secured thermocouples ensure error-free read-out when the mold is put to use again.

With externally heated blocks, an installed output of 0.002 W/mm^3 volume of the manifold is expected. The heating elements are usually tubular heaters and panel heaters. The latter have the advantage of being more suitable for molds that require highly accurate matching of the temperatures across several heating loops. However, they are less robust than tubular heaters.

6.10.2 Cold Runners

When injection-molding crosslinking plastics, the same design criteria with regard to the gating system may be applied as are used for injection molding thermoplastics. However, there is the disadvantage that, aside from the molded part, the molding compound also fully crosslinks in the runner system of hot runner molds and, unlike thermoplastics, cannot be remelted and returned to the process.

These material costs of fully crosslinked runner systems, which do not contribute to added value, are the most important reason for fitting out injection molds with cold runner systems. Admittedly, these do incur higher mold costs, so that cold runner molds are only worth while for large series in which the mold costs do not constitute a major factor in production costs [6.33].

6.10.2.1 Cold-Runner Systems for Elastomer Injection Molds

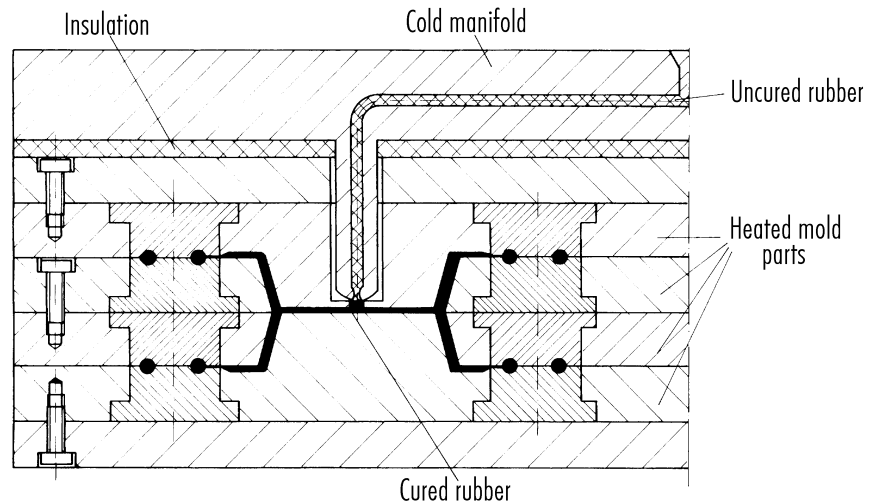
The task of the cold runner system is to keep the melt at a temperature at which scorching of the elastomer will be reliably prevented. The thermal separation of the cold runner from the heated cavity saves on materials and produces other advantages [6.34–6.36] that are of interest in the context of greater productivity and higher molded part quality, as well as greater degrees of automation. Examples are [6.37]:

- longer service lives, since there is no damage caused by flash residues,
- low thermal loading during the injection phase,
- reduction in heating time through higher mold temperature,
- easier automation,
- greater design freedom in rheological dimensioning and balancing the system.

In the simplest case, in which only one cavity is directly gated, the cold runner is the extension of the machine nozzle as far as the cavity. It is more common to have a runner system for several cavities.

The basic design of a cold runner shown in Figure 6.53 consists of the following modules: manifold block, nozzles, and temperature control with insulation. The manifold block contains the runners, the turnarounds, and the branch points. It comes in various designs, each with advantages and disadvantages.

Figure 6.53 Simple cold-runner design [6.38]



The nozzles connect the manifold block to the mold. They either lead direct to the molded part or to a submanifold which in turn supplies several cavities. The simplest type of nozzle is the uncooled one. However, it should only be used if the nozzles do not extend far into the cavity and a lifting cold runner block can be used [6.40] (see Figure 6.56).

If a molding is to be directly gated with a cold-runner nozzle, a more elaborate thermal separation is required. The cooled nozzles of the mold in Figure 6.54 for molding small bearings extend into the cavity area. The separation point of the gate is closely located to the molded part by a ceramic insert (Figure 6.55), which impedes heat transfer from the hot stationary mold platen into the cold runner. The gate separation is always in the transition range between cured and uncured elastomer [6.41].

Thermal separation can also be obtained by leaving the cold runner in contact with the hot mold for certain time periods only. The cold manifold is here, even in its movements, an independent component (Figure 6.56). The molded part in this 20-cavity cold-runner

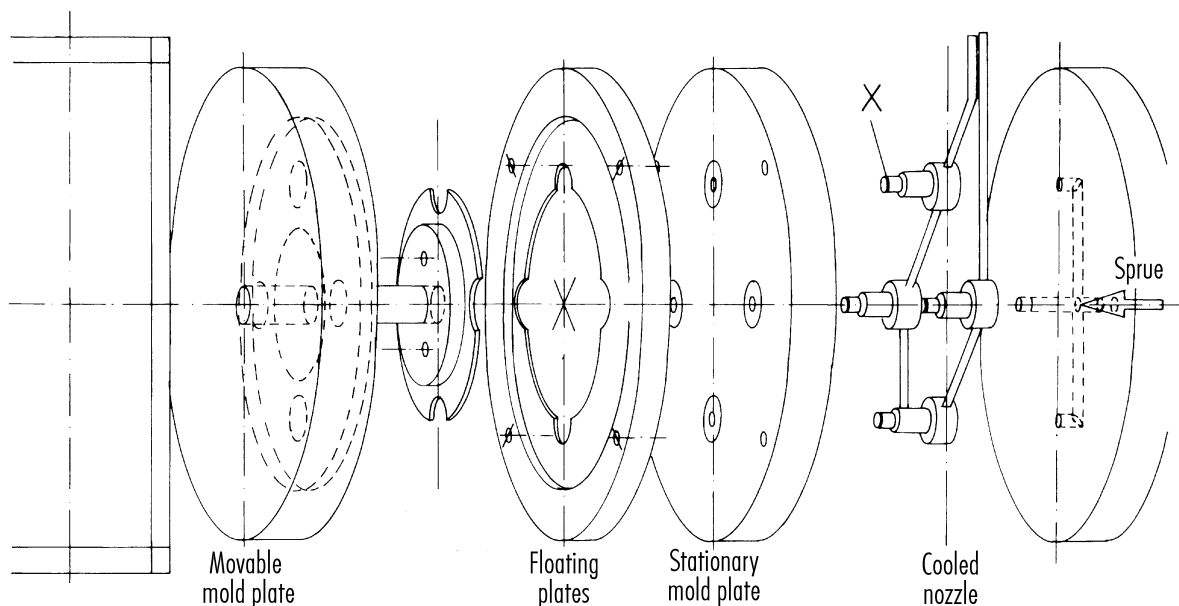


Figure 6.54 Cold-runner mold for the production of bearings [6.41]

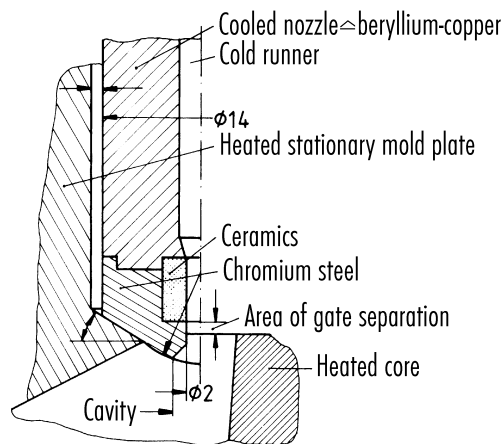


Figure 6.55 Design of the gate area of a cold runner [6.41]

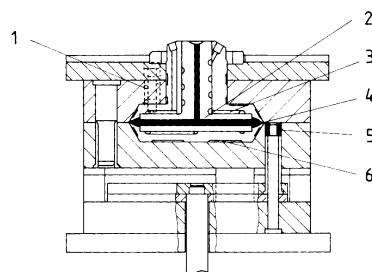


Figure 6.56 Cold-runner mold for elastomers [6.44]
1 Lifting device, 2 Cold manifold,
3 Cooling lines, 4 Pinpoint gate,
5 Molding, 6 Slots for air passage

mold are gated sideways without scrap. The cold-runner manifold is clamped in the parting line and is lifted off the hot mold parts during the mold-opening phase [6.42].

Another design solution starts with the idea that a contact between cold runner and hot mold is only needed as long as pressure can be transmitted, that is, until the gate is cured. Then a lifting of the cold runner at the end of the compression stage results in considerable technological advantages because the thermal separation is achieved in an almost ideal manner [6.43].

A corresponding mold is presented in Figure 6.57. The cold runner has the shape of a nozzle and is the immediate extension of the injection unit. Lifting of the cold runner is

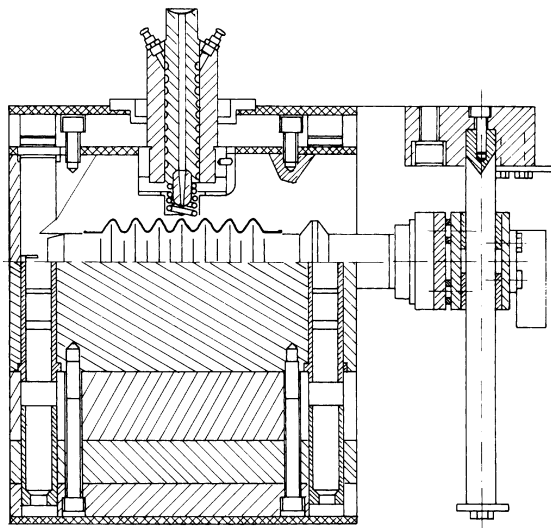


Figure 6.57 Cold-runner mold for molding of folding bellows [6.44]

caused by a spring, which lifts the cold-runner nozzle from the mold after the machine nozzle has been retracted. Now the mold can be heated without any heat exchange between the cold runner and the mold.

Figure 6.58 demonstrates the effect of the lift-off on the temperature development in the nozzle during one molding cycle. In the case of a lifting nozzle, one can clearly see how the temperature rises because of the heat flow from the mold into the nozzle. It drops back to its original level immediately after the nozzle is lifted off. This temperature development is not critical for the material in the nozzle. The contacting nozzle progresses and the nozzle is finally clogged [6.44].

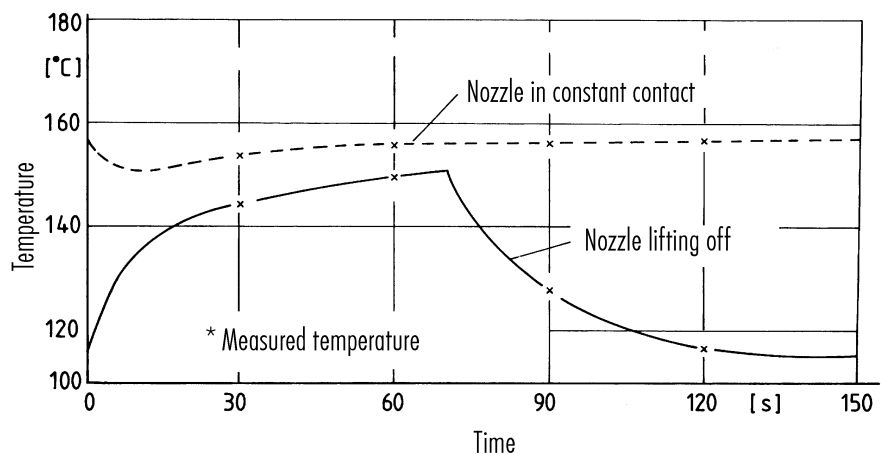


Figure 6.58 Change in melt temperature of a cold runner nozzle over one cycle [6.44]

This mold concept also permits multi-cavity molds to be designed. The special feature of the mold in Figure 6.59 is that it has two parting lines. The first parting line serves the conventional demolding. If during production an interruption occurs, e.g. by cured material in the nozzle, throwing of a locking bracket opens a second parting line and with it a plane of maintenance. The nozzles can be taken from the opened mold and purged. If the curing has progressed into the cold runner, it can be completely disassembled.

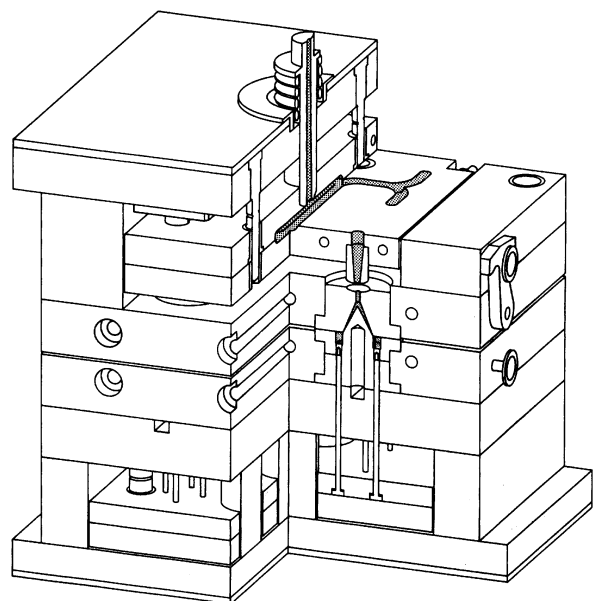


Figure 6.59 Eight-cavity cold-runner mold with curing disk gates [6.43, 6.44]

When designing cold runners, the following criteria should be observed to ensure optimum functionality [6.37]:

- minimal pressure loss: the lower the pressure consumption in the cold runner, the more pressure is available for the actual mold filling and the lower are the buoyancy forces that can lead to flash,
- no dead-water areas at turnarounds and branches,
- simultaneous filling of all mold cavities,
- low dwell times of the molding compound in the runner, to prevent scorching,
- adequate thermal separation of cold runner and mold for attaining adequate cross-linking in the gate area and avoiding scorching in the main runner,
- mechanical loading of the cold runner nozzles during transmission of the machine force in moveable cold runners,
- if interruptions in production occur and the material crosslinks in the runner, it should be easy to clean the runner.

These criteria should not be seen as being distinct from the design of the molded part, the performance of the injection molding machine or the mixture for processing. Successful use of the cold runner technique also necessitates appropriate training of the employees in order that they may be able to employ it competently. A detailed presentation of the advantages and disadvantages of the cold runner technique is contained in [6.33].

A special variant of the cold runner injection molding is the temperature-controlled transfer chamber used in injection transfer molding (ITM). ITM came into existence by applying transfer molding to an injection molding machine. The transfer chamber is filled with rubber from the injection mold unit via a runner in the transfer plunger. Appropriate heat-control keeps the transfer chamber at the plasticating temperature in order that the elastomer will not crosslink there. Figure 6.62 is a schematic diagram of the individual phases of the complete ITM process, which are described in the table below.

The duration of the various phases varies with the molded part and elastomer. In the manufacture of rubber-metal components, a further process phase may be needed for

Table 6.5 Sequence of processes in ITM shown in Figure 6.60

Name of phase	Description of process
Phase 1: Close Phase 2: Injection	Closing of all mold platens; space in front of screw (1) is filled Elastomer injected into cooled transfer chamber (2)
Phase 3: Transfer	Filling of cavities (3) via the runners (4) in the insulating plate (5) through closing of the transfer chamber
Phase 4: Heating	Crosslinking of the molded parts and the sprue slug through introduction of heat via the heating platen (6)
Phase 5: Opening	Opening of the mold platens; automatic separation of the sprue slug from the molded part; plasticating in the space in front of the screw for the next shot
Phase 6: Demolding	Removal of molded parts; removal of gate slug, e.g. with the aid of a brushing device; perhaps blowing off of mold platens and introduction of release agent

installing the inserts. The use of a transfer chamber heated to the plasticating temperature results in virtually scrap-free production, since only the sprue slugs in the short runners between the transfer chamber and the cavity area crosslink. The process is mainly used to manufacture a high number of small molded elastomer parts in one mold.

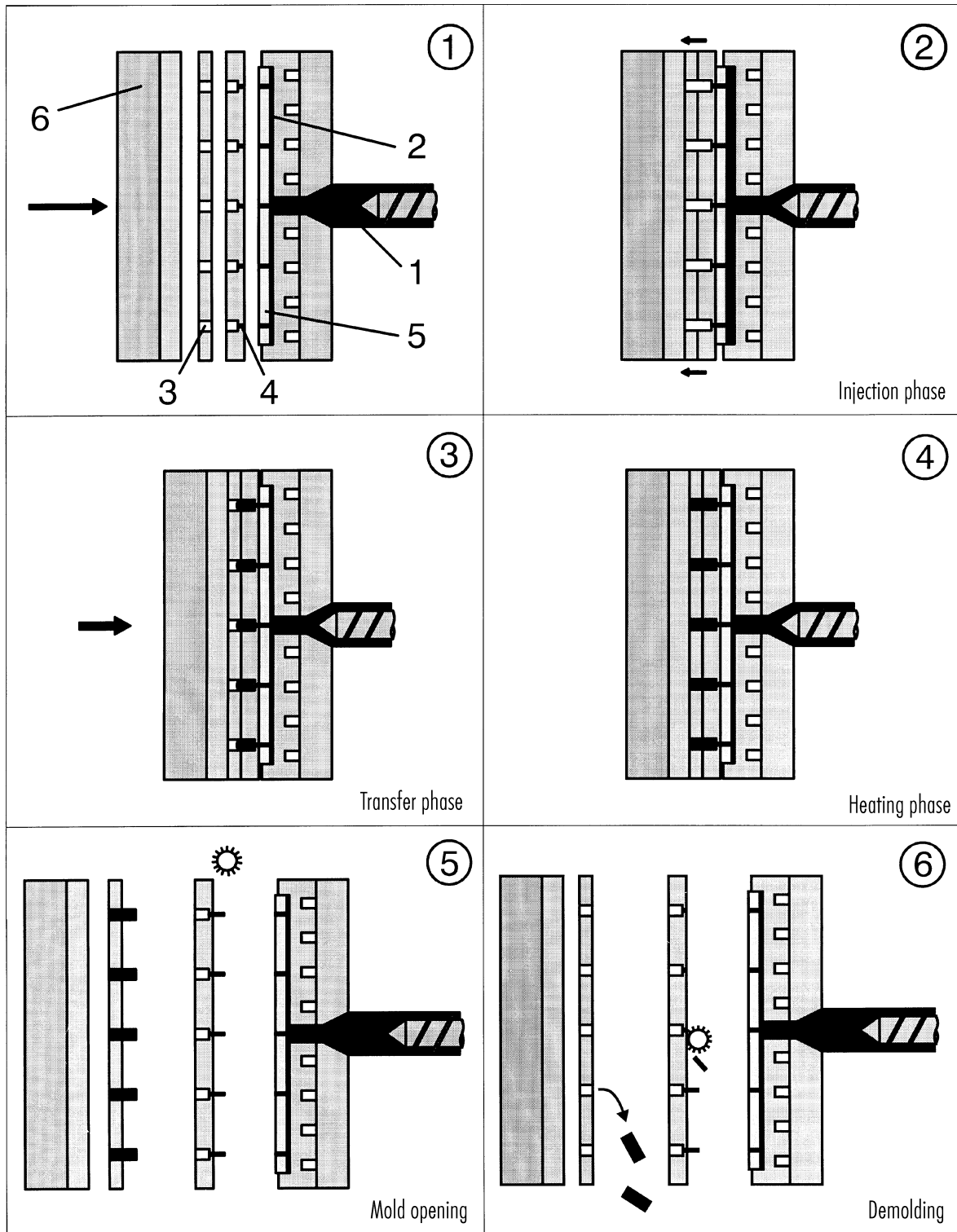


Figure 6.60 Schematic representation of phases in the ITM process

6.10.2.2 Cold-Runner Molds for Thermosets

Cold-runner molds are also employed for processing thermosets. Here one has to differentiate the kind of material to be processed. Based on lot to lot deviations, processing problems may occur with polycondensates. Experience has led to the limitation of today's runner systems on temperature-controlled sprue bushings or, in some cases, controlled machine nozzles for polycondensates.

With heat-controlled sprue bushings, a distinction has to be drawn between those with and those without a fixed pull-off point. The former have the advantage that a predefined pull-off point exists from a purely geometric point of view in the form of a cross-sectional constriction. The disadvantage is that greater pressure is needed for flow-through and thus there is greater stress on the material. Studies have shown that a uniform pull-off point is also attained in those sprue bushings without cross-sectional constriction, especially when the cycle time is very constant [6.45].

The use of the cold-runner technique for polymerized materials is wide-spread, particularly for wet polyester resins because of their low viscosity and the resulting low injection pressure for filling a mold [6.46].

A particular mold design is the use of cold runners in the so-called cassette technique (Figure 6.61).

The mold in Figure 6.61 is equivalent in its design to a two-platen mold with tunnel gate. The cold runner is formed by a temperature-controlled manifold (medium: water), which is vertically mounted to the stationary mold platen. A substantial advantage of this design is based on the ease of assembly or disassembly at interruptions or the end of a production run. The cold runner can be uncovered inside the machine in the open mold and subsequently cleaned. Mold costs are higher by 20 to 25% if compared with a

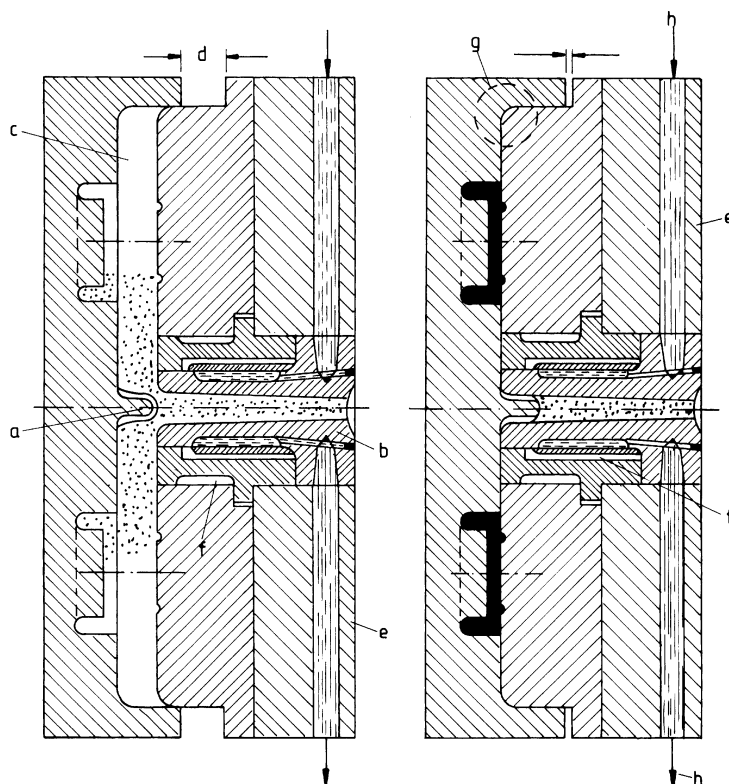


Figure 6.61 Common pocket mold for processing thermosets by coining [6.48]
 left side: During injection,
 right side: Closed,
 a Distributor, b Sprue bushing,
 c Common filling space,
 d Coming gap, e Insulating sheet,
 f Air space, g Closing shoulder,
 h Heat exchanger

conventional mold and have to be compensated by material savings. Thus, material losses in a corresponding eight-cavity mold could be reduced from 12 to 3% [6.47].

In cases where multiple gating is needed for certain moldings (e.g. headlamp reflectors), production without cold-runner cassettes is often not conceivable [6.46].

Cold-runner technique for thermosets is also used in the so-called common-pocket process (Figure 6.62). A combination with this process is the RIC technique (Runnerless Injection Compression), which reduces scrap to a minimum in a simple way. At the same time flashing is diminished. The plasticated material flows through a temperature-controlled runner into the slightly opened mold and is distributed there. The material is pushed into the cavities and formed by the clamping motion of the mold. The material distributor penetrates the tapered sprue bushing and closes it against the parting line. Temperature control keeps the material in the runner fluid and ready for the next shot [6.48].

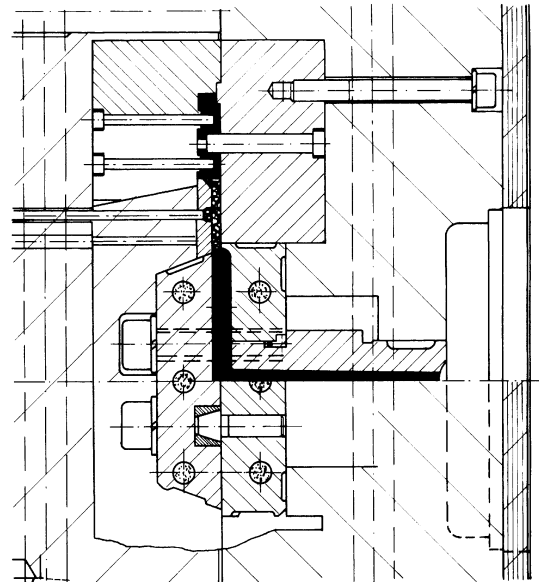


Figure 6.62 Cold runner mold
Bucher/Mueller system with tunnel gate
[6.47]

6.11 Special Mold Concepts

6.11.1 Stack Molds

A special mold design has come into use, the stack mold, for molding shallow, small parts in large quantities such as tape cassettes. Here, cavities are located in two or more planes corresponding to two parting lines and are filled at the same time (Figure 6.63). A molding machine with an exceptionally long opening stroke is needed. An increase in productivity of 100% as one might expect from doubling the number of cavities cannot be realized because of the time needed for the longer opening and closing strokes. The increase in productivity is about 80% [6.49]. The clamping force should be 15% higher than for a standard mold [6.49].

Hot manifolds are now employed exclusively. A stack mold with two parting lines has three main components, a stationary and a movable mold half, and a middle section. It contains the runner system (Figure 6.64).

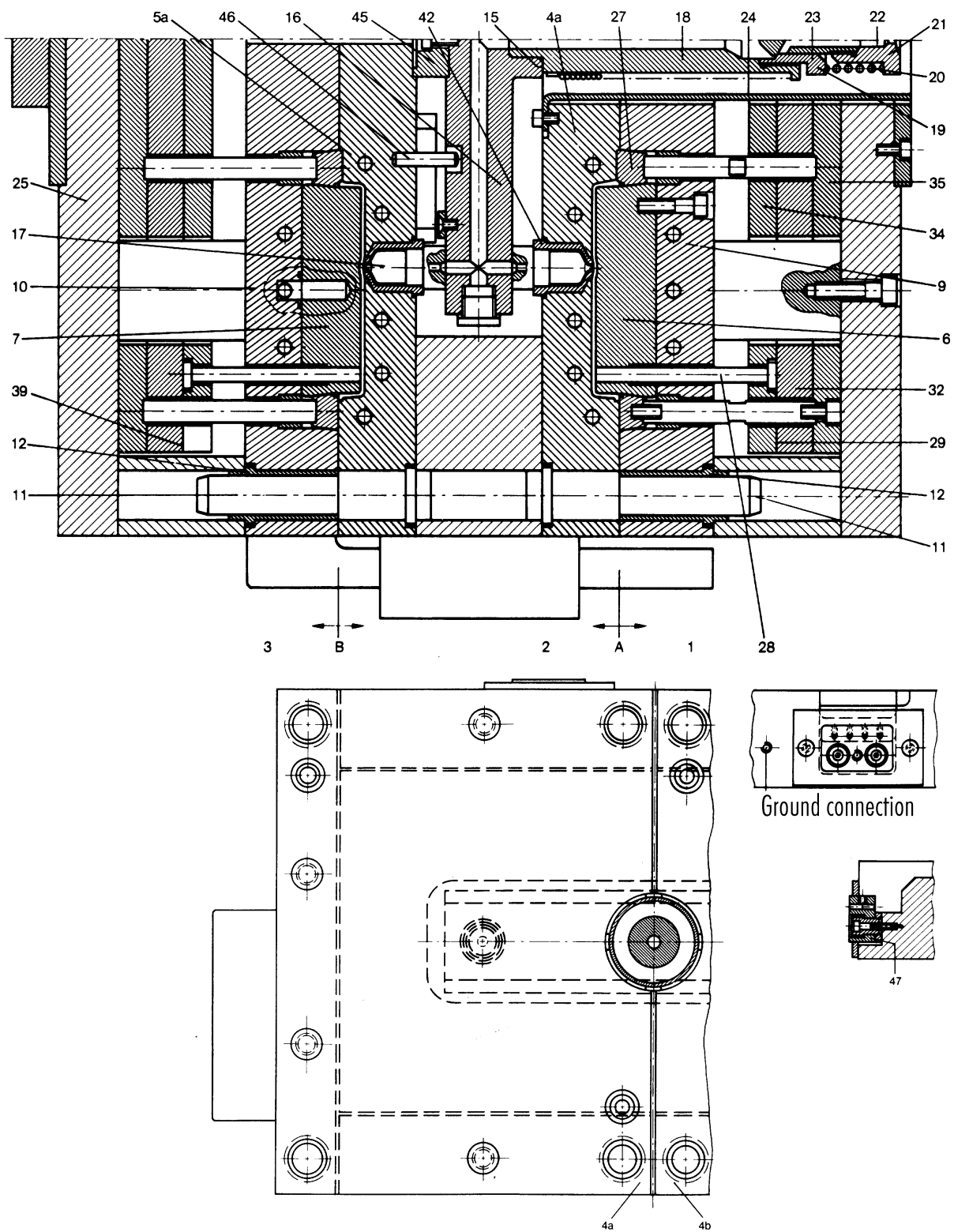


Figure 6.63 Stack mold with hot manifold [6.47]

A, B Parting lines; 1–3 Leader for center plate; 4a–4b Mold plates; 7–8 Cores; 9–10 Mold plates; 11 Leader for mold plates; 12 Leader bushing; 15 Heater for sprue; 16 Hot manifold; 17 Sprue to molded part; 18 Mold plate, as per 9; 19–23 Central sprue to machine as extended nozzle; 24 Sprue; 27 Stripper ring; 28 Ejector pins; 29–35 Ejector system; 39 Retainers; 42 Heated nozzle; 45–46 Interlocks

The mold section mounted on the movable platen and the center section are moved in the direction of the machine axis during demolding. With this, the extension is removed from the nozzle. The extension has to be sufficiently long that no leakage material can drop onto the leader pins and stick there during mold opening. This would impede their proper functioning [6.53, 6.54]. For this reason many stack molds are operated today with telescopic extensions and without nozzle retraction. While the outer section on the clamping side is mounted on the movable machine platen and moves positively with it during mold opening and closing, special elements are necessary to guide and control the movement of the center section. Because of the frequently large size of the molds utilizing the whole platen area, center sections are attached to the tie bars or are guided by means of guide bars with guide shoes [6.53, 6.54] (see Figure 6.64).

Today the motion is primarily produced by toggles or sometimes by racks (Figure 6.65). Previously systems were employed which used separate hydraulic cylinders for moving the center section.

Toggle and rack control open at both parting lines smoothly and simultaneously. Toggle controls also offers the option of using, within a certain range, opening strokes of different lengths. This allows the molding of parts with one height in one stack and parts with a different height in the other one. The curves of the opening path can be

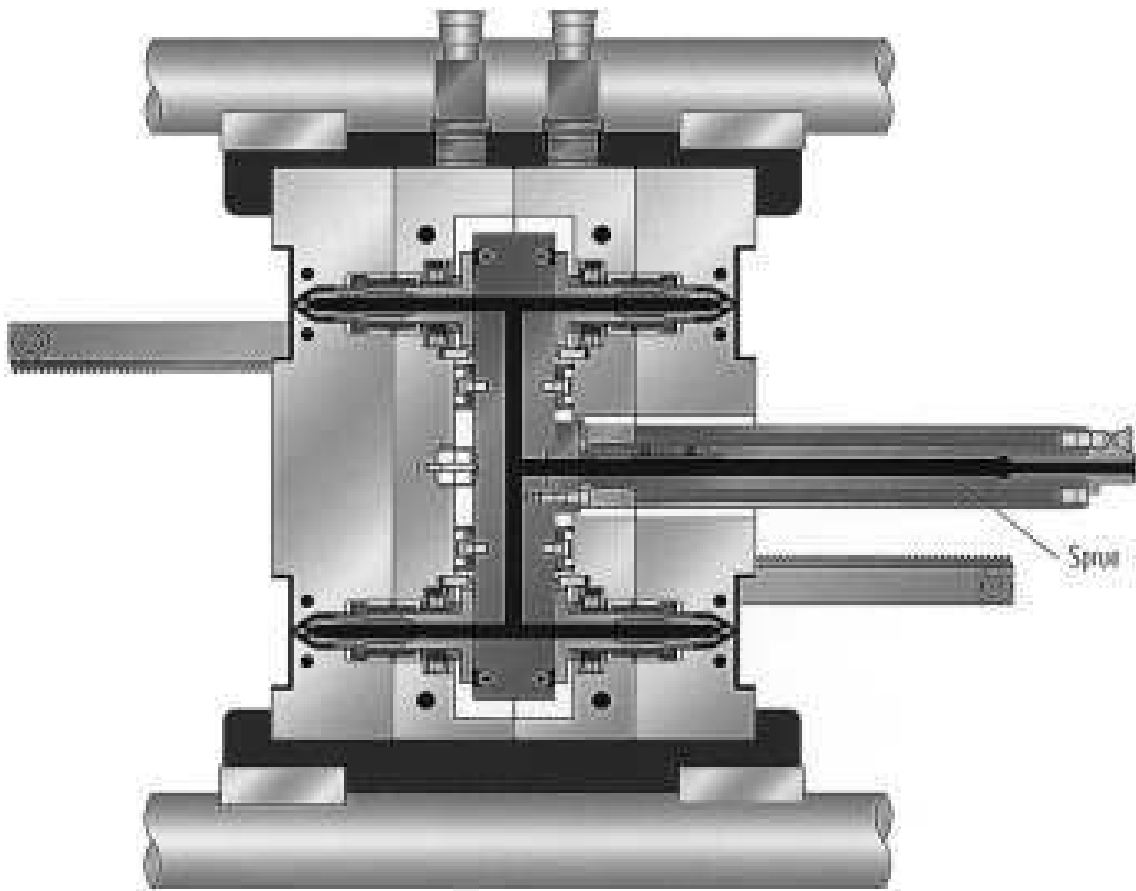


Figure 6.64 Stack mold [6.16]

Hot runner system for stack mold manifold and sprues and gates molds. The sprue is normally mounted at the level of the mold center and feeds the melt into the middle of the hot runner manifold. From there, the melt is distributed uniformly to all cavities of both mold daylight.

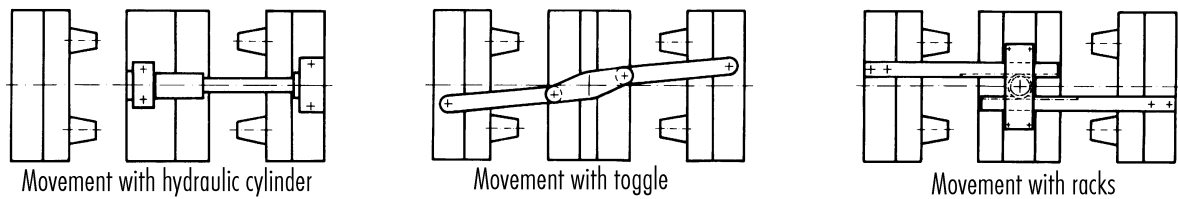


Figure 6.65 Methods of moving center section of stack molds [6.55]

Figure 6.66
Toggle mechanism
for stack molds
[6.55]

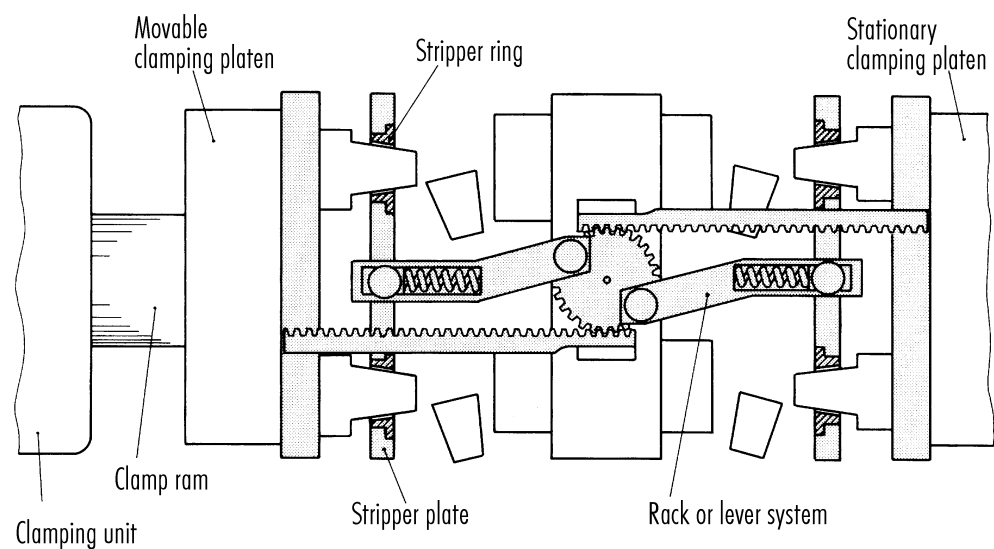
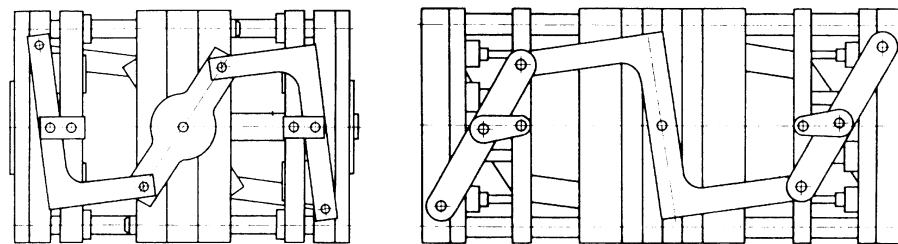


Figure 6.67 Ejector drive for stack molds [6.55]

adjusted within a wide range depending on pivotal point and toggle geometry. At the same time ejection is actuated by the same elements that move the center section. Various kinds of toggle control are shown with Figure 6.66. The rack control in Figure 6.67 is less rigid and permits a gentle start and build-up of demolding forces because of springs in the pulling rods connected to the crank drive.

6.11.2 Molds for Multicomponent Injection Molding

There are a large number of multicomponent injection molding techniques, in terms of processes and of names, which are explained in Table 6.6 [6.56, 6.57].

6.11.2.1 Combination Molds

Two-component combination injection molding in which two melts are introduced into the cavity in succession via separate gating systems requires special mold techniques since those areas of the mold that become filled by the second melt must be blocked off when the first material is injected, in order that it does not penetrate into those areas.

Table 6.6 Definition of several multicomponent injection molding processes

Process name	Definition
Multicomponent injection molding	All injection molding methods in which two or more materials are processed
Composite injection molding	Several melts are injected via several gate systems into the cavity in succession
2-Color injection molding	As above, but using one material in different colors
Multicolor injection molding	Same as 2-color injection molding, but using more than 2 colors
2-Component sandwich injection molding	Two melts are injected in succession through a gate system, to form a core and outer layer
Bi-injection	Two melts are injected simultaneously via two gating systems into the cavity

This separation has allowed the development of two-component combination injection-molded parts, such as housings with integrated seals.

The separation may be effected in either of two ways: by the rotating mold systems shown in Figure 6.68 and by the non-rotating core-back technique shown in Figure 6.69 [6.57–6.59].

Molds with Rotating Mold Platen or Rotating Mold Half

A rotating mold has several gating stations and different cavities. For a two-colored part, the first colored section is created by injection at the first mold position. After sufficient time has elapsed for the melt to cool, the mold opens and the mold-part section turns 180° into the second position. The mold closes to form the second cavity into which the second color or another material is injected via a second injection position. In the first mold position, meanwhile, the first molded-part section is being created again. In a similar fashion, three-colored parts can be made using three injection and mold positions and rotations of 120°. The mold is rotated either by means of a standard rotary platform that can be attached to the machine, irrespective of the mold, or by means of a rotary device integrated into the mold that allows a rotary plate to operate. The advantage of the standard rotary platform is its universal method of use, and in the smaller and less expensive design of the molds used. Usually the mold platen on the ejector side is designed to be the rotating side since rotation of the nozzle-side mold platen is more complicated in terms of gating system and rotating system. These molds require high precision mold making but are dependable in operation and do not require any elaborate melt feed [6.57, 6.60]. Typical applications are car tail light covers [6.60], three-colored keyboards [6.61], and the vent flaps of the Golf motorcar [6.62].

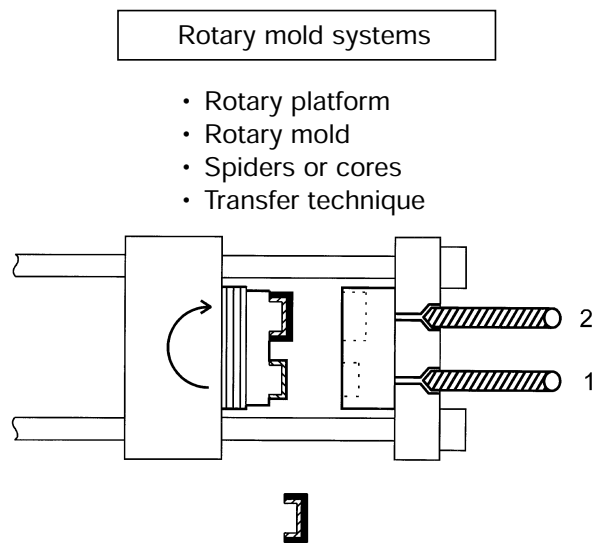


Figure 6.68 Rotary mold systems for composite injection molding

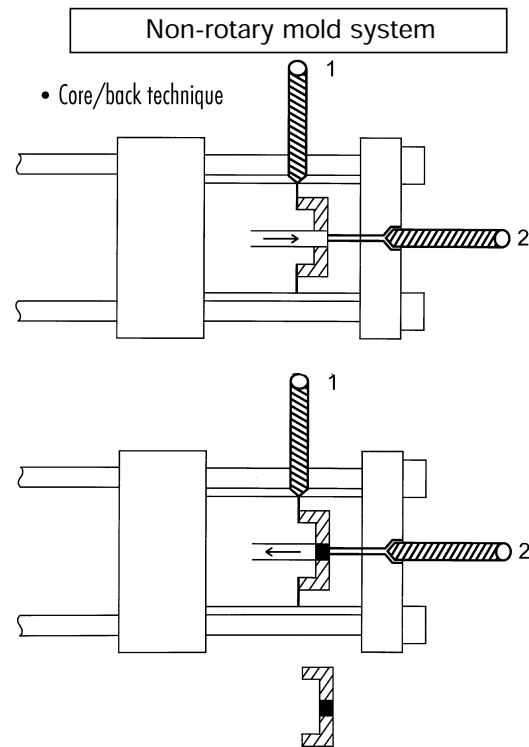


Figure 6.69 Core-back technique

Molds with Rotary Cores or Spiders

In this technique, only part of the ejector- or nozzle-side cavity with injected pre-molding is rotated (Figure 6.70). Both mold platens remain in position.

Molds with Transfer or Insert Technique

After the pre-molding is made in the first cavity, it is transferred by a handling device or by hand into the second cavity and molded to produce the final part with a second material. The term transfer technique is also used to describe using a different machine for molding to produce the final part. Generally, these molds are preferred to rotary molds for economic reasons because the complicated rotary device can be dispensed with, and usually more cavities can be accommodated on the mold platen. Furthermore, thermal separation of the pre-molding and final-molding positions is easier to accomplish (particularly important for thermoplastic-thermoset laminates). Disadvantages are the need for precise centering of the pre-moldings [6.57].

Molds with Retractable Slides and Cores (Core-Back Molds)

With comparatively low mold costs, it is possible to produce multicolor or multi-component injection molded parts in one mold without the need for opening the machine in between and further transport of a molded part by means of the core-back technique. The cavity spaces for the second material are first closed by movable inserts or cores and are opened only after the first material has been injected. The components can be arranged beside, above, or inside each other. This method does not suit material pairs that will not join or bond to each other since it is not possible to produce effective undercuts for interlocking with the injection partner. Furthermore, injection in these molds can only be carried out sequentially and not in parallel as in other methods. This results in longer

cycle times [6.57]. Separate temperature control of the cores or inserts is beneficial since the temperature of the impact surface onto which the second melt is injected can be controlled more accurately [6.64].

In combination injection molding, the rotary mold systems often employ hot runners for the pre-molding so as to yield a gateless pre-molding, since the gate interferes during

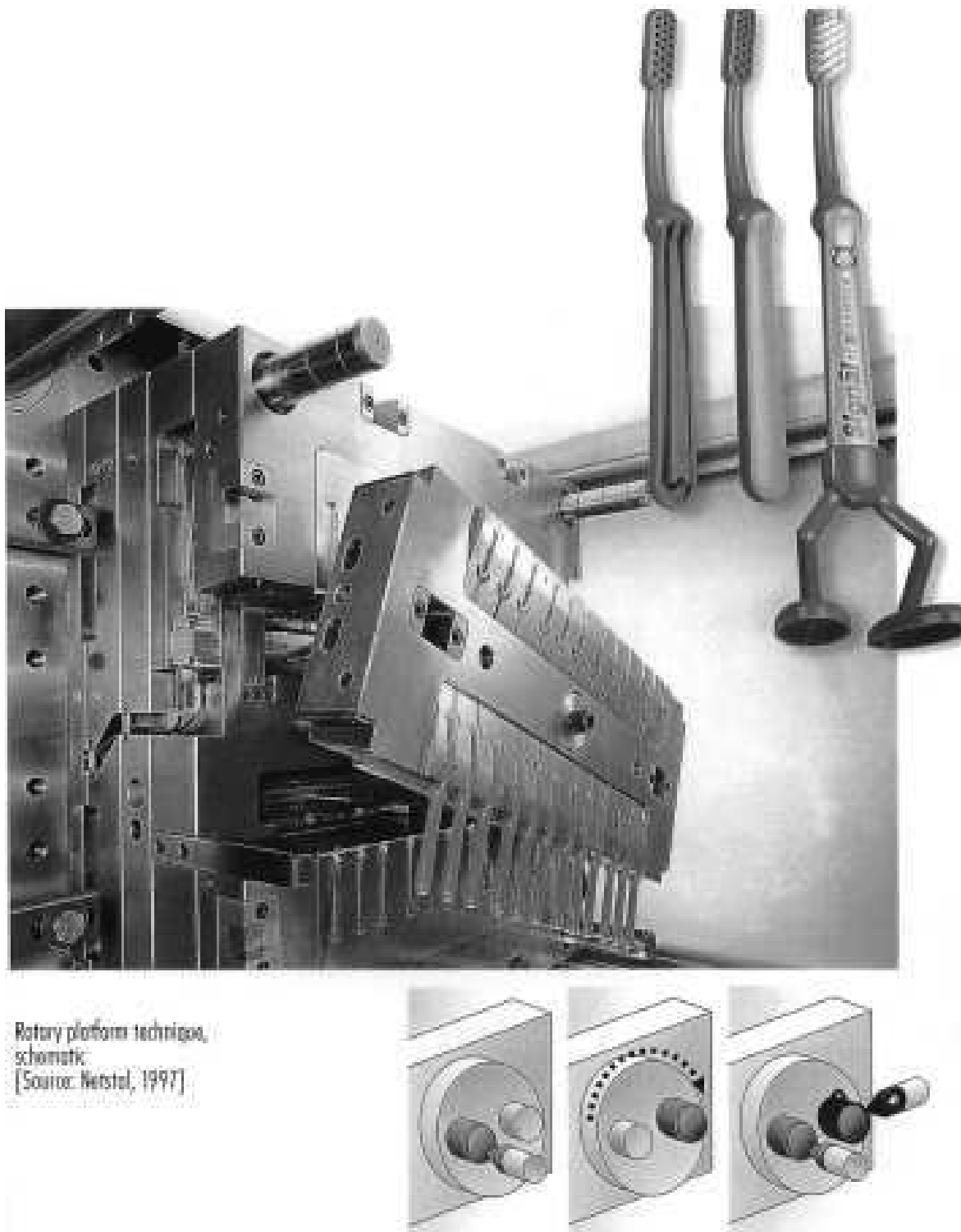


Figure 6.70 Overmolding by the rotary technique. Here: toothbrush made of two components [6.63]

rotation or transfer [6.64, 6.65] and would otherwise have to be removed prior to transfer.

The choice of method for a particular molded part must be established individually from technical and, economic aspects for every application. It must be remembered, however, that rotary mold systems are generally more expensive because of the need for two cavities and from the machine point of view, need a large distance between tie bars in order to be rotatable. Rotary molds do, however, offer greater design freedom and the possibility of thermal separation of the kind required for the manufacture of rubber-thermoplastic combinations (e.g. PA/SLR).

6.11.2.2 Two-Component Sandwich Injection Molds

In contrast to combination injection molding, sandwich molding theoretically does not require a special mold technology and may be performed with standard injection molds. Two melts are injected through a joint gating system into the cavity, to form a core and an outer skin. The melts meet in an adapter between the nozzle peaks of the injection units and the sprue bushing of the mold. It should be noted that all deviations from rotationally symmetrical molded-part geometry with central gating cause non-uniform core material distribution.

6.11.2.3 Bi-Injection Molds

In this injection molding method, two different melt components are fed into the cavity simultaneously through different gating systems. The weld line is affected by the positions of injection and wall thicknesses in the mold as well as by the injection parameters of the two components [6.68].

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