Appendix VIII

Velocity Control in Naturally Pressurised Filling Systems

Since going to press, the development of filling systems continues apace. This short appendix highlights recent developments that promise to be important to deal with the central issues of velocity control in naturally pressurised filling system designs. The appendix summarises the use of (1) filters, using either (i) multiple filters, one at each ingate, or (ii) a single filter at the runner entrance, which are both widely used although the underlying problems of quantification are seen to be elusive at this time. In addition, (2) the new concept of vortex stepped gates, and (3) a new possible simplification of the end-gate is outlined for the first time.

1. Filters in Running Systems

(i). A filter sited at each ingate for large or high value castings.

For large steel castings, perhaps upwards of 250 kg weight, there are good reasons to provide a filling system design in which the entire front end of the fill system should remain a simple and fully naturally pressurised design.

Figure 12.20 shows bottom-gated filling systems that might be used for steel castings. These are not recommended for use without a better distribution, and some velocity controlling mechanism. For instance as drawn, the melt would enter the mould as a jet, mainly through the furthest gate as seen in Figure 12.25 and would hit the top of the mould cavity, finally raining down on the incoming metal, similarly as seen in Figure 11.4.

To avoid such disastrous filling, the flow through the filling channels have to be balanced as described in Section 12.3, and velocity control features, such as filters, are best placed rather late in the system, i.e. at the entrance to the ingates.

The late placement of filters for each gate is an uncomplicated approach requiring no additional work or assumptions regarding the design variables. The siting of a filter near or at the gate has the great benefit that the velocity of the flow in this location is lowest, so that any inaccuracy or error of geometry in the runner/gate junction or filter print will have minimal effect, being a function of velocity $V$, or more probably, $V^2$. In addition, the simplicity of the approach avoids the very real dangers in steel casting of very high temperature metal running in only partly full channels, especially if not sized or moulded perfectly under shop floor production conditions.

The use of multiple filters, one for each gate, is therefore a realistic option and is recommended for large steel castings. Similarly, it is a good option for aerospace light alloy castings, where the additional cost of the filters is negligible compared to the value of the casting (although it is necessary to avoid the danger of one filter happening to prime prior to the others as is discussed below).

(ii). Smaller high volume production castings

For smaller, high volume production castings, the situation is quite different.
For instance costs are usually so critical that such castings usually cannot afford more than one filter, and even the cost of a single filter is usually a problem. Also, no volume production casting can possibly afford the expense of velocity control by a surge control riser system.

Additionally, from a technical point of view, there is the problem that vertical gates each containing a filter require about 50 to 100 mm of head pressure to prime the filter, because Al and Mg alloys are not particularly dense, and the strength of their oxides can add to the priming problem caused by surface tension. Also, the limited height of the mould often gives a vertical height of gates smaller than the 50 to 100 mm required to prime the filter; an ingate height of 50 mm above the filters is a luxury since mould costs are reduced to a minimum. The problem now arises that if one filter happens to prime first because, perhaps, of slightly larger pore size. Melt will then flow through this filter, up to the top of the ingate, but failing to prime the remaining filters that act to block the flow. The first ingate therefore continues to fill the base of the casting before the other filters prime, with the result that the remaining ingates fill from the top downwards, the metal raining down on to the top of the filters. The effect is illustrated for two gates in Figure A7. Since all the gates appear to be fully cast after the casting has solidified it is not easy to discern by visual inspection that a problem has occurred.

A gate that is taller than 100 mm above its foam filter should experience sufficient pressure to ensure that priming happens on every occasion. Tall gates are recommended.

**A single filter at the runner entrance**

The problem of cost is reduced and the danger of irregular priming is avoided by the use of a single filter at the entrance to the runner.

However, the filling system as a whole is now greatly affected by the insertion of a filter at this early site in the filling system. Furthermore, these changes have not been fully quantified at this time, so that guidelines to avoid problems are not yet properly formulated to assist the methoding engineer, as is explained below.

On falling back on shop floor experience of the action of filters, I have suggested in Chapter 13 that the introduction of a foam filter can reduce the velocity by a factor of 5, but to maintain pressurisation downstream of the filter, the runner should be expanded by only a factor of 4 or less. However, these factors are not as secure as one might wish as is explained below:

The siting of a ceramic foam filter in a channel of a running system will reduce the flow rate as a result of the two factors:
1. A reduction of the total cross sectional area for flow by approximately 15% (a 10 ppi reticulated ceramic foam filter has an 85% pore volume).
2. Frictional loss. This is currently unknown, but might be at least a further 15%.

Thus the volume flow rate Q may be reduced by a total of approximately 30%. This would be revealed by an extension of the fill time by 30%. (Extension of the fill time is usually not serious unless the filling of thin sections may be threatened.)
If, in isolated observations of generally non-pressurised flow conditions, the velocity of flow
through a filter is actually reduced by approximately a factor of 5, and if $Q$ is reduced by a
factor of 1.3, it follows that after the filter the area of the flow channel might be expanded by
a factor of $5/1.3 = 3.85$.

If the filter had been placed in a filling system calculated to be naturally pressurised, it
follows that the area downstream of the filter should remain (just) naturally pressurised after
this expansion of 3.85. Clearly a factor of 4 expansion is slightly too much, and pressurisation
might be lost. Fortunately, even if pressure is in fact lost, the danger here is much reduced as
a result of the much reduced velocities. Even so I now recommend factors of expansion less
than 4 as a result of this correction.

Unfortunately, the uncertainties in the sizing of the runner downstream of the filter has been
compounded by recent observations by Hsu and Lin (2011) who have investigated the flow of
liquid aluminium alloy in a runner from a 300 mm high sprue, giving a velocity of 2.45 m/s.
After the introduction of a 10 ppi foam filter the velocity fell to 0.86 m/s, a factor of only
2.85. This may have been the result of using the 10 ppi variety of filter rather than the 20 ppi
that I often find myself using (a change from 10 to 20 ppi would be expected to change the
pore diameter by approximately a factor of 2, and the total pore area will fall, significantly
raising the viscous friction that the flow would experience). Furthermore, these authors found
the total filling time to be not merely 30% longer, but closer to 100% longer. These results
highlight the lack of certainty regarding the precise values to use, giving serious cause for
concern. Further research on this subject is very much needed.

In the meantime, despite these uncertainties, I continue to believe the approach to expand the
runner downstream of the filter is correct, and in the absence of better information, I continue
to recommend an expansion in the region of 3, or 4 at most. We may need to recognise that
these values may apply to filters in the region of 20 ppi, and may need to be reduced
somewhat, perhaps to values in the region of 2.5 to 3, for 10 ppi filters.

However, the complications introduced by the use of a filter early in the runner system are
not over. New dangers can now occur downstream. These include

1. The melt may not initially fill the expanded channel, but simply run along the bottom
   of the newly expanded runner, only reaching the correct velocity when the whole
   channel is finally filled. The maximum height of runners should not exceed the
   height of the sessile drop, or should run uphill, so that the runner fills completely.

2. The upper parts of the filter may jet metal, thus oxidising and contaminating the
downstream melt, as a result of the channel being unfilled to the top, exposing the top
of the filter for an extended time. At the time of writing the phenomenon of jetting
from the back faces of filters has not been researched. Thus it is not known whether
the problem is a sensitive function of either pressure from the height of the sprue or
volume flow rate $Q$. To avoid this problem it is necessary to ensure the design of the
filter print uses gravity to cover the exit side of the filter quickly as is discussed in
some detail in Section 12.8.

Ultimately, it is regrettable that we have too little information on filters. For this reason, if I
can, I always try to avoid using a filter, not merely to reduce costs, but more importantly, to
avoid introducing uncertainty into the behaviour of the filling system.
Despite these concerns, I often meet the situation where the filling system is insoluble without a filter. This would, I expect, never happen for reasonably large steel castings, but in my experience happens in at least 50% of the time with light alloys.

2. The Vortex Stepped Gate

If the high speed flow in the runner is directed tangentially into the base of a cylinder, the melt will circulate around the wall of the cylinder, advancing in height at a rate, on average, that will be reduced by the ratio of the cross sectional areas of the channel to the cylinder. Thus a runner entering tangentially into a vortex cylinder of 10 times its area can expect an overall velocity reduction in a vertical direction of a factor of 10. This is the concept of the vortex gate. The simple ratio of areas does not take any account of an expected further reduction in outlet speed because of loss of energy within the vortex.

The concept has features in common with the concept of the surge control system.

However, the tangential entry of the melt is not easy to get accurate. Small errors of alignment will cause the impact of the liquid on the walls of the vortex cylinder to create a severe upward jump. Such unwelcome flow behaviour can be controlled by providing a groove, or step, around the base of the cylinder. Puhakka (2011) found that the melt entering this confined channel is prevented from jumping into the mould cavity by the upper part of the channel (i.e. the ‘step’). The concept of the ‘step’ is analogous to the step in the offset step basin, in which the action of the step is to encourage one part of the filling system to prime completely prior to the melt entering the next part of the system. It is significant that the use of the step was adopted from the start in early developments by Hsu and colleagues (2005).

The upper part of the vortex cylinder connects to the mould cavity by either a cylindrical gate as used by Hsu or a slot gate as used by Puhakka. In both cases the transition between the cylinder and the slot is relatively smooth, as illustrated in Figure A8.

Preliminary work by Bob Puhakka indicates that the total volume of the vortex gates should be in the region of Q, the volume per second filling rate for the casting. Thus for 2 vortex gates, each vortex would contain a volume of Q/2. This system clearly makes excellent steel castings as Puhakka has shown.

3. The End Gate

Figure 12.34b shows a fan-shaped end-gate design that is valuable, causing the metal to diverge, reducing its entry velocity into the mould without undue damage to the liquid. Figure A8 shows this classical fan-shaped design, alongside a new, simpler, rectangular design that appears to work practically as well, although little investigative work has been carried out so far.

Comparison of velocity-reducing gate designs

At this time it is not known which of the various gate designs, the filter, the vortex, or the different varieties of end-gate are the most effective in reducing the speed of entry to the mould and at the same time reducing damage to the melt. It seems possible that different
techniques may be required for different runner velocities. These open questions are important to answer.

Acknowledgement.
For Appendix V, I am indebted to steel founders (i) Bob Puhakka for a critical exchange of correspondence relating to vortex gates (For additional details a formal paper is planned for publication; in the meantime Bob’s web site www.castdifferently.com is recommended); (ii) Ian Furniss and Samuel Scholes of the UK foundry Furniss & White regarding practical and computing initiatives relating to end gate design.
Mould

Ingate

Filter

Runner

Filter successfully primed

Filter failed to prime due to limited head h
Fig A5.2