International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 2, No. 3, July 2014

Research Paper

GATING DESIGN CRITERIA FOR SOUND CASTING

Mazhar Iqbal[1]*

**Corresponding Author: Mazhar Iqbal* ✉ *mazhariq1@gmail.com*

Casting as a manufacturing process to make complex shapes of molten metal in mass production may experience many different defects such as porosity and incomplete filling. How to improve the casting quality becomes important. Gating/riser system design is critical to improving casting quality. The objective of the research presented in this thesis is to optimize gating systems with the goal of improving casting quality such as reducing incomplete filling area, decreasing large porosity and increasing yield

Keywords: Gating system, sprue, runner, ingates, shrinkage,

INTRODUCTION

As defined earlier, gating systems refer to all those elements, which are connected with the flow of molten metal from the ladle to the mould cavity. The various elements that are connected with a gating system are (Rao P N, xxxx).

Pouring basin, Sprue, Sprue base well, Runner, Runner Extension,In-gate.

Any gating system designed should aim at providing a defect free casting. This can be achieved by making provision for certain requirements while designing the gating system. These are as follows.

The mould should be completely filled in the smallest time possible without having to raise the metal temperature or use higher metal heads. The metal should flow smoothly into the mould without any turbulence. A turbulence metal flow tends to form dross in the mould. Unwanted material such as slag, dross and other mould material should not be allowed to enter the mould cavity. The metal entry into the mould cavity should be properly controlled in such a way that a aspiration of the atmospheric air is prevented. A proper thermal gradient should be maintained so that the casting is cooled without any shrinkage cavities or distortions. Metal flow should be maintained in such a way that no gating or mould erosion takes place. The gating system should ensure that enough molten metal reaches the mould cavity. The gating system design should be

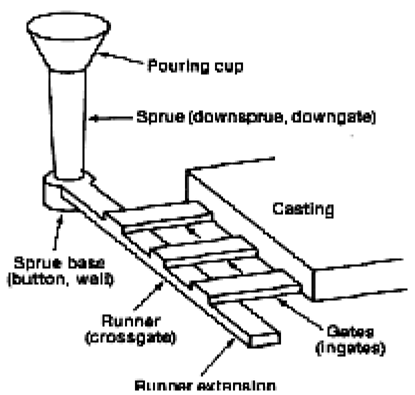
[1] NIFFT, National Institute of foundry And Forge Technology, Ranchi, Ranchi university.

economical and easy to implement and remove after casting solidification. Ultimately, the casting yield should be maximized. A gating system is the conduit network through which liquid metal enters a mold and flows to fill the mold cavity, where the metal can then solidify to form the desired casting shape. The basic components of a simple gating system for a horizontally parted mold are shown in Fig. 1. A pouring cup or a pouring basin provides an opening for the introduction of metal from a pouring device. A sprue carries the liquid metal down to join one or more runners, which distribute the metal throughout the mold until it can enter the casting cavity through ingates.

DESIGN VARIABLES

Methods used to promote any of the desirable design considerations discussed below often conflict with another desired effect. For example, attempts to fill a mold rapidly can result in metal velocities that promote mold erosion. As a result, any gating system will generally be a compromise among conflicting design considerations, with the relative importance of the consideration being determined by the specific casting and its molding and pouring conditions (Wallace J F and Evans E B, 1959; Sylvia J G, 1972).

Figure 1: Elements of Gating System (Sylvia J G, 1972)



Rapid mold fillingcan be important for several reasons.Especially with thin-section castings, heat loss from the liquid metal during mold filling may result in premature freezing,producing surface defects (for example, cold laps) or incompletely filled sections (misruns). Superheating of themolten metal will increase fluidity and retard freezing, but excessive superheat can increase problems of gas pickup by the molten metal and exaggerate the thermal degradation of the mold medium. In addition, the mold filling time should be kept shorter than the mold producing time of the molding equipment to maximize productivity.

Minimizing Turbulence

Turbulent filling and flow in the gating system and mold cavity can increase mechanical and thermal attack on the mold. More important, turbulence may produce casting defects by promoting the entrainment ofgases into the flowing metal. These gases may by themselves become defects (for example bubbles), or they may producedross or inclusions by reacting with the liquid metal. Turbulent flow increases the surface area of the liquid metal exposed to air within the gating system. The susceptibility of different casting alloys to oxidation varies considerably. For those alloys that are highly sensitive to oxidation, such as aluminum alloys; magnesium alloys; and silicon, aluminum, and manganese bronzes, turbulence can generate extensive oxide films that will be churned into the flowing metal, often causing unacceptable defects.

Avoiding Mold and Core Erosion

High flow velocity or improperly directed flow against a mold or core surface may produce defective castings by eroding the mold surface (thus enlarging the mold cavity) and by entraining the dislodged particles of the mold to produce inclusions in the casting.

Removing Slag, Dross, and Inclusions

This factor includes materials that may be introduced from outside the mold (for example, furnace slags and ladle refractories) and those that may be generated inside the system. Methods can be incorporated into the gating system to trap such particles (for example, filters) or to allow them time to float out of the metal stream before entering the mold cavity.

Promoting Favorable Thermal Gradients

Because the last metal to enter the mold cavity will generally be the hottest, it is usually desirable to introduce metal in those parts of the casting that would already be expected to be the last to solidify. One obvious method of accomplishing this is to direct the metal flow from the gating system into a riser, from which it then enters the mold cavity. Because the riser is generally designed to be the last part of the riser/casting system to solidify, such a gating arrangement will help promote directional solidification from the casting to the riser. If the gating system cannot be designed to promote some desirable thermal gradient, it should at least be designed so that it will not produce unfavorable gradients. This will often involve introducing metal into the mold cavity through multiple ingates so that no one location becomes a hot spot.

Maximizing Yield

A variety of unrecoverable costs must go into the metal that will fill the gating system and risers. These components must then be removed from the casting and generally returned for remelt, where their value is downgraded to that of scrap. Production costs can be significantly reduced by minimizing the amount of metal contained in the gating system. The production capacity of a foundry can also be enhanced by increasing the percentage of salable castings that can be produced from a given volume of melted metal.

Economical Gating Removal

Costs associated with the cleaning and finishing of castings can be reduced if the number and size of ingate connections with the casting can be minimized. Again, it may be advantageous to introduce metal into the mold cavity through a riser, because the riser neck can also serve as an ingate.

Avoiding Casting Distortion

It is especially important with rangy, thin-wall castings, in which uneven distribution of heat as the mold cavity is filled may produce undesirable solidification patterns that cause the casting to warp. In addition, the contraction of the gating system as it solidifies can pull on sections of the solidifying casting, resulting in hot tearing or distortion.

Compatibility with Existing Molding/Pouring Methods

Modern high-production molding machines and automated pouring systems often severely limit the flexibility allowed in locating and shaping the pouring cup and sprue for introducing metal into the mold. They also generally place definite limits on the rate at which metal can be poured.

Controlled Flow Conditions

A steady flow rate of metal in the gating system should be established as soon as possible during mold filling, and the conditions of flow should be predictably consistent from one mold to the next.

PRINCIPLES OF FLUID FLOW

Proper design of an optimized gating system will be made easier by the application of several fundamental principles of fluid flow. Chief among these principles are Bernoulli's theorem, the law of continuity, and the effect of momentum.

Bernoulli's Theorem

This basic law of hydraulics relates the pressure, velocity, and elevation along a line of flow in a way that can be applied to gating systems. The theorem states that, at any point in a full system, the sum of the potential energy, kinetic energy,pressure energy, and frictional energy of a flowing liquid is equal to a constant. The theorem can be expressed as:

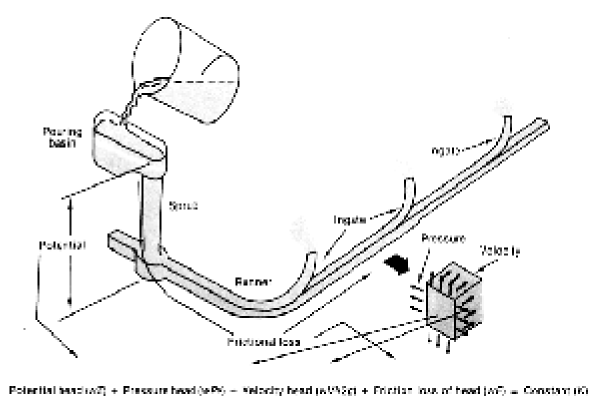
$$wZ + wPv + wV^2/2g + wF = K \quad ...(1)$$

where *w* is the total weight of the flowing liquid (in pounds), *Z* is the height of the liquid (in inches), *P* is the static pressure in liquid (in pounds per square inch), v is the specific volume of liquid (in cubic inches per pound), *g* is the acceleration due to gravity (386.4 in. / s2), *V* is the velocity (in inches per second), *F* is the friction loss per unit weight, and *K* is a constant.

If Equation (1) is divided by *w,* all the terms reduce to dimensions of length and will represent:

- Potential head *Z*
- Pressure head, *P*v
- Velocity head *V*2/2*g*
- Frictional loss of head *F*
- Equation 1 allows prediction of the effect of the several variables at different points in the gating system, although several conditions inherent in foundry gating systems complicate and modify its strict application. For example:
- Equation 1 is for full systems, and at least at the start of pouring, a gating system is empty. This
- Indicates that a gating system should be designed to establish as quickly as possible the flow conditions of a full system
- Equation 1 assumes an impermeable wall around the flowing metal. In sand foundry practice, the permeability of the mold medium can introduce problems, for example, air aspiration in the flowing liquid
- Additional energy losses due to turbulence or to friction (for example, because of changes in the direction of flow) must be accounted for
- Heat loss from the liquid metal is not considered, which will set a limit on the time over which flow can be maintained. Also, solidifying metal on the walls of the gating system components will alter their design while flow continues
- Bernoulli's theorem (Eq 1) is illustrated schematically in Figure 2, and several practical interpretations can be derived. The potential energy is obviously at a maximum at the highest point in the system, that is, the top of the pouring basin. As metal

Figure 2: Illustration of Bernoulli's Theorem (Sylvia J G, 1972)



flows from the basin down the sprue, potential energy changes to kinetic energy as the stream increases in velocity because of gravity. As the sprue fills, a pressure head is developed.

Once flow in a filled system is established, the potential and frictional heads become virtually constant, so conditions within the gating system are determined by the interplay of the remaining factors. The velocity is high where the pressure is low, and vice versa.

The Law of Continuity

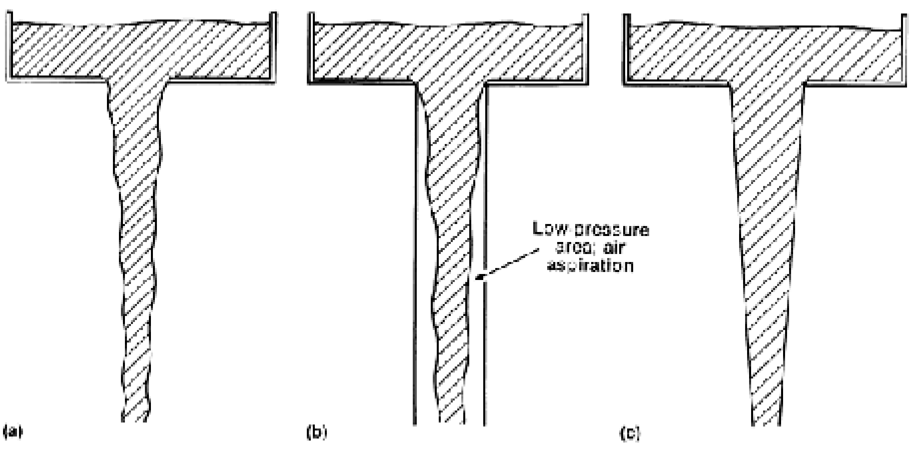
This law states that, for a system with impermeable walls and filled with an incompressible fluid, the rate of flow will be the same at all points in the system. This can be expressed as:

$$Q = A1\mu1 = A2\mu2 \quad ...(2)$$

where *Q* is the rate of flow (in cubic inches per second), Ais the cross-sectional area of the stream (in square inches), is the velocity of the stream (in inches per second), and the subscripts 1 and 2 designate two different locations in the system. Again, the permeability of sand molds can complicate the strict application of this law, introducing potential problems into the casting process.

One practical implication of the law of continuity is illustrated in Figure 3, which illustrates the flow of metal from a pouring basin. As indicated in Eq 1, potential energy is high but velocity is low as the stream leaves the basin. Velocity increases as the stream falls, so the cross-sectional area of the stream

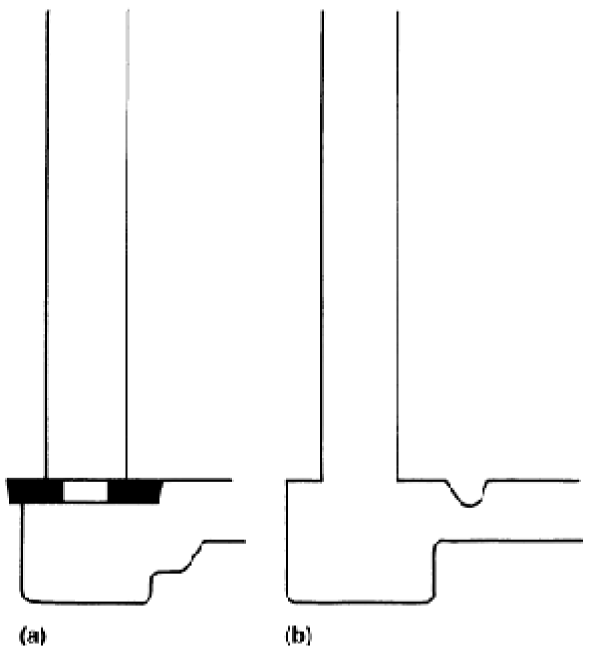
Figure 3: Schematic Showing The Advantages Of A Tapered Sprue Over A Straight-sided Sprue. (a) Natural Flow Of A Free-falling Liquid. (b) Air Aspiration Induced By Liquid Flow In A Straight-sided Sprue. (c) Liquid Flow In A Tapered Sprue (Sylvia J G, 1972)



must decrease proportionately to maintain the balance of the flow rate. The result is the tapered shape typical of a free-falling stream shown in Figure 3(a).

If the same flow is directed down a straight-sided sprue (Figure 3b), the falling stream will create a low-pressure area as it pulls away from the sprue walls and will probably aspirate air. In addition, the flow will tend to be uneven and turbulent, especially when the stream reaches the base of the sprue. The tapered sprue shown in Figure 3(c) is designed to conform to the natural form of the flowing stream and therefore reduces turbulence and the possibility of air aspiration. It also tends to fill quickly, establishing the pressure head characteristic of the full-flow conditions required by Eq 1. Many types of high-production molding units do not readily accommodate tapered sprues, so the gating system designerwill try to approximate the effect of a tapered sprue by placing a restriction, or choke, at or near the base of the sprue to force the falling stream to back up into the sprue (Figure 4).

Figure 4: Choke Mechanisms Incorporated Into Straight-sided Sprues To Approximate Liquid Flow in Tapered Sprues (a) Choke Core (b) Runner Choke (Sylvia J G, 1972)



Momentum Effects

Newton's first law states that a body in motion will continue to move in a given direction until some force is exerted on it to change its direction.

Reynolds's Numbers and Types of Flow

The flow of liquids can be characterized by a special measurement called the Reynolds's number, which can be calculated as follows:

$$N_R = vdr/m \quad ...(3)$$

where *NR* is the Reynolds's number, *v* is the velocity of the liquid, *d* is the diameter of the liquid channel, ρ is the density of the liquid, and μ is the viscosity of the liquid.

Reynold's number, *N*R, and its relationship to flow characterization. (a) *N*R < 2000, laminar flow. (b) 2000 £*N*R < 20,000, turbulent flow. (c) *N*R^3 20,000, severe turbulent flow (Sylvia J G, 1972).

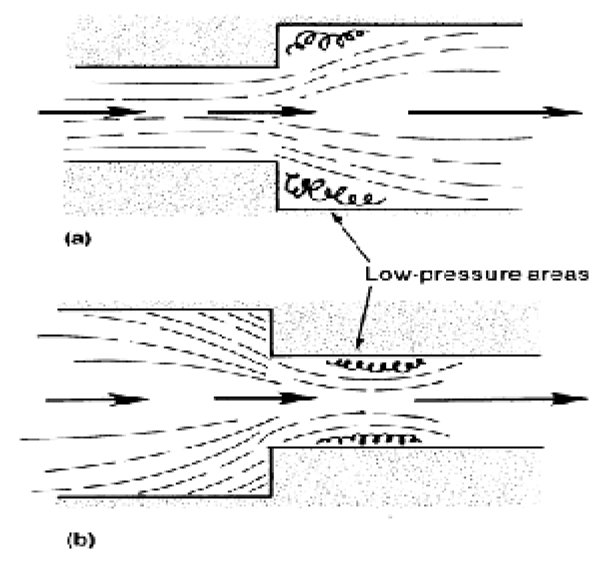
If a fluid flow system has a Reynold's number between 2000 and 20,000, some mixing and turbulence will occur but a relatively undisturbed boundary layer will be maintained on the surface of the stream. This type of turbulent flow, common in most foundry gating systems, can be considered relatively harmless so long as the surface is not ruptured, thus avoiding air entrainment in the flowing stream. With a Reynold's number of about

20,000, flow will be severely turbulent. This will lead to rupturing of the stream surface with the strong likelihood of air entrainment and dross formation as the flowing metal reacts with gases.

Abrupt Changes in Flow Channel Cross Section

As shown in Figure 6, low-pressure zones—with a resulting tendency toward air entrainment—can be created as the metal stream pulls away from the mold wall. With a sudden enlargement of the channel (Figure 6a), momentum effects will carry the stream forward and create low-pressure zones at the enlargement. With a sudden reduction in the channel (Figure 6b), the law of continuity shows that the stream velocity must increase rapidly. This spurting flow will create a low-pressure zone directly after the constriction. The problemsillustrated in Figure 5 can be minimized by making gradual changes in the flow channel cross section; abrupt changesshould be avoided.

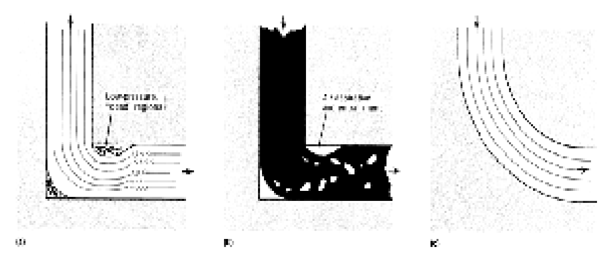
Figure 5: Schematic Showing The Formation Of Low-pressure Areas Due To Abrupt Changes In The Cross Section Of A Flow Channels (a) Sudden Enlargement of the Channel (b) Sudden Reduction of the Channel



Abrupt Changes in Flow Direction

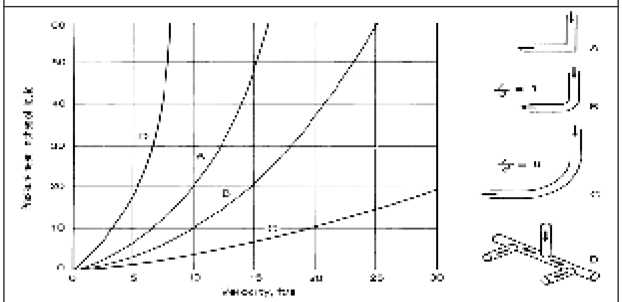
As shown in Figure 6, sudden changes in the direction of flow can produce low pressure zones, as described above. Problems of air entrainment can be minimized by making the change in direction more gradual.

Figure 6: Schematic Illustrating Fluid Flow Around Right-angle And Curved Bends In A Gating System (a) Turbulence Resulting From A Sharp Corner (b) Metal Damage Resulting From A Sharp Corner (c) Streamlined Corner That Minimizes Turbulence And Metal Damage



Abrupt changes in flow direction, in addition to increasing the chances of metal damage, will increase the frictional losses during flow. As shown in Figure 7, a system with high

Figure 7: Effect of Pressure Head and Change in Gate Design on the Velocity of Metal Flow: (a) 90° Bend; (b) *r*/*d* = 1; (c) *r*/*d* = 6; (d) Multiple 90° Bends. The Variables *r* and *d* are the Radius of Curvature and the Diameter of the Runner, Respectively



Source: Sylvia J G, 1972

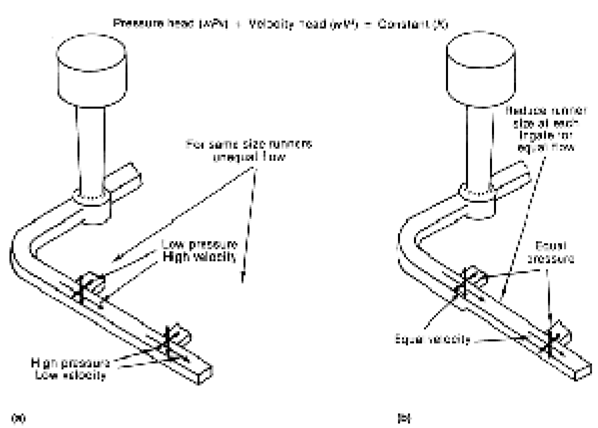
frictional losses will require a greater pressure head to maintain a given flow velocity.

Using a Runner Extension

Use of a runner extension beyond the last ingate is illustrated in Figure 1. The first metal entering the gating system will generally be the most heavily damaged by contact with the mold medium and with air as it flows. To avoid having this metal enter the casting cavity, momentum effects can be used to carry it past the ingates and into the runner extension. The ingates will then fill with the cleaner, less damaged metal that follows the initial molten metal stream.

Equalizing flow through ingates by decreasing the runner cross section after the ingate is illustrated in Figure 8; this is done for systems with multiple ingates. As noted earlier, in the filled system shown, potential and frictional energies become constants, so they can be dropped from consideration in Eq 1 to show the interaction of pressure and velocity effects.

Figure 8: Applying Bernoulli's Theorem to Flow From a Runner at two Ingates For a Filled System and Comparingvelocity and Pressure at the Ingates for two Runner Configurations (a) Same Runner Cross Section at Bothingates (b) Stepped Runner Providing Two Different Runner Cross Sections at Each Ingate



Source: Sylvia J G, 1972

At the first ingate, velocity is high as momentum effects carry the flowing stream past the gate. At the second ingate, velocity decreases in the runner as it reaches the end, causing higher pressure and resulting in higher flow through the gate. By stepping down the runner after the first ingate, metal velocities and pressures at the two ingates can be equalized. Thiseffect can be achieved by gradually tapering the runner to a smaller cross section along its length, but patternmaking limitations usually make it simpler to incorporate actual steps in the runner.

DESIGN CONSIDERATIONS

In applying fluid flow principles to the design of a specific gating system, several design decisions must be made before the actual sizes of the various components can be calculated.

Runner and Ingate

Figures 1 and 2 show gating systems with ingates coming off the top of the runner and then into the casting. This arrangement of cope ingates and drag runners is common and has the advantages that the runner will be full before metal enters the ingates. This establishes the full-flow conditions discussed earlier in this article. A full runner will reduce turbulence and will help to allow any low-density inclusions in the flowing stream to float out and attach themselves to the mold wall.A system of cope runners and drag ingates (or ingates coming off the base of a cope runner) is also common and has strong proponents (Sylvia J G, 1972). The basis of this design is that momentum effects will carry the first metal past the ingates, and if the runner can be quickly filled (at least above the level of the ingates), clean metal will flow from the bottom of the runner, while inclusions carried along in the metal stream will float above the ingates. A common element of this system is that the total cross-sectional area of the ingates should be smaller than the crosssectional area of the runner. Such a pressurized system is intended to force the metal to back up at the ingates and rapidly fill the runner, although complete filling of a cope runner will often depend on at least partial filling of the casting. During this period of incomplete filling, turbulence and the potential for air entrainment and dross generation are increased.

Pressurized Versus Unpressurized Systems.

The difference between these two systems is in the choice of the location of the flow-controlling constriction, or choke that will determine the ultimate flow rate for the gating system. This decision involves the determination of a desired gating ratio, that is, the relative cross-sectional areas of the sprue, runner, and gates. This ratio, numerically expressed in the order sprue: runner: gate, defines whether a gating system is increasing in area (unpressurized) or constricting (pressurized). Common unpressurized gating ratios are 1:2:2, 1:2:4, and 1:4:4. A typical pressurized gating ratio is 4:8:3. Both types of systems are widely used.

The unpressurized system has the advantage of reducing metal velocity in the gating system as it approaches and enters the casting. Lower velocities help encourage laminar (or less turbulent) flow, so unpressurized systems are recommended for alloys that are highly sensitive to oxide and dross formation. Pressurized systems generally have the advantage of reduced size and weight for a given casting, thus increasing mold yield. The single greatest disadvantage of pressurized systems is that, by design, stream velocities are highest at the gatesjust as the metal enters the casting. This increases the potential for mold or core erosion and places a premium on proper location of ingates to minimize such damage.

Some gating ratios[1] used in practice are

Aluminium	1:2:11:3:31:4:4
Aluminium bronze	1:2.88:4.8
Brass	1:1:11:1:31.6:1.3:1
Copper	2:8:13:9:1
Ductile Iron	1.15:1.1:11.25:1.13:1
Grey Cast Iron	2:1.5:12:3:1
Magnesium	1:2:21:4:4
Malleable Iron	1:2:9.51.5:1:2.52:1:4.9
Steels	1:1:71:2:11:2:1.5

Gating System and Types

A mould cavity must be filled with clean metal in a controlled manner to ensure smooth, uniform and complete filling, for the casting to be free of discontinuities, solid inclusionsand voids. This can be achieved by a well-designed gating system. The first step involvesselecting the type of gating system and the layout of gating channels: the orientation andposition of sprue, runner and ingate(s). The most critical design decision is the idealfilling time, based on which the gating channels are designed.The main objective of a gating system is to lead clean molten metalpoured from ladle tothe casting cavity, ensuring smooth, uniformand completefilling. Clean metal impliespreventing the entry of slag and inclusions into the mould cavity, and minimizing surfaceturbulence. Smooth filling implies minimizing bulk turbulence. Uniform filling impliesthat all portions of the casting fill in a controlled manner, usually at the same time.Complete filling implies leading molten metal to thin and end sections with minimum resistance [4]. The major elements of a gating system include pouring basin, sprue, well, runner and ingate, in the sequence of flow of molten metal from the ladle to the mould cavity. The pouring basin or bush or cup is a circular or rectangular pocket that accepts the molten metal from the ladle. The sprue or down sprue, usually circular in crosssection, leads molten metal from the pouring basin to the sprue well. The sprue well or base changes the direction of molten metal by right-angle and sends it to the runner. The runner takes the metal from the sprue to close to the casting. Finally, the ingate leads the metal to the mould cavity. Another major element is filter or slag trap, usually placed in the runner or between the runner and ingate, meant for filtering out slag and other inclusions.

The sprue is always vertical. The well, runner and ingate are usually located in the parting plane. Depending on the orientation of the parting plane, the gating systems can be classified as horizontal and vertical gating systems. Thus in horizontal gating systems, the sprue is perpendicular to the parting plane, whereas in vertical gating systems, the sprue is parallel to the parting plane.Gating systems can be classified depending on the orientation of the parting plane (which contains the sprue, runner and ingates), as horizontal or vertical. Depending on the position of the ingate(s), gating systems can be classified as top, parting and bottom.

Horizontal gating systems are suitable for flat castings filled under gravity. They are widely used in sand casting of ferrous metals, as well as gravity diecasting of non-ferrous metals.

Vertical gating systems are suitable for tall castings. They are employed in high-pressure sand mould, shell mould and diecasting processes, where the parting plane is vertical.

Top gating systems, in which hot molten metal enters at the top of the casting, promote directional solidification from bottom to top of the casting. These are however, suitable only for flat castings to limit the damage to metal as well as the mould by free fall of the molten metal during initial filling.

Bottom gating systems have the opposite characteristics: the metal enters at the bottom of the casting and gradually fills up the mould with minimal disturbances. It is recommended for tall castings, where free fall of molten metal (from top or parting gates) has to be avoided.

Middle or side or parting gating systems combine the characteristics of top and bottom gating systems. If the gating channels are at the parting plane, they are also easier to produce and modify if necessary, during trial runs. The most widely used system is the horizontal gating with ingates at the parting plane. In vertical gating systems, ingates may be positioned at top, bottom andside.

Gating Channel Layout

The most important decision here is the number and location of ingate(s). Let us consider horizontal gating systems with side ingates. Their location is governed by the following considerations

Side feeders

If side feeders are employed, then their efficiency can be improved by filling with the first stream of hot molten metal through ingates. It also reduces the fettling effort and the resulting marks on the casting, since the ingates do not have to be removed separately.

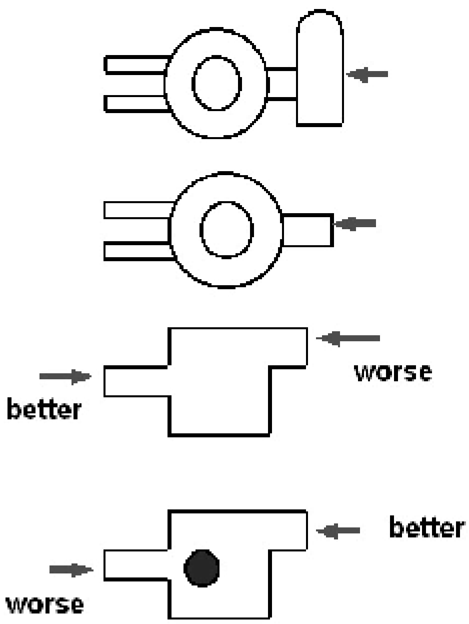
Thick Sections

The next best position after a side feeder is a thick section, which will allow molten metal to flow to other sections with minimal cooling. It will also reduce occasional breakage during fettling of ingates.

Clear Path

In sand casting, the molten metal should be allowed to flow with minimal obstructions and change of direction (particularly at sharp corners) to avoid turbulencerelated problems. Ingates should never be placed directly opposite a core.

Figure 9: Heuristics for Ingate Location



Source: Sylvia J G, 1972

Low Free fall

The ingate should be located where the free fall of molten metal inside the mould cavity is low. This minimizes oxidation during fall and erosion at the point of impact of molten metal.

The number of ingates must be sufficient enough, so that the distance of flow from any ingate to the farthest point filled by that ingate is less than the fluidity distance.

The sprue conducts the molten metal from the pouring basin at its top to the plane in which the runners and ingates are located. Its location is governed by the following considerations:

Flow Distance

The sprue location must minimize the total flow distance within the gating channels, to reduce heat loss as well as maximize yield.

Heat Concentration

Since the hottest metal flows through the sprue, it must be away from hot spots (essentially thick sections) in the casting.

Mould Layout

The sprue must be located to minimize the size of the bounding box enclosing the entire casting (including the gating channels), so that a smaller mould is required. This also applies to multi cavity layout, where the sprue and runner(s) are shared by multiple cavities.The runner layout is simply given by the shortest path to connect the ingates with sprue.

MOULD FILLING PHENOMENON

Fluidity

It is not a physical property. It is a technological characteristic. It indicates theability of liquid metal to flow through a given mould passage – even as it is solidifying – and fill the cavity to reproduce the design details. It is quantified in terms of the solidified length of a standard spiral casting.mThe fluidity as defined by the foundry community is different that defined by physicists(as the reciprocal of viscosity). The casting fluidity is driven by metallostatic pressure and hindered by: viscosity and surface tension of molten metal, heat diffusivity of mould, back pressure of air in mould cavity and friction between the metal-mould pair.

Metallostatic Head

The metallostatic pressure is given by ρ g h where ρ is the metaldensity and h is the height of liquid metal column above the filling point. A higher metallostatic pressure gives higher velocity of molten metal, and there by higher fluidity.

Viscosity

Viscosity depends on the metal family, composition and the instantaneous temperature. For most metals, the viscosity at the pouring temperature is close to that ofwater (1 centistokes); aluminum: 1.2 and iron: 0.9 centistokes. In comparison, the viscosity of typical mineral oils is about 600.

Surface Tension

For a flat plate of thickness t, the relation between head, thickness and surface tension is given by: ρ g h= γ/ t, where ρ is the surface tension. At the pouring temperature, the surface tension of aluminum and iron is 0.5 and 0.9 N/m respectively; similar to mercury at room temperature (0.46 N/m), but higher than water (0.07 N/m).

Heat Diffusivity

Moulds with high heat diffusivity transfer heat faster from the moltenmetal, causing it to freeze earlier and stop flowing. It is given by √(Km ρm Cm), where Km is thermal conductivity, ρm is density and Cm is specific heat of the mould material.

Back Pressure

As molten metal advances in the mould, the back pressure of air that isbeing compressed in the cavity ahead effectively reduces the metallostatic pressure, andthus hinders filling. The back pressure depends on the cavity volume, mould permeability and the velocity of the advancing front. Venting helps.

Friction

The rough surface of sand mould hinders metal flow. Thus mould coating(usually water based, containing silica flour and graphite) reduces the friction betweenthe metal and mould, contributing to higher fluidity. In general, fluidity of pure metals is higher than alloys. Within alloys, eutectics havehigher fluidity than non-eutectics. The fluidity of grey iron ranges between 0.5-1.0 m,and can be estimated by the empirical equation:

$$\text{Fluidity} = 14.9\ CE + 0.05\ T_p^- - 155\ \text{inch.}$$

where CEis the carbon equivalent given by CE= %C + 0.25 %Si + 0.5 %Pand Tp is the pouring temperature in Fahrenheit.

Turbulence

It implies irregular, fluctuating flow with disturbances. It is observed when:(1) inertia forces (which make the fluid continue in the same direction), are much higherthan the drag forces (which tend to stop the fluid motion), and (2) there are obstructions in the path of flow, such as a sharp corner or a change of section thickness. The drag forces include those caused by viscosity and surface tension. The viscous forcesmainly operate in the bulk of the liquid metal, whereas surface tension forces operate near the mould wall. Thus we have two types of turbulence: bulk and surface.

Bulk Turbulence

It is quantified by Reynolds number *Re*, which is the ratio of inertia toviscous pressure in a fluid. It is given by ρ V d / μ where ρ is the density, μ is the viscosityand V is the velocity of the liquid; dis a characteristic dimension of the flow path. If *Re* ismore than 2000, then the flow is usually turbulent.

Surface Turbulence

It is quantified by the Weber number We, which is the ratio of inertiato surface tension pressure in a fluid. It is given by ρ V2 r / $\gamma$where ris the radius ofcurvature of the free liquid surface. For Weis less than 1, surface turbulence is absent.When it is 100 or more, surface turbulence is prominent, leading to violent mixing ofsurface layers with the bulk of the molten metal. The path of molten metal during casting process comprises mainly four parts:

1. Pouring of molten metal from ladle to the cup in the mould
2. Flow within the gating channels, from pouring basin to ingate
3. Jet of molten metal emerging from ingate and entering the mould cavity
4. Filling of mould cavity by liquid movements in the bulk as well as near the surface.In general, the entire path of molten metal, within the gating system as well as the mould cavity, is turbulent in most castings. This can be readily ascertained by calculating thevalue of Reynolds number for a typical casting. A major purpose of the gating system (instead of pouring metal directly into the mould cavity) is to reduce the turbulence, though it cannot be completely eliminated.

There are mainly three major classes of casting defects related to mould filling: incomplete filling, solid inclusions and gaseous entrapments

INCOMPLETE FILLING

This is primarily caused by poor fluidity of molten metal, andmanifests in the form of a cold shut or mishrun. A cold shut occurs when two streams ofmolten metal coming from opposite directions meet, but do not fuse completely. A misrun occurs when the molten metal does not completely fill a section of the mould cavity (usually an end section far from the entry point). The presence of surface oxide sand impurities on the advancing front of liquid metal aggravates such defects.

Solid Inclusions

This is primarily caused by the turbulence in molten metal, and manifests in the form of sand inclusion or slag inclusion. Sand inclusions are mainly caused by bulk turbulence in gating channels or mould cavity, which dislodges sand particles from the mould wall. Slag inclusions can be caused by surface turbulence any where along the path of molten metal, leading to mixing of surface oxide layers with the rest of molten metal.

Gaseous Entrapments

This class of casting defects includes air and gas entrapment, usually in form of blow hole and gas porosity, respectively. They occur when the air orgas inside the mould cavity cannot escape through the mould. The major source of gases includes dissolved gases in the molten metal, vaporization of mould sand moisture andcombustion of binders in core or mould sand. The occurrence of these defects increases when the amount of air entrapped or gas generated is high, filling and solidification of molten metal are fast, the venting of the mould is poor.

Optimal Filling Time

A casting that fills too slow can have discontinuities such as cold shuts and misruns. Too fast filling can lead to solid and gaseous inclusions. The higher limit of filling time (slowest filling) is governed by the need to avoid premature freezing in thin sections before complete filling. The lower limit of the filling time (fastest filling) is governed by the onset of surface turbulence. The correct filling time lies some where in between, and is a function of cast metal, weight, minimum section thickness and pouring temperature.

Several empirical equations for determining the correct filling time for major metals have been developed by casting researchers, based on experimental investigations. The filling timetfis expressed as a function of casting weight W in kg, section thickness t in mm and fluidity length Lf in mm.

A generalized equation for filling time can be written as:

$$\tau f = K0\ (KfLf / 1000)\ (Ks + Ktt / 20)\ (Kw\ W)P$$

There are five coefficients: K0 is an overall coefficient, and Kf, Ks, Kt, Kw are the coefficients for fluidity, size, thickness and weight, respectively. For grey iron the following values may be used: K0 = 1.0, Kf= 1.0, Ks = 1.1(for castings of size 100-1000 mm), Kt=1.4(for wall thickness up to 10 mm), Kw = 1and P = 0.4. Based on individual experience, an expert casting engineer can set the values of the coefficients for each metal-process combination. These form a valuable part of the knowledge base of a foundry specializing in specific castings.

Metal Velocity

The optimal filling time is determined such that gating channels can be designed to avoid surface turbulence and minimize bulk turbulence within the gating channels as well as the mould cavity. This mainly depends on the velocity of the molten metal, which varies widely within the gating channels as well as inside the mould cavity. For a given location in the casting, the velocity also changes with time, from the start to end of filling. The most important event is that of molten metal emerging from the ingate, just after the filling of gating channels and before the filling of mould cavity. The metal is both hot and fast at this location and instant, and can lead to considerable damage if not controlled properly. The velocity of molten metal at the ingate depends on mainly two parameters: (1) the metallostatic head and (2) the ratio of cross-sections of sprue exit, runner(s) and ingates(s), referred to as the gating ratio. In general, the velocity of molten metal must be kept lower than 1 m/s for ferrous metals and 0.5 m/s for aluminum alloys.

GATING ELEMENT DESIGN

The gating system can be designed to fill a given casting in a predetermined time, by keeping a constant level of liquid metal in the pouring basin during pouring, to achieve a controlled rate of flow through the choke. The choke is the smallest cross-section in the gating system that controls the flow rate of molten metal. The element (sprue exit, runners or ingates) with the smallest value in the gating ratio is considered the choke. The choke area Acis given by:

Ac = W / (ρ c τ f V c)

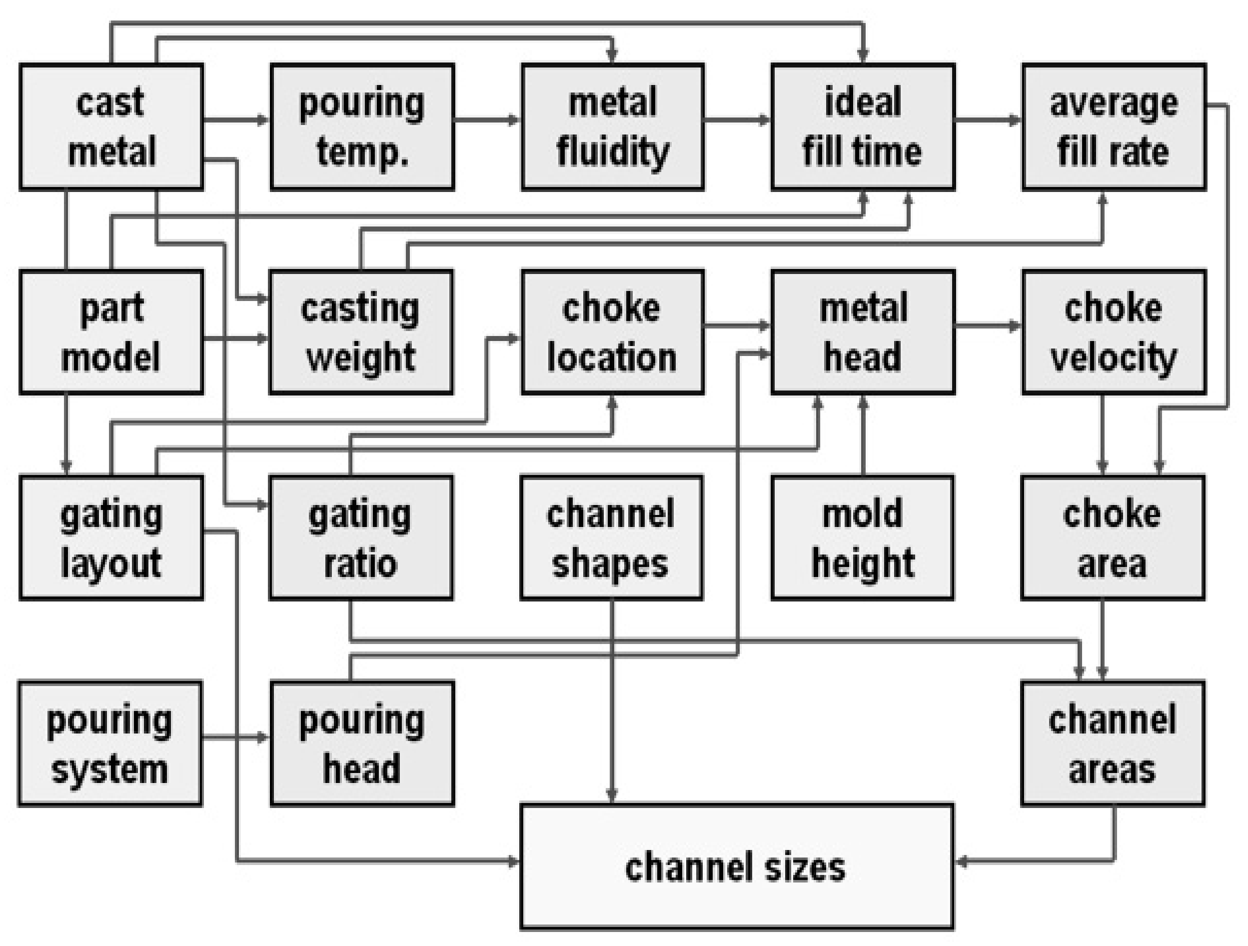
where, W is the total casting weight (including feeders and gating channels), ρ c is the metal density, *tf* is the total filling time and *Vc* is the choke velocity.

The choke velocity is given by:

Vc = Vp+ cf√(2 g H)

where H is the metallostatic pressure head, given by the vertical distance between the

Figure 10: Flow Chart of Gating Element Design



liquid level in pouring cup and the centerline of the choke. The value of pouring velocity Vp is non-zero, if poured from a height or if bottom pouring ladles are used. The friction factor cf within the gating system depends on its geometry and surface finish, and ranges between 0.6-0.9.

Note that the weight of the gating system is unknown at the time of calculating the mould filling time and choke area. This can be overcome by determining the total casting weight after a gating design and repeating the calculations.During actual filling, the metallostatic pressure head gradually decreases after the molten metal starts rising above the level of choke. Thus the average value of actual choke velocity is less than the one used above, leading to slower filling. This can be compensated by estimating the actual filling time (as described in a later section), and then correcting the choke area.

The cross-sectional area of sprue exit, runners and ingates, is initially determined based on the choke area, gating ratio and the number of individual elements. Then the sectional area of individual elements, as well as their shape and dimensions are determined as follows.

Sprue

It usually has a circular cross-section, which minimizes turbulence and heat loss.The cross-sectional area at the sprue exit or bottom is calculated from the choke area and gating ratio. The area of the sprue top should be calculated using mass and energy balance equations, to prevent flow separation in the sprue. Essentially,

$A1 \sqrt{H1} = A2 \sqrt{H2}$ where, *H1* and *H2* are the metallostatic pressure head at the top and bottom of the sprue, respectively; *A1* and *A2* being the respective cross-sectional areas. The ideal sprue must be larger at the top and smaller at the bottom. Since this leads to an undercut, such a sprue can not be created by the pattern during moulding operations, and must be formed by a core. If this is not economical, then the choke can be created in the beginning of runner.

Sprue well

It arrests the free fall of molten metal through the sprue and turns it by a right angle towards the runner. It must be designed to minimize turbulence and air aspiration. The recommended shape of a sprue well is cylindrical, with diameter twice that of sprue exit and depth twice that of runner. A fillet between the well and runner will facilitate smooth transfer of molten metal.

Runner

The main function of the runner is to slow down the molten metal, which speeds up during its free fall through the sprue, and take it to all the ingates. This implies that the total cross-sectional area of runner(s) must be greater than the sprue exit. In general, a ratio of 1:2 is recommended. A much higher ratio (such as 1:4) may lead to flow separation in the runner. The second implication is that the runner must fill completely before letting the molten metal enter the ingates. Finally, in casting where more than one ingate is present, the runner cross-section area must be reduced after each ingate connection (by an amount equal to the area of that ingate), to ensure uniform flow.

Ingate

The ingate leads the molten metal from the gating system to the mould cavity. A number of conflicting requirements apply to the design of ingates, as listed below. Ingate section must be designed to reduce the metal velocity below the critical limit.This implies that in general, the ingate area must be more than the sprue exit (choke). Ingate must be easy to fettle. This implies a smaller cross-section, preferably a flat section (against a square one), is preferred. Ingate must not lead to a local hot spot. This implies that the ingate modulus (ratio of volume to cooling surface area) must be smaller than that of the connected section. Flow of molten metal through an ingate (and therefore its cross-sectional area) mustbe proportional to the volume of the connected casting region.The number, shape (aspect ratio) and dimensions of ingates must be carefully designed to optimize the above requirements.

Optimization and Validation

Several iterations of gating system design and mould filling analysis may be carried out until filling related problems are eliminated. In general, several different gating designs (essentially, the number, location and dimensions of gating channels) may lead to defect free castings. We will therefore, develop a set of criteria to assess a given gating design,which can be used in an optimization exercise. Finally we describe different experimental techniques to observe mould filling for validating the gating design.A given design of gating system can be assessed using the following criteria. All criteria have been normalized and are sought to be maximized.

Mould Filling Time

The actual filling time as determined by computer simulation or actual experiment must be close to the optimal filling time for which the gating system was designed. This criterion is expressed as follows:

$$CG1 = 1\ (/\tau f\text{-actual} - \tau f\text{-optimal}/)\ /\ \tau f\text{-optimal}$$

Note that if a casting is found to have filling-related defects at the optimal filling time, but is defect-free at some other filling time, then the empirical equation for optimal filling time may be corrected for the particular combination of geometry, metal and process.

Ingate Velocity

The velocity of molten metal emerging from the ingate must be as low as possible to minimize turbulence.

$$CG2 = 1\ (Vingate/\ Vcritical)$$

where, Vcritical is the recommended limit of velocity depending on the metal: about 1 m/s for iron, and 0.5 m/s for aluminum.

Impingement

The velocity and direction of the first stream of molten metal emergingfrom an ingate and striking a mould face affect mould erosion at that location. A faststream striking in a direction perpendicular to the face of impingement should beavoided. This is expressed as follows:

$$CG3 = Vimp\text{-}limit\ /\ (\ Vimp(\ nimp.\ nf))$$

where, Vimp-limitis the limiting value of impingement velocity for the onset of mould erosion, Vimp is the velocity of impingement; nimp and nf are the unit vectors along the direction of impingement and normal to the casting face of impingement, respectively.

Gating Yield

The volume of the gating system must be minimized to increase the yield.

The criterion is given by:

CG4 = Ncvc/ (Ncvc+ vg)

Where, Nc is number of casting cavities per mould, vc is the volume of each cavity, and *vg* is the volume of the common gating system for all the cavities in the mould.

Fettling

The size of an ingate must be small compared to the connected portion of the casting to avoid casting breakage or cracks during fettling. When several ingates are present, one that is most likely to cause damage determines the criteria assessment value.

CG5 = mini (1(tgi/ tci)

where, tgi is the thickness of ingate i and tci is the thickness of the connected portion of casting. The gating design can be validated by various techniques. Visualization of mould filling – g,)g – even if indirect (since the moulds are opaque)– g,) g – provides a useful pointer to filling related defects and their causes. Other techniques are briefly described here.

Shop Floor Trials

Sample castings are produced using the materials and processes that will be finally used for production castings. Then their surface, sub-surface and internal quality may be observed by visual, destructive and non-destructive testing. Destructive testing includes machining and cutting the sections through critical regions.

High-speed Radiography

This involves recording the mould-filling phenomenon using a high-speed x-ray camera. This is most useful for observing all major phenomenon in mould filling, including initial filling of the gating system, the sequence of filling through different ingates, branching and rejoining of streams, etc. It is however, limited to low density metals and small castings (in terms of thickness along the direction of rays).

Partial Filling

Several moulds are prepared; and say only 10% of metal is poured in the first mould, 20% in the second mould, and so on. The sequence of partially filled and solidified castings facilitates visualizing the mould filling. This is suitable for thin castings in which the mould filling time is comparable to the casting solidification time.

Open Mould

This is suitable for castings that are primarily in the drag. A portion of cope directly above the casting cavity is cut away, leaving the gating system. A standard video camera is used to record the molten metal stream emerging from the ingate and the gradual filling of the mould. The video can later be played back in slow motion. The absence of back pressure of air in the mould may lead to some errors.

Contact Wire Sensing

Contact wires can be placed in different parts of the mould. The completion of circuit when the metal reaches a particular wire is recorded by a multi channel recorder. Based on the sequence of observations, the time taken for the metal to reach different parts of the mould can be assessed. This is however, useful only to record the initial flow of metal to different parts of the mould.

Water in Transparent Mould

Since the viscosity of water is close to that of most molten metals, the flow of water in a transparent mould (constructed by Perspex or other transparent polymers) provides a very useful indicator. A color marker (if turbulence is low), oil droplets or particles are introduced for better visualization and determination of velocity in different sections. This is however, not suitable for studying flow in thin castings in which the flow of molten metal is affected by the onset of solidification.

CONCLUSION

1. Pouring basin, sprue , sprue base well, runner and runner extension serves the purpose of allowing clean molten metal to enter the mould cavity.
2. Parting gate is the most widely used gate while the top and bottom gates are sometimes used for specific application that favors them.
3. Fluid mechanics law, together with empirical relations, is applied to the design the optimum gating system.
4. It is important to make sure that slag entering the gating system be removed completely before the metal enters the mould cavity.
5. Sometimes chills may be need to be added to reduce porosity at isolated sections that are not fed by risers.

REFERENCES

1. Atlas of Casting Defects, Institute of British Foundry men.
2. Guleyupoglu S (1995), "A general approach to the parting direction problem for sand castings", Ph.D. Thesis, The University of Alabama, Tuscaloosa, AL.
3. Guleyupoglu S and Hill J L (1995), "Parting direction and parting plane selection criteria forsand castings", *AFS Transactions,* Vol. 103, pp. 259-264.
4. Guleyupoglu S, Yu K O and Hill J L (1996), "Analysis and optimal design of risers based on section modulus method", In *Proc. 9th World Conference on Investment Castings,* San Francisco, CA, October.
5. Karsay S I (1981), *Ductile Iron III: Gating and Risering,* QIT—Fer et Titane, Inc.
6. Khanna O P (2011), *Foundry Technology*, 15th Reprint. Principles of Gating, pp. 203-237.
7. Rao P N (2007), "Manufacturing Technology", Vol. 1, *Gating System for Casting*, pp. 126-133.
8. Richins D S and Wetmore W O (1951), *AFS Symposium on Principles of Gating,* p. 1, AFS, Des Plaines, IL.
9. Ruddle R W (1956), *The Running and Gating of Sand Castings.* The Institute of Metals, London, England.
10. Ruddle R W (1978), "Risering—past, present and future", *British Foundryman,* Vol. 71(a), p. 197.

11. Ruddle R W (1982), "A computer program for steel risering", *AFS Transactions,* Vol. 90, pp. 227-237.

12. Swift R E, Jackson J H and Eastwood L W (1949), "A study of principles of gating", *AFS Transactions,* Vol. 57, pp. 76-88.

13. Sylvia J G (1972), *Cast Metals Technology,* Addison-Wesley.

14. Wallace J F and Evans E B (1959), "Principles of Gating", *Foundry,* Vol. 87, Oct ober.

15. WWW.emt-india.net