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DEVELOPMENT OF FEEDER DESIGN USING CASTING SIMULATION

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Abstract

In metal casting, defect free castings which require least finishing operations has been the primary goal since the inception of technology.It is always desired that the yield of casting is maximized against the volume of feeder/riser accommodated to meet the solidification shrinkage requirement. Major casting defects, such as shrinkage cavity, porosity, hot tears etc. occurs during or as a result of solidification phenomenon of the molten metal. These defects can be minimized by appropriate changes in feeding parameters, such as feeder location, feeder shape and size, feeder neck shape and size. Selecting the correct set of parameters that lead to the desired quality and yield, is important but difficult to achieve. The practical approach of design of feeder has high factor of safety and due to that oversized feeders have normally been designed and tested on shop floor. This consumes lot of time and resources. Thus, there is a need for computer aided optimal feeder design coupled with solidification simulation so as to reduce the no. of the shop-floor trials and obtain enhanced yield and high quality, in minimal possible time. The initial design is the aluminium casting part (without feeder) which is simulated online in Efoundrytodetect the location of hotspot. Then a feeder is designed on the following steps: determination of the feeder-neck connection point on the casting surface, initial feeder design and feeder shape optimization using Efoundry till the hotspot is obtained in the feeder tself. The same part is then experimentally poured and verified with cut-section. It is observed from actual pouring that shrinkage cavity had shifted towards the feeder whereas it remained at the centre of the unction in the non-feeder part. It is concluded at the end that the selection of proper feeder affects the quality of casting during solidification.

Keywords:

Simulation
Efoundry;
Feeder Design.
shrinkage defect,
directional solidification.

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Introduction

Metal casting is a 5000 years young manufacturing process in which molten metal is poured in a mould and removed after solidification. These castings are all around us right from simple rings to complex engine cylinders and are employed in industries varying from aerospace, medical devices, automobiles, sanitary, electrical machineries, home appliances etc. Indian casting industry with an annual production of 7.5 MT is the 2 nd largest casting producers in the world after China. With an approximated count of 4500 SME foundries and accounting for employing nearly 1 million people, the process is still considered as an art in itself to produce defect free and sound casting [1]. The successful casting of pre-designed geometry is heavily dependent on the skill and experience of foundry engineer. Steps in metal casting Casting can produce variety of products, which account for various metal process combinations with complex geometry and varying weight. Almost all the metals or alloys which can be easily melted under controlled conditions are castable [2]-[4]. It is a near net shape manufacturing process involving less or no further operations required.

Casting process has a wide range of process parameters depending upon the type of metal (aluminum alloy, steel, cast iron etc.), mold material (e.g. sand, metal, ceramic etc.), molding techniques and the methods by which the molten alloy is introduced into the mould cavity (e.g. gravity, low pressure, high pressure etc.). Some other processes are investment casting, shell molding, continuous casting, squeeze casting, lost foam casting etc[3]-[5]. Sand casting is the most widely used process, suitable for producing intricate parts in almost every metal that can 2 be melted. Nearly 80% of the components produced by weight are made through sand casting process only. Casting Feeding System [6]-[7].

During the process of casting solidification, liquid metal starts solidifying from the mold boundary till it reaches to certain point/points in the mold-cavity known as hot spot/spots. This hot spot region is a local temperature maximum, which effectively feeds adjacent regions in the casting. Since molten metal shrinks in volume during solidification (1-5% by volume) in the mold cavity, a portion of fresh molten metal should be fed or compensated to make up for the shrinkage at the hot spot region. However, the fresh molten metal cannot be fed to an isolated non-solidified metal completely surrounded by solidified metal, due to which porosity defects such as a cavity and other void regions are formed [8]. The cavity thus formed is called a shrinkage cavity which is one of the most serious casting defects and accounts for maximum casting rejections. The most important aspect of designing a sound and defect free casting is design of perfect feeding system. Feeding system design includes use of feeders, insulation around a feeder, provision of chills, and exothermic pads which ease or facilitates molten metal flow, microscopically, to the hot spot regions [9]. Feeders are applied to the casting to compensate the solidification shrinkage and providing the directional solidification (from casting to feeders) so the last solidification points are shifted to the feeders. Therefore, suitable design of feeding system (number, position, size and shape of feeders) is a key for production of sound castings. Hot spot must be inside the feeder to ensure defect free casting.

Mathematical modeling of casting processes and its numerical simulation has become a mature field and a number of computational systems are available specifically for this purpose as shown in Table 1. In each case, following the analysis, there is a requirement to examine the results and to make a judgment on whether the system design is satisfactory or whether it needs to be improved in any way to ensure part integrity. One of the major objectives of solidification simulation and its analysis is to predict the presence of casting defects, primarily hot spots i.e. the locations in a casting which solidify last, which leads to shrinkage related defects and accounts for maximum casting rejections. Simulation allows the foundry men to analyze problems in detail, faster, and at an early stage in the design cycle, thus enabling decisions to be made towards improving design and quality. Therefore, the costs and the risks associated with the trial and error procedure of experimental castings are minimized [10].

The design of casting feeders should be such that it must solidify at the same time as or later than the casting, which has to be satisfied by ensuring that the feeder has a modulus that is sufficiently larger than the casting [11]-[12]. The volumetric contraction of the casting must be compensated by the feeder and thus should have volume greater than the shrinkage volume. At the same time, overdesigned feeders with large safety margins increase the cost and reduce yield (ratio of weight of casting to total weight with feeding system). So, fundamental problem facing foundries is in developing feeder design, which fulfills the need for supplying additional molten metal to the solidifying region with the minimum volume of extra metal. Thus, there is a need to study optimal feeder design and its implementation. There are numerous optimization techniques but selecting and implementing the most efficient one is a challenge. Coupling numerical simulation with feeding optimization technique is one way of adopting a more systematic approach towards casting design and its optimization. This coupling enables visualization of the process of freezing inside a casting and identification of the last freezing regions or hot spots. This facilitates the placement of feeders and feeding aids in order to ensure casting soundness while trying to maximize the overall yield without expensive and time-consuming shop floor trails.

Manufacturing of defect-free components at low cost and high productivity is important for the casting industry today. The major challenges that the industry faces are large number of shop floor trials, high rate of rejection and low casting yield. These can be overcome by adopting solidification simulation technology. The major defects that occur in a casted product are porosity due to shrinkage, blow holes, scars, cracks and misrundefects[13]-[14]. A clear analysis of the causes of these defects is to be known and thus should be prevented to provide sound castings. Thus, these are eliminated by using softwares like AUTOCAST, CREO, CASTPRO are used to check for defects and simulating the casting process. A simulating software by the professors at IIT- Bombay called EFoundry, by virtue of which we can simulate the solid model and generate the hotspot.

Experimental method

Although there are many methods for feeder design, here, we have used Caine’s method for design of the feeder. The mathematical representation of caine’s equation is given as-

$X = (a / Y-b) + c$

Here, X= Freezing ratio

Y= Volumetric ratio

a,b,c= Constant values depending on the metal used in casting process.

Using Autodesk Fusion 360, we first generated the solid model of the stepped shaft as shown *fig 1* and *fig 2*

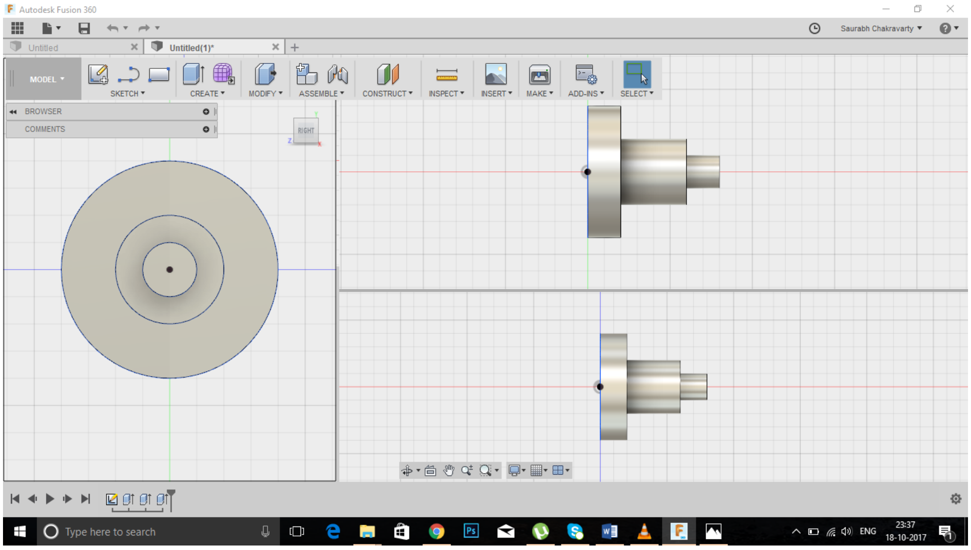

fig 1:orthographic projections of solid stepped pulley (Fusion360)

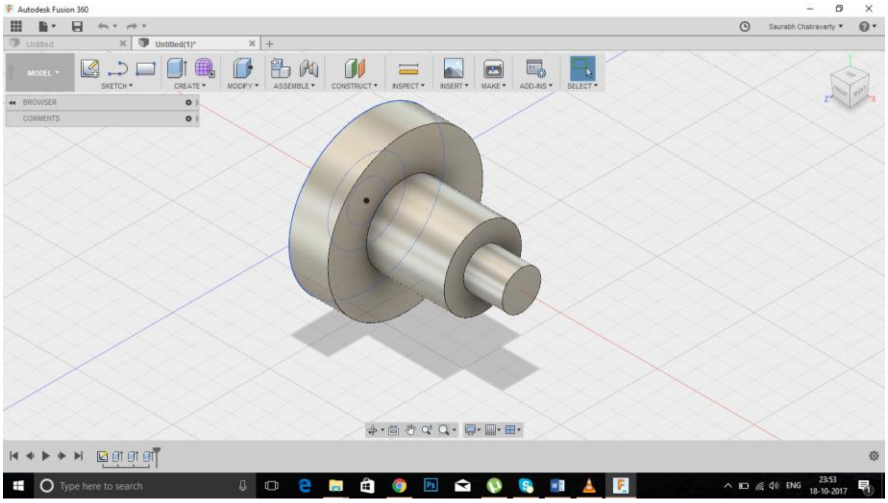

fig 2:Isometeric View of stepped pulley

The solid model is then simulated. After Simulation we observe that the body has mainly 5 types of colours.
1>Blue
2>Red
3>Orange
4>Yellow
5>White

Blue colour shows, the minimum shrinkage and porosity defects that may occur, and as go on with the colours the area covered with orange, yellow and white contains the maximum amount of shrinkage and porosity defects. Thus this area is called hotspot.

Our objective is to design a feeder that can shift the hotspot region from the pattern towards the feeder itself. By this we obtain more defect free casting.

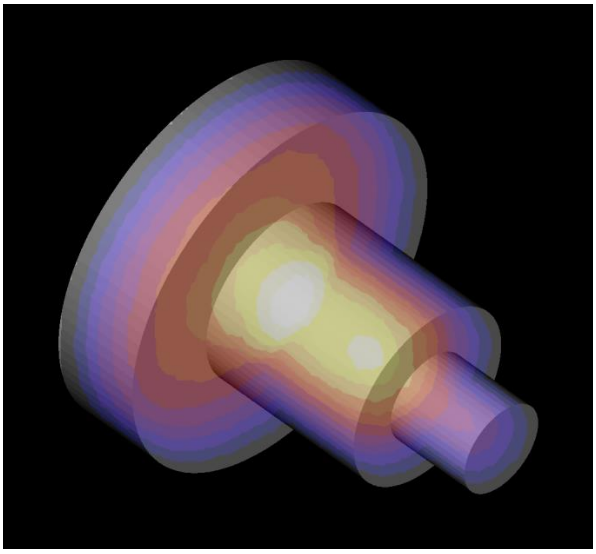

fig 3:Location of hotspots.

After obtaining the hotspots we design a feeder for the stepped pulley using caine’s method. After the designing the stepped pulley and the feeder are assembled, the joint specified is rigid joint ie 0 degrees of freedom for the feeder.

After calculating we obtain the feeder design. Orthographic views of the feeder and pattern is shown in *fig 4.*

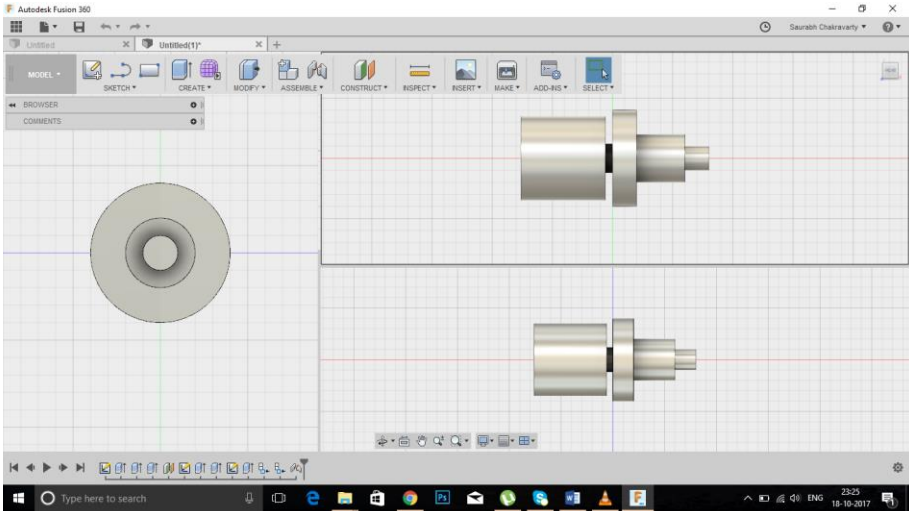

fig 4:Orthographic Projections of feeder and stepped pulley

Below fig 5 shows the isometric view of the assembled feeder and pattern.

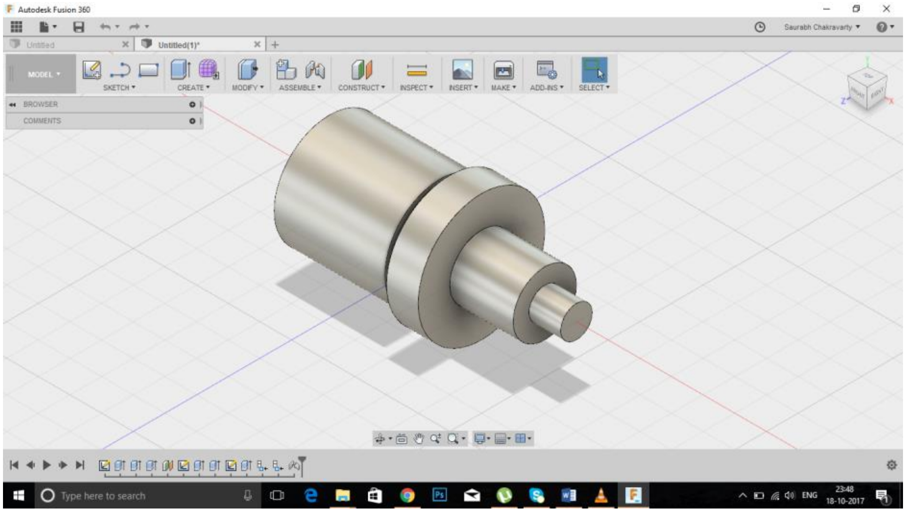

fig 5:Isometeric view of assembled feeder and stepped pulley

The assembly of feeder and pattern (stepped pulley) is then simulated.
The result obtained is shown in *fig 6.*

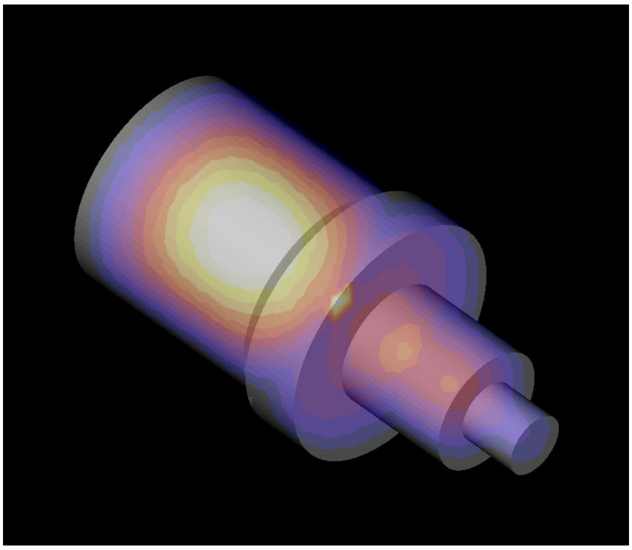

fig 6:Shifting of hotspot from pattern to feeder

As we can observe from fig *6* Hotspot that was previously present in the middle of the stepped pully now has been shifted to the centre of the feeder, Shrinkage and pororsity defects arise more when there is an uneven cooling taking place. After the alignment of feeder we observe that the complete patter is of now blue colour with few red splashes in the middle that shows that now uniform cooling is taking place. Thus, shrinkage and porosity defects in the pattern are reduced.

RESULTS

CASTING

PARTICULARS	VALUES
Mass	53.014 gm
Volume	17671.33 mm^3
Surface Area	5340.708 mm^2

Considering a cylindrical feeder for the pattern.

Assuming height of riser to be half of the diameter
H=D/2
Feeder volume (V_f)
$=1/4 *\pi*D^2*D/2$
$=1/8 *\pi*D^3$

Feeder Surface (SA_f)
$=(\pi*D*H)+(\pi*D^2)/4$
$=(\pi*D^2)/2+(\pi*D^2)/4$
$=3*\pi*D^2/4$

Freezing ratio (X)
$=(SA_c/V_c)/(SA_f/V_f)$
$=(5340.708/17671.33)/((3*\pi*D^2/4)/(\pi*D^3/8))$
=0.05037D

Ratio of the volume of feeder to the volume of the casting (Y)
$=\pi*D^3/8*17671.33$
$=2.22*10^{-5} D^3$

Putting the values of X and Y in the caine'sEquation .
X=(a/y-b) +c
a, b, c are constants they differ from metal to metal.
a=0.10; b=0.06; c=1.08; (for aluminium)
$Y=2.22*10^{-5}D^3$

$0.05037 = (0.10 / (2.22*10^{-5} D^3) - 0.06) + 1.08$

D = 28mm
Considering nearest value =30mm and taking H=15mm

An optimal methods design is highly iterative in nature, requiring considerable technical skills, effort and time, with the advancement in computer technology and use of high end simulation programs; it is now easy to evaluate the effect of feeding system design

FEEDER

PARTICULARS	VALUES
Surface Area	1847.256 mm^2
Volume	8620.530 mm^3

Diameter of the neck(D_n) = 12mm

Length of the neck (L_n) = 12 - (0.2*30) = 6 mm

Modified Surface area of casting = 5340.708 - (π*12^2) = 4888.3186 mm^2

M_c=17671.33 / 4888.3186 = 3.615

M_f=V_f/SA_f= 3.83

Considering it as 4

M_f>M_c

That means the design is safe .Simulating results

By simulating we obtain a slight hotspot to reduce it further Considering D = 35mm and H=D

H=35mm The Final dimensions for the feeder is D=35 mm and H=35mm .

The feed path based optimization tool can only be evaluated for symmetric parts in which a cross section is analyzed for feeder optimization. This approach can be implemented on a 3D environment thereby addressing more complex part geometry.

Conclusion

The selected stepped shaft junction is simulated in Efoundry to locate the hotspot formation. An appropriate feeder is designed using Caine's method and keeping in mind the rules laid out by Campbell for feeder design. The feeder diameter so obtained is 35 mm. The feeder is then added to the geometry and is simulated till the hotspot gets shifted to the feeder itself. The final feeder diameter is 35 mm where the entire hotspot formation is in the feeder itself. The feeder selected is an open type top feeder. The shrinkage cavity in the junction without a feeder is obtained in the form of small amount of porosity holes distributed across the parting line or the core of the junction. This confirms to the hotspot location obtained in the Efoundry simulation. An actual type of cavity as expected is not obtained due to the actual alloy composition whereas efoundry simulated for pure Al.

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