Experiments of Part III

Metal Casting and Foundry

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1. Objective:

The main objective of this experiment is to enhance the practical knowledge of the students in the field of metal casting technology and to review the basic principles for the design of casting patterns, feeding systems and gating systems, in addition to the investigation of the main factors affecting the function of such casting elements. In particular, the main objectives of this part are:

1. Practice reverse engineering through measuring and re-drawing of castings.
2. Practice casting design (pattern) process for a simple selected parts through the design of casting, gating, and feeding (risers) systems, and mold, considering all types of allowances.
3. Practice- where possible- the process of pattern making
4. Practice green sand molding, melting, pouring, and shakeout process

2. Background:

For more information about the subject of the experiments, it is recommended for the student to review chapter five of Serope Kalpakjian and Steven Schmid (2016).

3. Theory:

It is a popular mean by which a material is converted into a final useful shape; a solid is *melted*, heated to a proper temperature, and sometimes *treated to modify its chemical analysis*. The molten material, generally metal, is then *poured* into a *mold cavity*, which contains it in proper shape during solidification. The resulting product can have virtually any configuration the designers want (*patterns*). In addition the resistance to working stresses can be optimized, properties can be controlled (*heat treatment*), and a good appearance can be produced (*fettling and finishing*).
In general the following sub-processes are involved in casting process:

1. Casting design.
2. Melting process.
3. Tapping and pouring techniques.
4. Mold cavity.
5. Solidification process.
6. Shakeout process.
7. Shot blasting process
8. Fettling and finishing
9. Heat treatment
10. Painting of final castings (products).

3.1 Classification of molding and castings processes.

Processes, techniques and operations that being used for producing molds and castings can be classified as follow:

1. Expendable (single-use) Molds with multiple-use pattern. This category includes the followibg;
    1. Sand-mold casting
    2. Shell-mold castings
    3. V-process (Vacuum Molding) Casting
    4. Plaster -mold castings
    5. The Shaw process-castings.
    6. Graphite-mold castings.
    7. Rubber-mold castings.

2. Expendable (single-use) Molds with single-use pattern. This category includes;
    1. Investment casting
2. Permanent Molds (Multiple-use-mold) casting processes. This category includes;
    1. Slush castings
    2. Corthias castings
    3. Low-pressure permanent-mold castings
    4. Vacuum permanent-mold castings
    5. Die castings
    6. Squeeze castings (or liquid-metal forging)
    7. Centrifugal Casting
    8. Semi centrifugal Casting
    9. Ingots and Continuous Castings.
    10. Electromagnetic castings.

3.2 Casting terminology.

Figure 1 illustrates the cross section of a typical two-part casting mold and incorporates many features of the process. Parting line, cope, drag, mold cavity, riser, gating system, sprue, pouring cup, core, core box and many other features are shown.

Types of sand molds. Figure 1 represented a green sand molds , which is a mixture of sand, clay and water, it is the cheapest molding method. Bentonite, cement Sodium silicate, and Furan resin and hardener can be used also as sand binder.

3.2 Characterization of basic foundry sand.

The most important specifications of basic sand are: moister content, fineness (clay content), grain shape, refractoriness, chemical composition and grain size distribution (sieve analysis).

1. Moister content: Sand should be dry, speedy moister tester.
2. Grain shape: Splintered, sub-angular, angular and round shapes.
3. Fineness: particles less than 0.02 mm in diameter considered as fines particle.
4. Thermal expansion: each sand type has its own thermal expansion coefficient.
5. Refractoriness of sand or sand mixture is defined as the temperature at which most of the sand grains are sintered.

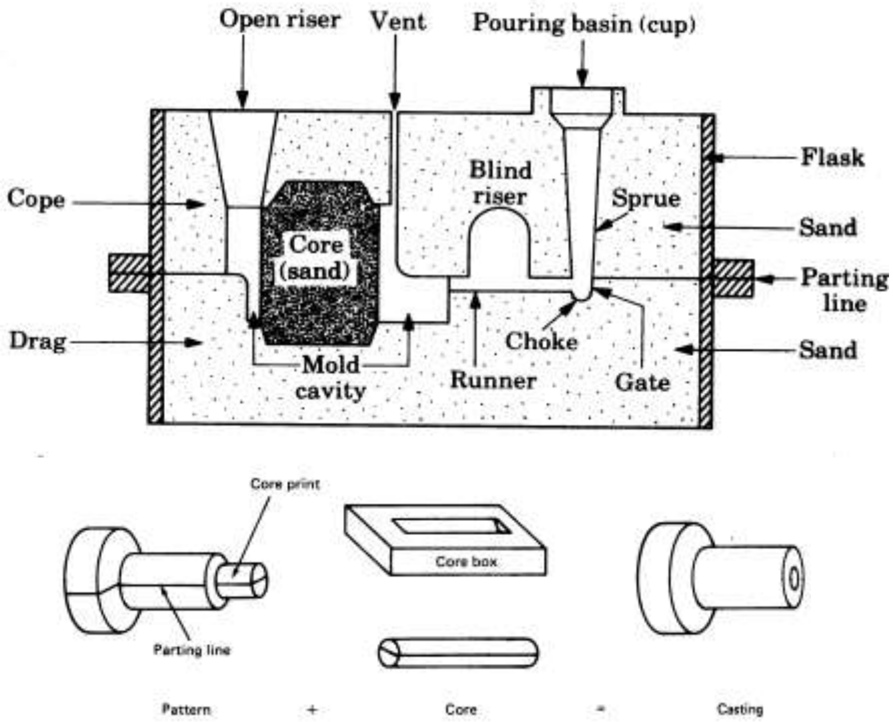

Figure 1: Some features of sand mold casting

3.3 Design of Casting process

The process for making a casting is designed in a definite sequence, which includes the following:

1. the drawing of the part to be cast, such a process is the main process document.the drawing is define all the features of the casting process and is the basis for the design and manufacture of the moulds and patterns. The elements of foundry technology indicated on the drawing should specify the following:
    1. The best parting plane for the mold and pattern.
    2. The positions of the mold for pouring which is depending on the shape of casting, kind of metal, gating system geometry, specifications of cast metal density, surface finish and many others.
    3. The machining allowences of the casting (thickness of metals to be removed after casting).
    4. Draft alloawnces of the casting.
    5. Number of cores to form the internal cavities in the castings.

Figure 2. illustrates the manner in which taper (draft), and machining allowances are included in the pattern for a simple shape casting. Since allowances tend to be removed by machining, efforts made to reduce the allowances will be well received. Factors affecting the draft allowances are; molding method(hand or machine); pattern material(wood, metal etc.); pattern height; molding material (sand mixture, rubber, etc.); material to be casted; and finally the parting plane location. Conversly factors

affecting the machining allowances considered as; nominal weight of casting and class of accuracy; casting size and nominal dimension of the detail to be machined; surface position while casting; molding method(hand or machine); and material to be casted.

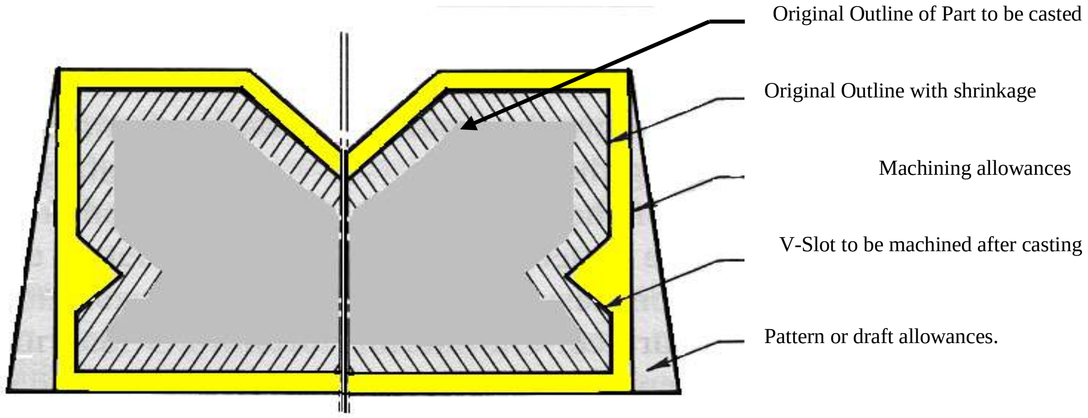

Figure 2. Types of allowances added to the casting design

3.4 Risering System Design

Risers are elements of the gating and feeding system, which are intended for displacing shrinkage cavity and porosity outside of the casting. By the principle of directed solidification. The thinner sections of a casting should preferably be located at the bottom and the thicker ones, at the top.

Side risers are provided for the hot spots. Using internal and external chills can also bring about directed solidification. Drawings of castings are checked for the probability of formation of shrinkage defects by the method of inscribed circle (Figure 3 a), which should freely roll out, as it were, from lower sections of a casting into the upper ones and further into the riser. For the casting shown in Figure 3 a, this condition is not satisfied ($R_1 > R_2$), and therefore, shrinkage cavity 1 is likely to appear in the hot spot. After marking the machining allowances, draft 2 and fillet 3 in the drawing (Figure 3 b), the inscribed circles will roll out freely ($R_1 < R_2$) from the bottom of the casting upwards into the riser, which will ensure the directed solidification, and therefore, the absence of shrinkage cavity in the casting.

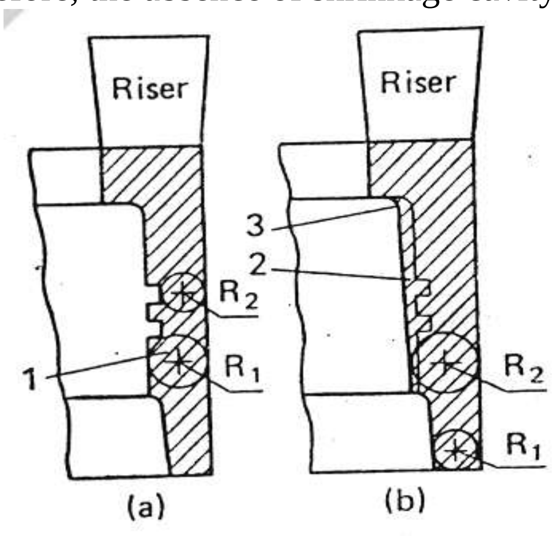

Figure 3. Risers design and directional solidifications

However, the basic requirement of a riser should:

1. Be the last portion to solidify;
2. Be effective in establishing a pronounced temperature gradient within the casting to promote directional solidification towards the risers;
3. Have sufficient volume to compensate for shrinkage in the casting;
4. Completely cover the casting section that is to be fed;
5. Ensure the maximum yield possible. Apropos maximum yield.

3.5 Inscribed circle method for Riser Calculations.

The riser diameter is obtained by multiplying the diameter of the largest circle (hot spot) that can be inscribed in the section to be fed by an arbitrary factor which normally ranges from 1.5 to 3, i.e. riser diameter D = 1.5 to 3 times diameter of the hot spot. Though this method is empirical, it is still very much in use because of its simplicity.

3.6 Modulus Method

The Modulus of a casting M is given by: $M_c = \frac{V_c}{A_C} = \frac{\text{Volume of Casting}}{\text{Surface Area of the Casting}}$. The modulus of the riser must be at least 1.2 times the modulus of the casting. To ensure that the riser solidifies later than the casting, after obtaining the modulus, the size of the riser can be calculated by assuming a suitable height to diameter ratio.

$$M_r = 1.2\, M_c$$

3.7 Determination of the numbers of risers.

Number of required risers can be calculated using the following formula:

$$n_F = \frac{L(mm)}{d_F(mm) + FD.T(mm)}$$

Where: n_F : Risers numbers required.

L : Casting length or mean circumference.

d_F : Is the riser diameter.

T : Is the thinnest casting section through which to feed?

FD : Feeding distance factor, which is (4-5 for steel), (5 for malleable iron), (10 for AL), (5-6 Al alloys), etc.

3.8 Example on risers design

The casting shown in the figure 4. below weighs 4300 Kg. The casting can be divided into the central hub portion and a ring of outside diameter 108’’, inside diameter 90’’ and height 11 ½’’. The risers that will be kept on this portion will feed the projection and the arms.

Using hot spot circle method:

a. Outside Ring.

Hot spot diameter = (108-99)/2 = 4.5.

Riser diameter D = 1.5 to 3 times diameter of the hot spot,

Riser diameter = **(**2.5**)** (4.5) = 11.2 say 12.

Riser height =1.5 D = (1.5) (12) = 18.
Number of risers

$$n_F = \frac{L(mm)}{d_F(mm) + FD.T(mm)}$$

$$n_F = \frac{Circumference = (\pi.108)}{12 + (4)(11.5)} = \frac{339}{58} = 5.8 = 6$$

b. Central portion.
Hot spot diameter = (16-11)/2 = 2.5.
Riser diameter D = 1.5 to 3 times diameter of the hot spot,
Riser diameter = (1.5) (2.5) = 3.75. This is an annular riser with external diameter of (3.75) (2) + (11) = 18.5
Riser height =1.5 D = (1.5) (3.75) = 5.6. But the height will consider as shown in the figure same as height of the outside ring riser.

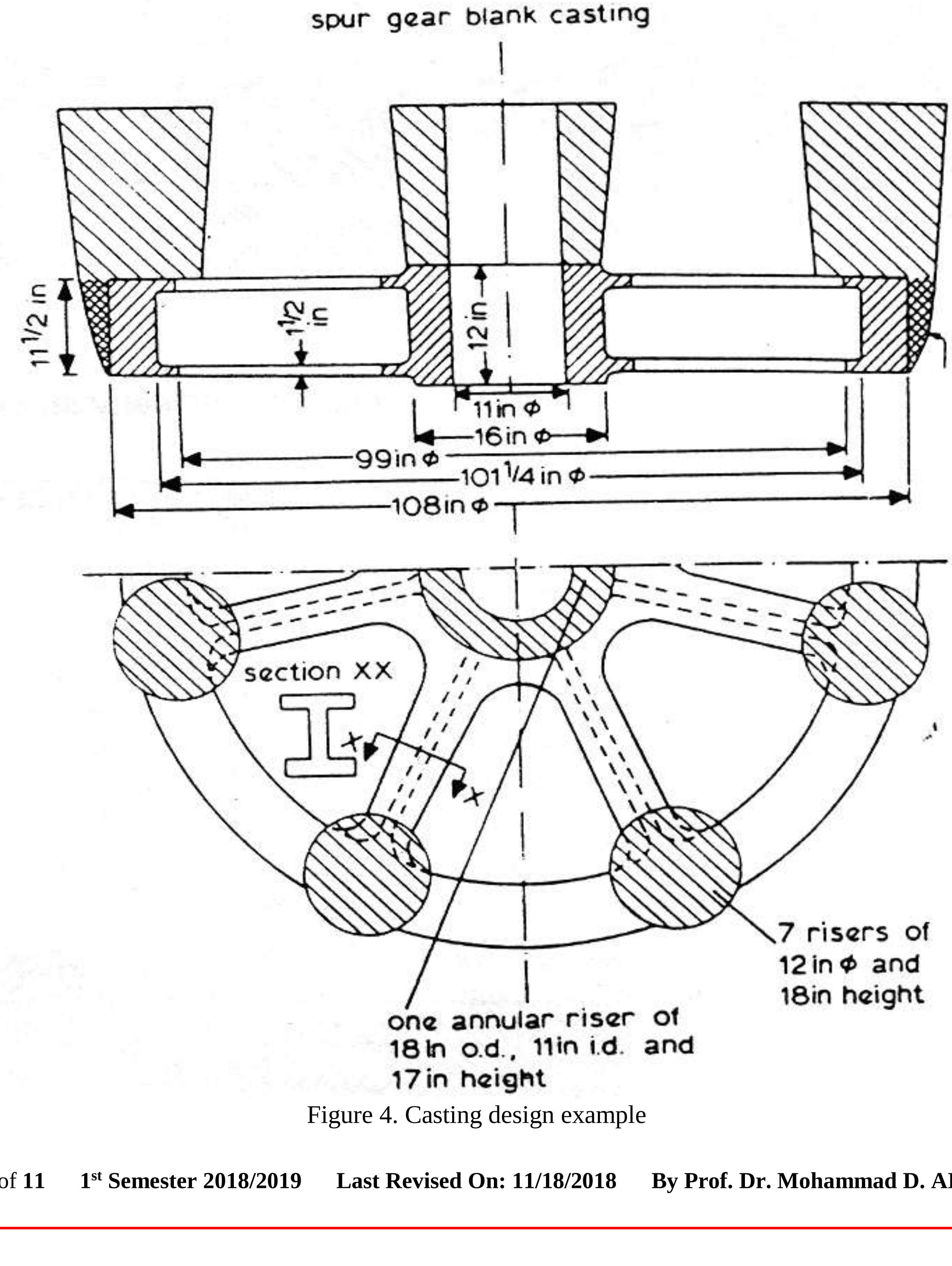

Figure 4. Casting design example

Using modulus method.

$$M_c = \frac{V_c}{A_c}$$

$$\text{for the rim, } V_c = 2500, A_c = 1545$$

$$M_c \frac{2500}{1545} = 1.62$$

$$M_r = 1.2\, M_c = (1.2)(1.62) = 1.94 = \frac{V_r}{A_r}$$

$$\frac{\frac{\pi . D^2}{4}(1.5)D}{\pi\frac{D^2}{4}\times 2 + \pi D \times 1.5} = 1.94 = \frac{1.5D}{8}$$

$$\therefore D = \frac{1.94\times 8}{1.5} = 10.35 \text{ say } 11$$

$$H = 1.5\times 11 = 16.5$$

$$n_F = \frac{L(mm)}{d_F(mm) + FD.T(mm)}$$

$$n_F = \frac{Circumference = (\pi.108)}{11+(4)(11.5)} = \frac{339}{57} = 5.8 = 6$$

$$M_c = \frac{V_c}{A_c}$$

$$\text{For Central Portion, } V_c = 1260, A_c = 1247$$

$$M_c \frac{1260}{1247} = 1.05$$

$$M_r = 1.2\, M_c = (1.2)(1.05) = 1.26 = \frac{V_r}{A_r}$$

$$\frac{\pi/4\left(D^2 - 11^2\right)16.5}{\frac{\pi}{4}\left(D^2 - 11^2\right)2 + \pi}(D+11)16.5$$

$$1.26 = \frac{(D-11)\times\frac{16.5}{4}}{0.5(D-11)+16.5}$$

$$(D-11).4 = (0.5D + 11.5)1.2$$

$$\therefore D = 17$$

$$H = 1.5\times 17 = 25$$

3.9 Design of Gating System.

The ideal optimum gating system should:

1. Fill the mold quickly.
2. Fill a mold with a minimum of turbulence.
3. Establish thermal gradients, which promote soundness.
4. Avoid reoxidation of metal in the gating system.
5. Remove slag and dross from the metal as it flows through the gating system.
6. Not distort the casting during solidification.
7. Maximize casting yield.
8. Be economical to remove.
9. Be compatible with the pouring system used.

Figure 5 shows gating systems with various schemes of metal feeding showed below:

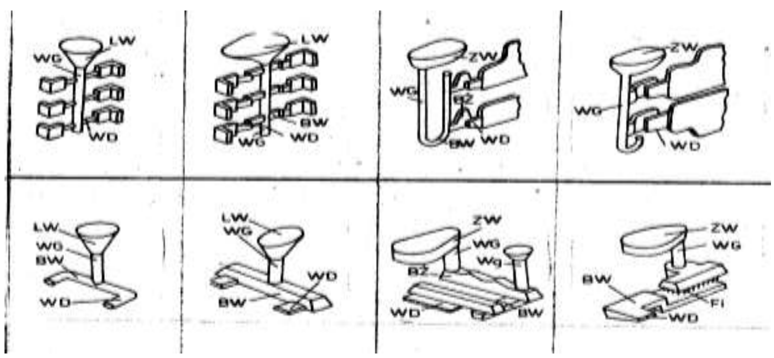

Figure 5. Variant gating systems design

3.10 The members of the gating system.

In the following, the individual members of gating systems and of their assembly will be briefly presented:

1. **Pouring basin.** Pouring basins- figure 6 a - that contain a well deeper than their depth at the sprue junction to effectively absorb the impact of the arriving stream, and flow velocity will be governed by sprue height only. Another advantage of this design is that pouring may start out slowly without iron entering the sprue. Once the proper location of the ladles lip has been established, fast pour and sprue filling begins with minimum slag entry.
2. **Sprue.** Circular cross sections – Figure 6 b- are being used most commonly. Tapering the sprue downwards is always a good practice. Straight or nearly straight sprues may be used in all pressurized systems. Chocked at the bottom (or sprue basin) of the sprue must be used in a non-pressurized gating systems.

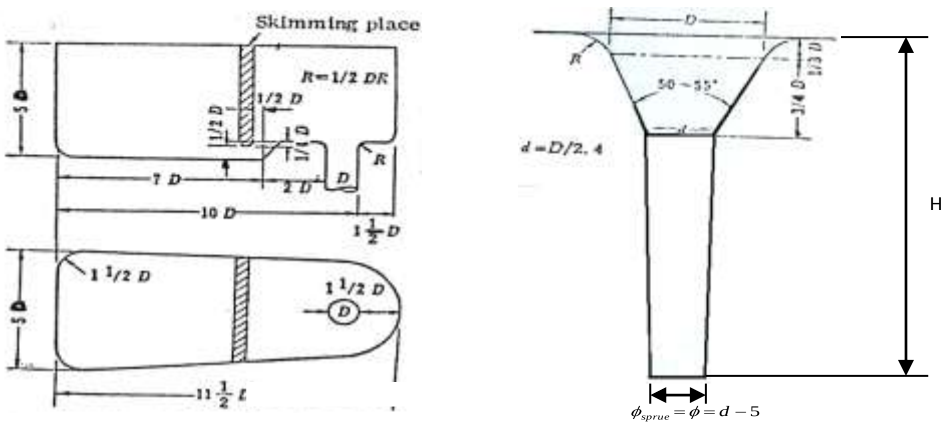

Figure 6. a) Pouring basin, b) Sprue

3. **Runner.** A straight runner is the best choice of space permits it. If bending the runner is unavoidable, it should be done with as large radius as space permits, because curvatures introduce additional turbulence. A minimum distance of 4 inch between the end point of the runner and the next gate us recommended. The cross section of the runner is almost always rectangular with thickness to height ratio of 1:2 in a pressurized system. Figure 7 presents the runner and some other elements.

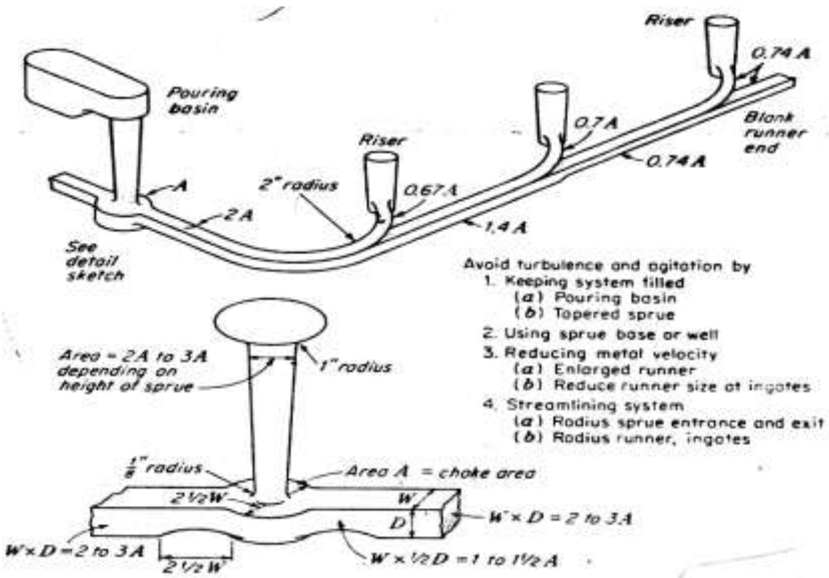

Figure 7. An example of a gating system and its elements

4. **Sprue runner junction.** The first rule in shaping the sprue-runner junction is that it must not locally decrease the calculated sprue bottom cross-section area. If then, the sprue cross section is largely in any dimension than the horizontal section of the runner, the sprue bottom should extend to the bottom of the runner, see the previous figure.
5. **Gates.** Gates are the most delicate members of the system, Gates should be thin and correspondingly wide, and should be easy to remove. The optimum gate cross section is rectangular with a little draft as condition permit.
6. **Runner-gate Junction.** A gate must never be placed in straight continuation of the runner. Gates must branch off the side(s) of the runner at near right angles.
7. **Gate-Casting junction.** The gates need to join the thinnest sections of the casting as much as layout limitations permit. The aim is to equalize cooling rate between the different segments of the casting.

3.11 Example on gating system.

The casting shown in the figure 8 below weighs 4300 Kg. As we find from previous section, at the ring portion, number of needed risers are 7 each has 12 unit diameter and 18 unit height. At the central (hub) one hollow riser of external diameter, eternal diameter and height of 11.0, 18.5, 18 unit respectively. It is required to design a proper gating system to cast this part.

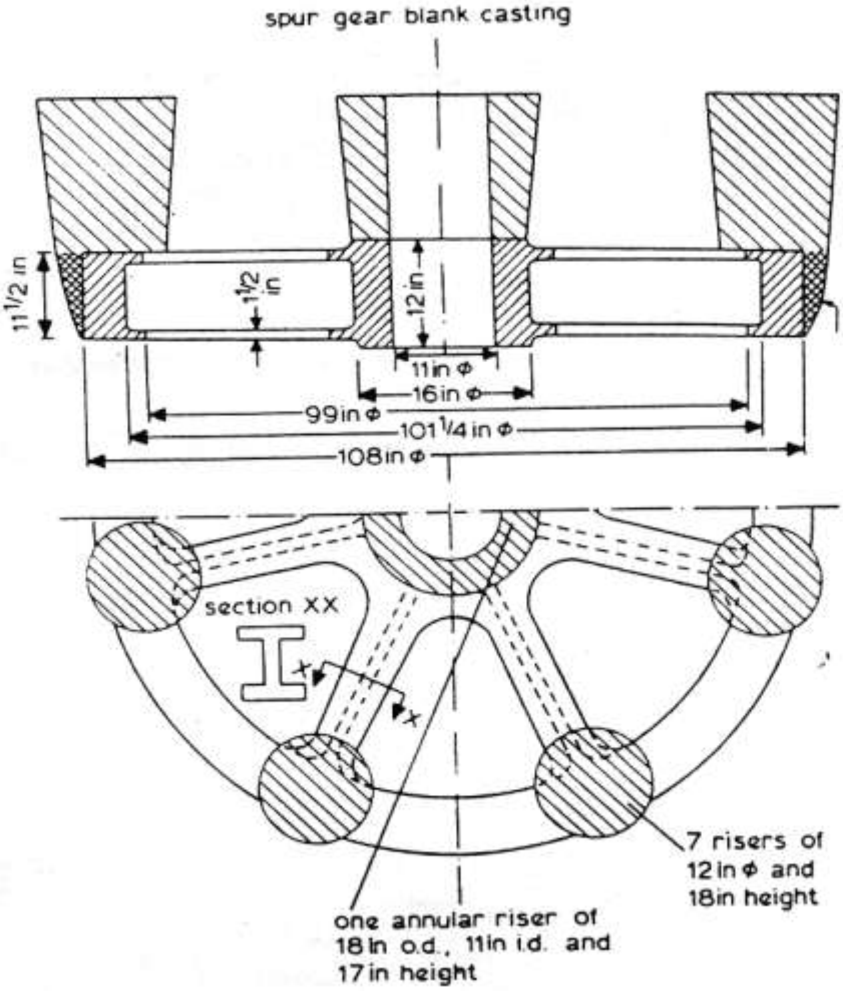

Figure 8. Casting design example

Solution.

Assuming the density of cast metal is 0.097 kg/Inch^3 (because all dimension of this example in inches).

Total feedable weight G_t = weight of casting G_c + weight of all risers G_r.

G_t = 4300 + [(2035.8 *7) +3127]. [0.097] = 5988Kg.

The surface area of the needed gate(s) AS_{gate}, could be found by the following equation:

$$AS_{gate} = \sqrt{\frac{G_t}{2}} = \sqrt{\frac{5988}{2}} = 55 \text{ Inch}^2$$

If we recommend 7 gates then

$$AS_{gate} = \frac{55}{7} = 7.8 \text{ Inch}^2$$

$$weightofgate(s) = 7.8 \times 5 \times .097 \times 7 = 3.7 \times 7 = 26.5Kg$$

Geometry of each gate recommended being as in figure 9A. Consider a closed gating system (pressurized) with gating ratio as below:

$$SA_{sprue} > SA_{runner} > SA_{gate}$$

$$SA_{sprue} : SA_{runner} : SA_{gate}$$

$$1.2 \quad :1.1 \quad :1.0$$

Total surface area of the runner will be (1.1). (55) = 60.5. If the sprue in the middle of the runner then we can say that there are two runners each have (60.5/2 = 30.25 Inch^2) surface area, weight =983 Kg. Runner dimensions and shape shown in figure 6B.

The sprue surface area will be (1.2) (55) = 66 Inch^2

$$\frac{\pi \times D^2}{4} = 66$$

$$\therefore D = 9.2 \text{ Inch}$$

$$\varphi_{sprue} = 9.2 \text{ Inch}$$

$$\text{weight Sprue} = 66 \times 9.2 \times 1.05 \times 0.097 = 121 \text{Kg}$$

Total casting weight = sprue weight+ runner weight+ gate(s) weight + G_t

= 121+983+26.5+5988 = 7118 Kg

Casting yield = G_c / 7118= 4300/7118 = 60%

The overall shape of this gating system is presented by Figure 6(c)

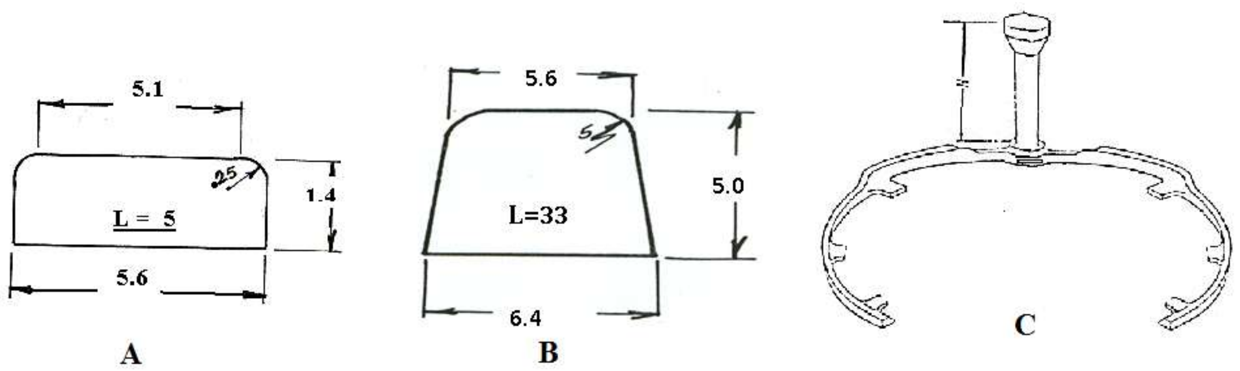

Figure 9. (A) Gate dimensions and shape, (B) Runner dimensions and shape, (C) overall shape of the gating system.

4. Materials:

Aluminum scrap, green sand molding mixture, molding equipment and tools, wooden pattern, isolating material (dust), and some other materials are required.

5. Equipment:

The following equipment and tools are necessary to perform a sand casting process by the use of the above materials:

Furnace	Flask measuring tools	Ladle (crucible)	Clamps
Rammers	Handling equipment	Shrinkage rule	different casting tools

6. Procedures:

1. Select 3 different simple castings
2. Measure the selected castings then draw full engineering drawings for each
3. Based on the drawing design a wooden pattern with reasonable gating and Risering system. All needed allowances should be added.
4. Prepare the sand molding mixture and prepare all the needed tools and equipment.
5. Prepare the furnace, the charging material, the refractory materials and the handling equipment and tools.
6. Prepare the casting mold, in the mean while start melting the charge in the furnace.
7. Pouring of the molten metal in the mold cavity.
8. Wait a proper time tell the poured metal is solidify then shake out the mold to get the final casting.

7. Requirements:

1. Summarize the procedures of the experiments?
2. Draw the part to be cast, and then indicate on the drawing the parting line, shrinkage rate, machining allowances (if there is machining), and draft allowances, cores etc.
3. Calculate a proper risering system (use scribed circle method) and draw the risers?
4. Calculate a proper gating system; spree, runner(s) and gate(s), draw sketches?
5. Draw (sketches) the final casting with risers, and gating system and find the total weight, then find the yield of the casting?
6. Draw (Sketches) the used sand mold and calculate the used sand weight. Then calculate the sand to metal ratio?
7. Indicate the melting, pouring and tapping temperatures?
8. Discuss the defects of the final casing.

8. References

1. Serope Kalpakjian and Steven Schmid (2016). Manufacturing Engineering & Technology, 7th Edition, Prentice Hall.
2. Serope Kalpakjian and Steven Schmid (2010). Manufacturing Engineering and Technology, 6th edition. Prentice Hall.