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Impact of Sprue Base in Gating System on Quality of Filling – the Compromise Between Theory and Practice

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Abstract

Foundry technologists use their own style of gating system designing. Most of their patterns are caused by experience. The designs differ from plant to plant and give better or worse results. This shows that the theory of gating systems is not brought into general use sufficiently and therefore not applied in practise very often. Hence, this paper describes the theory and practical development of one part of gating systems - sprue base for automated horizontal moulding lines used for iron castings. Different geometries of sprue bases with gating system and casting were drawn in Solid Edge ST9. The metal flow through the gating systems was then simulated with use of MAGMA Express 5.3.1.0, and the results were achieved. The quality of flow was considered in a few categories: splashes, air entrapment, vortex generation and air contact. The economical aspect (weight of runner) was also taken under consideration. After quantitative evaluation, the best shape was chosen and optimised in other simulations with special attention on its impact on filling velocity and mould erosion. This design (a sprue base with notch placed in drag and cope) is recommended to be used in mass production iron foundries to reduce oxide creation in liquid metal and especially to still metal stream to improve filtration.

Keywords: Casting defects, Simulation, Gating system, Filtration, Bi-films

1. Introduction

The gating system theory was widely examined around the world from different points of view. The general overview and principles can be found in many foundry textbooks [1-4]. The most important task for gating system is providing filling without turbulence in a presumed time. If turbulence occurs, more defects like oxide films, bubbles, dross, slag, and sand inclusions can occur. The more turbulent the flow is, the more defects the casting suffers [5].

More specific examinations on gating systems are based on the impact of: metallurgical quality [6-8], materials used (e.g. filters) [9-12] and different geometries of some parts of gating systems or the whole gating system itself for specific casting [13-20].

Professor's Campbell book [21] is the most complete work about gating system design. Some clues on how to design different parts of gating systems can be found in it. Still, there is the necessity to precise the exact shape of each part of gating system geometry and to customise it to the specific casting. One of described parts is sprue base. Although some tips can be find, the author encourages to make another examinations on this part of gating system.

Biggest part of literature about the design of gating system focuses on inlets and runners [14,15,17,19]. In [15] authors try to reach the most convenient shape of ingates using simulations. The factors that change are runner and ingate width and height. The optimisation criterion is based on three factors – yield, porosity and velocity of metal inside the gating system.

Some part of literature focuses on pouring basin and sprue shape [14,15,17]. In [17] instead of sprue base the L-junction is used. The same geometry is used to connect runner and ingates. That kind of connection gives about 30% loss of speed because of friction. Having this knowledge in mind it is still lack of information about some issues so the article purposes was to clarify some of them.

2. The aim of research

The aim of studies was to find the best design of sprue base for horizontal automatic moulding line for cast iron, especially nodular. Authors know the optimal shape of gating system suggested by professor Campbell [20]. Although the scrap rate received with use of professor's Campbell gating system pattern is extremely low, it is sometimes not economically accepted by foundries, especially those which work in field of mass iron production because technical problems may occur as mentioned below.

One of recommended designs of sprue is conical (tapered down like the stream of metal). It is very valuable, especially for working applications, where the gating system is made by hands and can be fully customised. Unfortunately, in most cases of moulding lines it can not be used at all because of construction of moulding line, in other cases it can lead to drop of production speed. Therefore, most mass iron foundries use conical tapered up shape of sprue. This is obviously wrong pattern as it leads to air sucking into a liquid metal and oxide generation. However, most foundries aim is to have acceptable scrap rate and production speed at once, so they have to accept this compromise.

The question asked by authors sounds: is there a possibility to reduce the oxide generation by sprue base, although the sprue itself is designed incorrectly? To answer to this question was another aim of this article.

Two main criteria for sprue base were chosen: reduction of oxide generation and improvement of filtration ability (reduction of metal speed, assuagement of metal flow before the filter).

3. Methodology

Geometry of gating system with filter was designed in Solid Edge ST9. It was based on FOSECO's filter print for 40x40x15 filter. The gating system was depressurised instead of sprue, which was intentionally bigger to simulate the real behaviour of gating systems used in foundries, as it is explained in Chapter 2. Ratios of gating system cross sections are 2,5 : 1 : 1,3. The areas were shown in Figure 1. Casting was tapered cuboid with dimensions 50x60x100. The only thing that was changed between each version was sprue base.

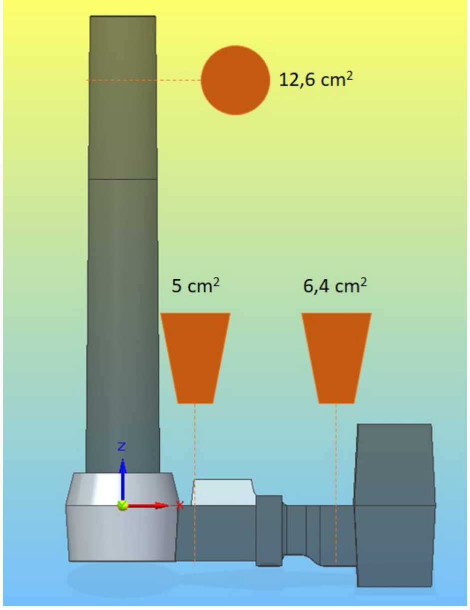

Fig. 1. Gating system design used in all simulations, height of cope is 300 mm; the sprue intentionally widened towards bottom

Different designs of sprue base were implemented into gating system and then simulated in MAGMA Express 5.3.1.0. The number of cavity cells in mesh oscillated between 260 000 and 270 000. In all simulations Automatic Filling Control was used with parameters shown in Table 1. Parameters of metal, mould and filter are shown in Table 1. Following parameters of simulation were used: consider sand permeability, consider water content, consider microstructure of the cast iron. Feeding algorithm used was extended, mould dilatation used was weak mould. Results were taken after each 0,5% step of filling.

Table 1.
Simulation parameters used in all versions

Automatic filling control	
Pouring basin fill level [%]	70
Wait time [s]	0
Filling condition	Maximum flow rate 690 cm^3/s
Handling of pouring basin after filling	Stop pouring at reference volume
Parameters of metal, mould and filter	
Cast alloy	GJS 500
Initial temperature of metal [˚C]	1400
Filter	FOSECO/SEDEX_15mm_20ppi
Sand mould	Green sand
Initial temperature of mould [˚C]	40

After the simulations were made, the results were taken. Criteria used to describe quality of filling were: splashes, air contact, air entrapment, weight of runner, and quantity of vortexes in sprue base. The results were taken from one cross section (2D).

For splashes, the results of velocity were used. Droplets of metal that do not hit the filter got 1 point, for droplets that hit the filter – 2 points, for droplets that stays on filter after 5 steps of results – 3 points. If the stream was flowing on the bottom of filter cavity and then hit the filter with velocity more than 1 m/s the geometry got 3 points, if the stream was not flowing on the bottom of filter cavity and then hit the filter with velocity higher than 1 m/s – 6 points. Also time of above phenomena was calculated and could increase the result. Patterns with low scores were the best.

Air entrapment criteria was calculated by adding each critical point that occurred in steps of time from beginning of simulation to fill of filter cavity. Critical point example was shown in Figure 2. The more critical points the worse the result.

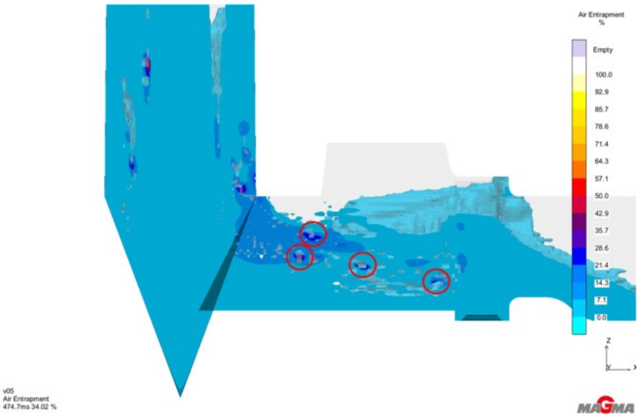

Fig. 2. Critical points for air entrapment; 4 points in one step (critical points calculated only inside filter cavity)

Air contact and weight of runner were taken directly from simulation results and simulation information. Vortex in base were calculated. Vortex occurrence is shown in Figure 3.

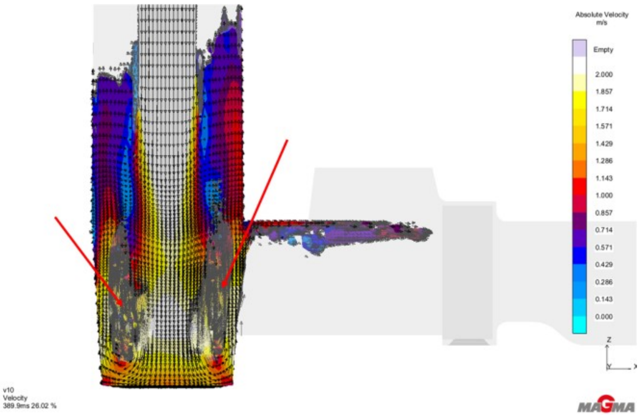

Fig. 3. Two vortexes in sprue base

Simulations were separated in two parts – searching for the best shape and evaluation of the designs used in foundries (v01-13) and improvement of the best geometry (v14-20). For both parts different importance of parameters was used. For second part also mould erosion parameter was taken into account. The less points the pattern received, the better.

4. Description of achieved results

4.1. Searching for the best design of sprue base and evaluation of the shapes used in foundries

Different geometries of sprue bases were shown in Figure 4.

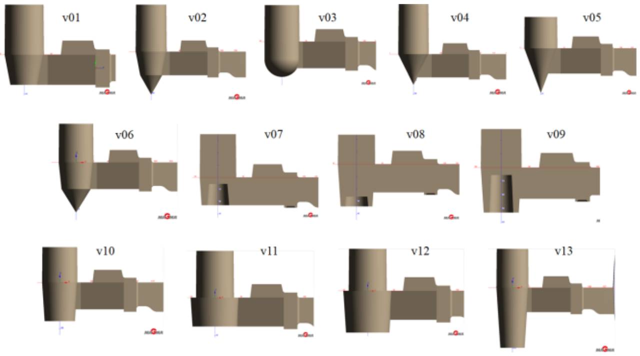

Fig. 4. Sprue base designs in first step

In first step different shapes of sprue bases were compared to each other. The most important factor that was considered in this part of research was occurrence of splashes. Versions v01-06 and 10-13 were commonly used patterns found in foundries, v07-09 were based on literature [21]. The worst and best shapes are compared in Figures 5-7.

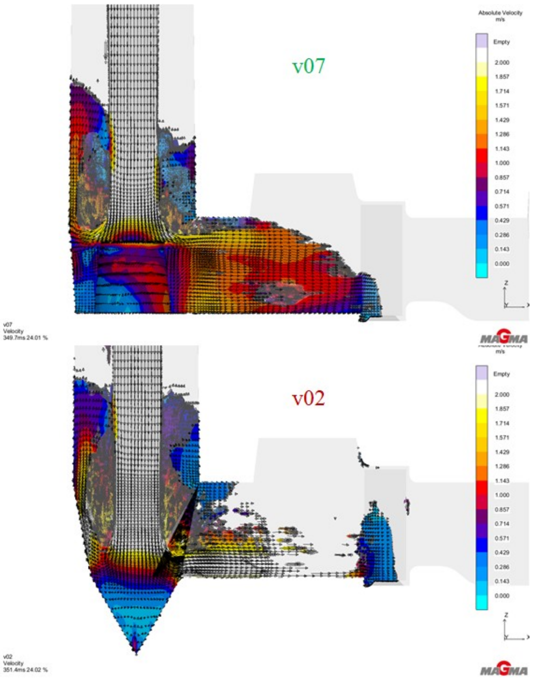

Fig. 5. Splashes comparison – best version v07, worst version v02

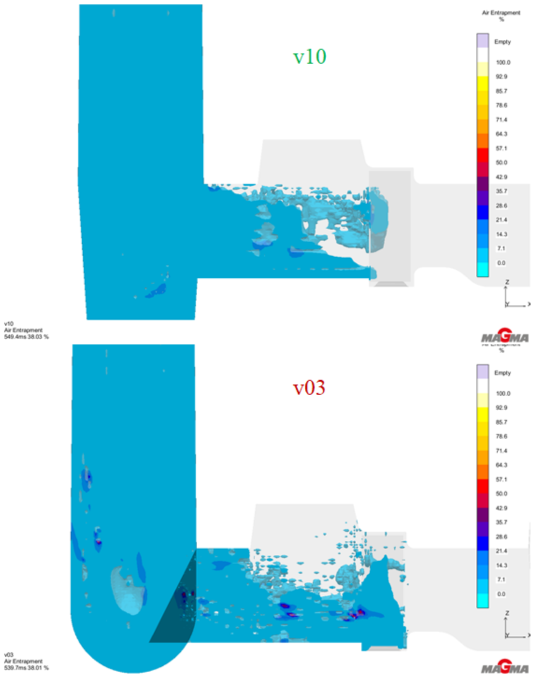

Fig. 6. Air entrapment comparison – best version v10, worst v03

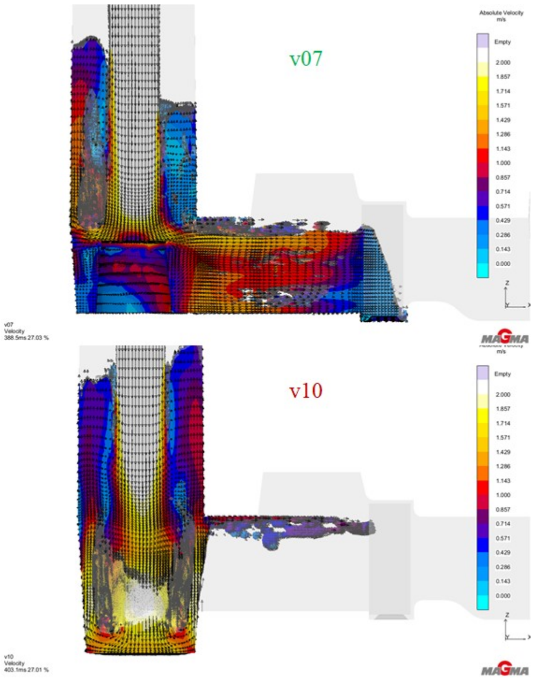

Fig. 7. Vortex comparison – best version v07, worst v10

The comparison of results after quantitative evaluation was shown in Table 2. The scale of results is also shown in the table. The results were ordered from the best to the worst.

Table 2.
Results of quantitative evaluation of simulation results for versions v01-v13. The best results were marked green, the worst - red. S – splashes, AC – air contact, AE – air entrapment, W – weight, V – vortex quantity

Ver	S	AC	AE	W	V	SUM
v07	1	2	3	1	0	7
v09	2	1	3	2	0	8
v04	2	1	4	1	1	9
v05	4	1	2	1	1	9
v06	6	1	2	3	1	13
v10	3	3	1	3	3	13
v01	5	2	4	1	2	14
v08	4	3	2	3	2	14
v12	2	2	1	6	3	14
v13	2	2	1	6	3	14
v11	6	1	2	4	2	15
v02	8	1	3	2	2	16
v03	7	2	4	3	2	18
Scale	1-8	1-3	1-4	1-6	0-3	-

4.2. Improvement of the best design of sprue base

The geometry from v07 was chosen to be improved. The patterns are shown in Figure 8. Designs from versions v07 and v09 were added for comparison. The best and the worst shapes were compared in different categories in Figures 9-11.

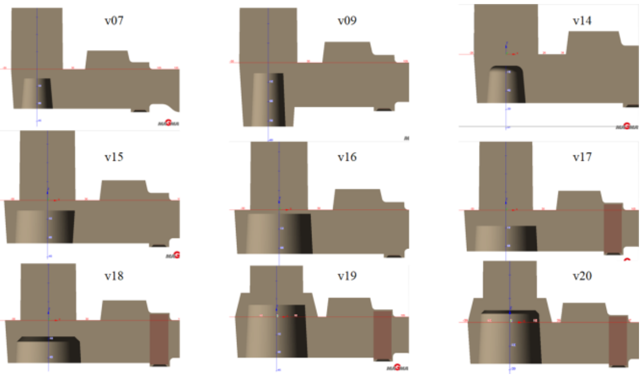

Fig. 8. Sprue base design in second step

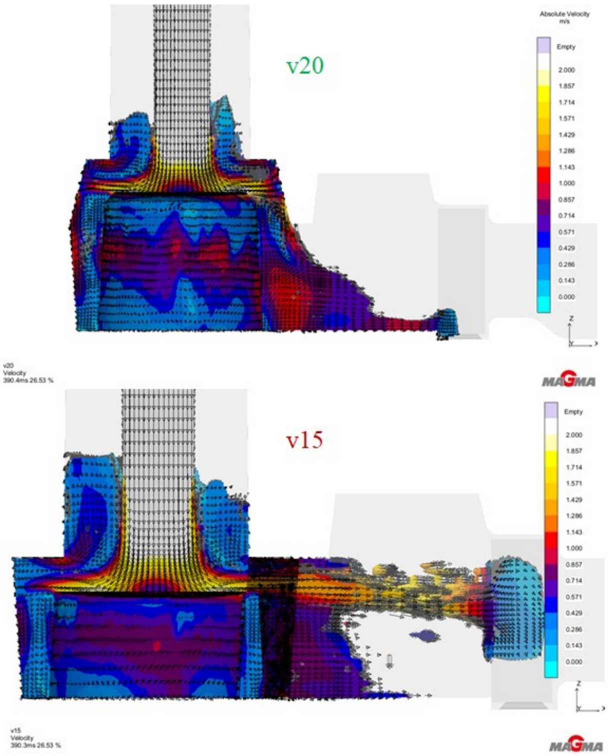

Fig. 9. Splashes comparison – best version v20, worst version v15

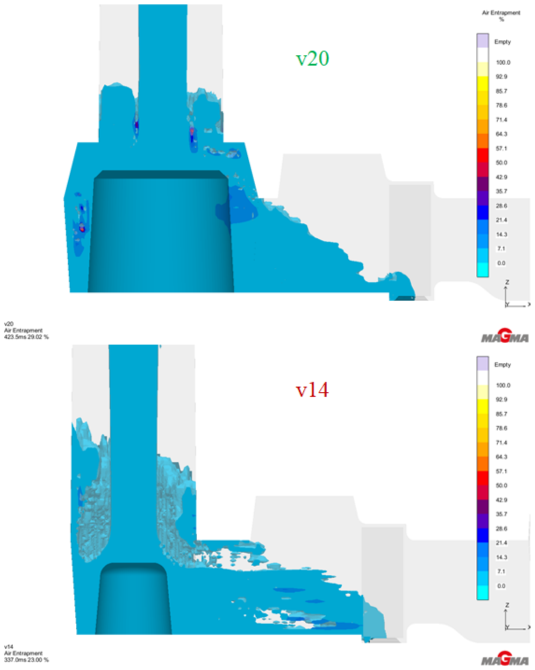

Fig. 10. Air entrapment comparison – best version v20, worst v14

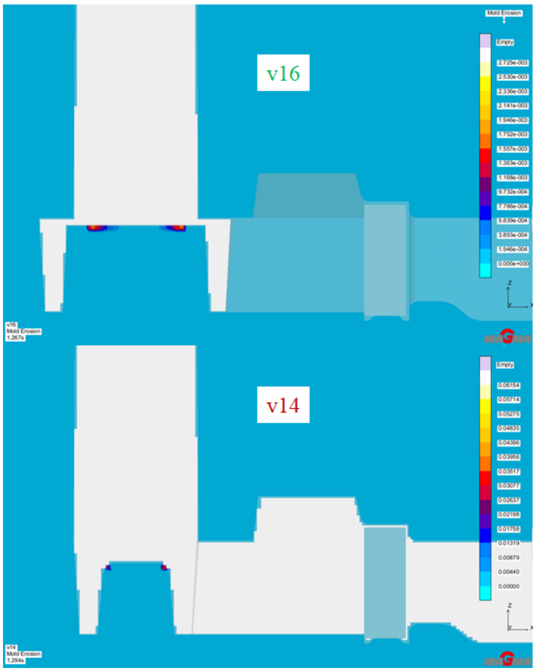

Fig. 11. Mould erosion comparison – best version v16, worst v14

The comparison of results after quantitative evaluation was shown in Table 3. The scale of results is also shown in the table. The results were ordered from the best to the worst.

Table 3.
Results of quantitative evaluation of simulation results for versions v07, v09 and v14-v20. The best results were marked green. S – splashes, AC – air contact, AE – air entrapment, W – weight, ME – mould erosion

Ver.	**S**	**AC**	**AE**	**W**	**ME**	**SUM**
v20	1	1	1	3	1	7
v19	1	1	1	3	2	8
v07	1	3	3	1	1	9
v14	1	1	4	1	3	10
v09	2	2	4	1	1	10
v17	4	2	1	3	1	11
v18	3	1	3	3	1	11
v16	4	2	4	2	1	13
v15	5	2	2	3	1	13
Scale	1-5	1-3	1-4	1-3	1-3	-

5. Conclusions

1. The design of sprue base has significant impact on occurrence of turbulent flow and metal splashes, which can follow with oxide pollution and problems with filtration of molten metal. Although that, sprue has also big impact on oxide generation in gating system. Connection of wrong sprue and correct sprue base can probably lead only to slight

drop of oxide inclusions, although it is hard to predict the scale of reduction.

2. The most valuable shape of sprue base is the one with chamfered notch that is located in both drag and cope (v20).

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