Reduced energy consumption by using streamlined gating systems

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**Abstract:** In foundries a lot of effort is done to minimize energy consumption in the production to reduce costs and hence increase the competitiveness. At the same time the foundries must live up to the increased demands for high quality castings.

Traditional gating systems are known for a straight tapered down runner, a well base and 90º bends in the runner system. Previous work has shown that the traditional way of designing gating systems creates high inconsistency in flow patterns during filling. In the streamlined gating systems there are no sharp changes in direction and a large effort is done to confine and control the flow of the molten metal during mould filling.

The main objective in the work presented here is to use the principles of the streamlined gating systems to reduce the weight of the gating system relative to the traditional layouts. By reducing the weight of gating system and thereby improving yield, the amount of molten iron needed is also reduced, hence reducing the energy consumption for melting.

Experiments in real production lines have proven that it is possible to achieve a reduction in the poured weight by using the streamlined gating systems. In a layout for casting of three valve housings in a vertically parted mould the weight of the gating system was reduced by 1.1 kg changing from the traditional layouts to the streamlined gating systems. This weight reduction corresponds in this case to a 20% weight reduction for the gating system.

Using streamlined gating systems with fan gates to give a beneficial heat distribution in the castings may be an efficient tool to eliminate the need for heat treatment. In the experiments the change in gating system from the traditional layout to the streamlined layout removed the need for heat treatment. This obviously means a huge energy saving in the foundry. The energy consumption for heat treatment of iron has been found to be 0.489 kWh/kg. The valve housing in the experiments weighs 3 kg so when the need for heat treatment is removed, around 1.5 kWh is saved per casting. Along with the reduction in energy used the foundry also save the cost of handling the castings for the heat treatment and the production times is reduced considerably.

When the moulds for the vertical layout is produced on a DISAMATIC that produces 350 moulds an hour the total energy saved per hour for both melting and heat treatment becomes 2,000 kWh and per eight hour work day 16,000 kWh. Seen in this perspective the potential for saving energy in the foundries is substantial.

Furthermore the experiments where ductile iron valve housings was cast also proved that it is possible to lower the pouring temperature from 1,400ºC to 1,300ºC without the risk of cold runs. This is possible due to a high flow rate during mould filling in combination with low velocities due to the use of fan gates. All of this has also been investigated in experiments using glass plate fronted moulds.

**Key words:** streamlined gating systems; energy consumption; mould filling; weight; layout

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1 Principles in the traditional gating system

An example of a traditional layout for a gating system can be seen in Fig.1. This layout represents the original layout for casting a valve housing using a DISAMATIC automatic moulding machine.

It is typical to use the cross sectional area \( A_1 \) as the governing area. This means that \( A_1 \) is used as a basis to define all the remaining cross sectional areas. Other places in the gating system can be used for the governing cross section instead, but the exit of the down runner is very commonly used. \( A_1 \) can be calculated using Equation 1.

**Equation 1:**

\[
A = \frac{G}{t \cdot \rho \cdot (1 - m) \sqrt{2 \cdot g \cdot h}}
\]

Where:

- \( G \): Weight of casting and runner after the chosen cross section;
- \( t \): Filling time for the casting and runner after the chosen cross section;
- \( \rho \): Density of the melt;
- \( h \): Height of down runner;
- \( g \): Gravity acceleration.
To achieve a realistic result when calculating $A_1$, a loss factor $m$ related to the velocity is necessary. This factor can be seen as representing the percentage of loss in velocity due to friction between melt and mould wall and due to pressure drop. The value for the loss factor is based upon experience, but the value 0.5 is normally used.

The relation ship between the areas in two cross sections $x$ and $y$ in the down runner can be found if the principle of continuity in Equation 2 is used giving Equation 3. This equation is to find the area for the cross section $A_y$ and sometimes depending on experience in the foundry furthermore expanded by 20%–25%.

Equation 2: $A_x \cdot v_x = A_y \cdot v_y$

Equation 3: $A_y = A_x \frac{h_x}{h_y}$

The cross sectional areas $A_x$ and $A_y$ in the horizontal runners seen in Fig. 1 is normally found by multiplying the area at the base of the down runner $A_1$ by a factor between two and six depending on the alloy and experience in the foundry.

In the previous section some of the downsides of the traditional gating system were pointed out. To avoid these problems a more streamlined approach in the gating design is needed. An example of a streamlined gating system can be seen in Fig. 2. It should be mentioned that the valve housing here have also

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2 Principles in the streamlined gating system

In the traditional gating systems, 90° bends in the running system is another characteristic. These bends are known to cause the formation of vena contracta resulting in air entrapment and oxide formation. A well base at the bottom of the down runner can help to avoid some of these problems, but it is not always sufficient and the problem might still occur.

It is common to use dead-ends in the horizontal runner in the traditional gating systems in an additional attempt to reduce the velocity of the melt. It has been shown although this approach does not work very well. When the melt reaches the dead-ends in the horizontal runner, a pressure shock upwards into the in-gates is formed. In the traditional layout here the pressure shock results in a jet of melt into the feeders.

One characteristic that the traditional gating systems are known for is that flow patterns in identical moulds are never identical even though experiments are carried out under identical circumstances.
been optimized compared to the castings in the traditional layout and therefore the need for feeding has been reduced. The basic idea behind the streamlined gating system is to use the surface tension and boundary layer friction of the molten metal to keep the front of the flowing molten metal coherent during the mould filling. This is done primarily by keeping the runner width as small as possible. In addition to this, all 90° bends are avoided and more soft curves are used instead. In this way it has been shown that it is possible to keep the runner system filled at all times.

When using Equation 1, one of the basic assumptions is that the gating system is kept full at all times. However, in most cases using the traditional layout this is not the case often due to vena contracta that creates an artificial choke. This often means that the pouring time becomes longer than anticipated leading to cold runs, air entrapments, oxide formation and other defects. It also, in many cases, means that the solution to the problem is to enlarge the down runner leading to an increase in the poured weight.

When designing the down runner in the streamlined gating system the same equations are used as for the traditional layout. The area $A_1$ is found using Equation 1. But when designing the rest of the down runner Equation 3 is used with much smaller steps from top to exit. The aim is to achieve a down runner with geometries as close to the theoretically correct shape as possible.

The in-gates in the streamlined gating systems are designed in the same way as fan gates used in high pressure die casting. These types of in-gates are being used in the streamlined gating systems because they have proven beneficial in two ways. First of all the loss factor is increased. Secondly the fan gates gives uniform melt velocities over the cross sections and the front of the flowing molten metal is kept coherent.

In the streamlined gating system turbulence has been decreased by pouring directly into the filter. More important is the part of the gating system just below the filter. In order to keep the down runner filled at all times during filling it is necessary to be sure the cross section at the very top is filled. If this is not the case it is not possible to keep the rest of the down runner filled. By using some of the principles once again from the design of fan gates in the design of a funnel a full down runner is achieved.

However it is important to emphasise that no matter what principles are used for the design of the gating system and pouring cup it is not possible to maintain the down runner full through out the mould filling if the initial melt is not sufficient to fill the top cross section of the down runner and keep this section full.

3 Filling simulations and comparison of the two layouts

Simulations have been done for both the traditional and the streamlined gating systems. Selected parts of the results from these simulations are presented in the following. Simulations have shown that the thickness of the centre flange in the valve housing can be reduced by 50%. This leads to a decreased need for feeding hence smaller feeders in the streamlined gating system. Comparing the results from the traditional and the streamlined layout it is important to notice that the volumes of the castings, feeders and gating systems are not the same. This means that 10% filled in the traditional layout is not the same as 10% filled in the streamlined layout, so the percentages filled cannot be compared directly.

3.1 The traditional gating system

The simulation results from Fig.3 reveal many problems in the flow pattern. First of all is it clear that it is not possible to keep the down runner full. The down runner backfills and is actually not full till 22% filled. At approximately this time two jets are also seen inside the feeders. These jets could be seen as a result of the disappearance of the vena contracta in the down runner, but also as a consequence from that the dead ends in the horizontal runner are filled. At 30% filled the jets have calmed down and the melt starts to flow into the castings. The feeder necks are attached to the centre flange which means the first melt that enters the castings will drop half the height of the casting. This will again cause turbulence and air entrapment. Normally for ductile iron a drop of this height will not be considered a problem. Once the level of melt reaches the height of the feeder necks the remaining part of the filling is very calm. The flow pattern during the filling leaves some very distinct temperature gradients which will cause non-uniform material properties in the casting. Normally to achieve better and uniform mechanical properties the castings would be heat treated.

3.2 The streamlined gating system

It is seen from Fig. 4 that the flow pattern of the first melt to enter the castings in the streamlined gating system is very calm, and it also is clearly seen how the fan gates help to spread out the flow of melt around the core. The remaining of the filling is just as calm and the melt enters the feeders not simultaneously but almost.

The temperature in the feeders at the end of the filling is seen in the traditional layout to be around 1,380 °C whereas the temperature in the streamlined layout is found to be around 1,340 °C. So the difference in temperature in the feeders is only around 40 °C even though the feeders in the traditional layout are hot and in the streamlined cold. The reason that the feeders are not colder in the streamlined layout is the high flow rate reducing the loss of heat during mould filling. The temperatures in the final results from the filling reveals a much more even temperature distribution in the castings than what was seen in the traditional layout. This is due to the flow pattern during filling which gives a more beneficial heat distribution and hence more uniform material property in the castings.
4 Experiments with glass plate fronted moulds

To get a clearer picture of the flow patterns during the mould filling, experiments were carried out with glass plate fronted moulds. The idea is that one half of the mould is replaced by glass. In this way it is possible to film the mould filling. A picture of the mould can be seen in Fig. 5. The streamlined gating system is symmetric at the parting line so there should be very little or no difference in the flow patterns between the experiments with half a mould and an entire mould. To be able to mount the glass plates on the mould, special halved cores were made. In Fig. 5 the cores are seen when placed in the mould. The pressed filter is seen at the top, just above the
funnel. Part of the results from one of the glass plate fronted moulds can be seen in the following.

In streamlined gating system with pressed filter, the mould filling time in these experiments was found to be between 4 and 6 seconds. This corresponds very well with the pouring time of 4.1 seconds for the entire mould. It should be taken into account that some of the glass plates break during the filling so that some of the melt is spilled which of course prolongs the filling time.

Comparing the results from the simulations and from experiments using glass plate fronted moulds reveals a very good accordance in flow patterns.
5 Experimental casting using the streamlined gating system

The production facilities at Dania A/S include two DISAMATIC 2013 MK5. The details for castings using the traditional layout are taken from the normal production of the valve housings. The melt is poured at a temperature of approximately 1,400 °C. The pouring time for this layout was found from the automatic pouring device to be 6.5 seconds. The castings are all made of ductile iron grade EN-GJS 400-15.

The streamlined gating system was tested in the same way as if it was used in the real production. Just like for the traditional layout the castings are all done using ductile iron grade EN-GJS 400-15.

Fig. 5 In the picture a mould used for the experiments using glass plate fronted moulds is seen

Fig. 6 Streamlined gating system – A pressed filter is used
The automatic pouring device was used with a new ladle of molten iron, enough for about 50 moulds. The time from the magnesium treatment of the melt to the last mould poured was 18 minutes, which is just below the 20 minutes which are normally allowed in the foundry. If more time is used, too much magnesium evaporates from the melt and the microstructure of the castings will not be approved. To be sure that the melt lived up to the requirements, samples were taken for analysis.

6 Comparison of the traditional and the streamlined layout

6.1 Reduction in pouring time
The traditional layout has a pouring time of 6.5 s whereas the streamlined layout has a pouring time of only 4.1 s. Often the pouring time is critical when using automatic moulding machines like the DISAMATIC used in these experiments. If the pouring time is too long, it will slow down the moulding machine, reducing the overall production capacity in the foundry. Therefore this possibility of reducing the pouring time considerably by using streamlined gating systems, but also by improving the casting and the feeders without reducing the quality of the castings, can be of great economical value to the foundry.

6.2 Reduced minimum pouring temperature
Normally it is desired in most iron foundries to have a pouring temperature of around 1,400 ºC. However the pouring temperature for the experiments using the streamlined gating system starts at 1,385 ºC. The reason for this rather low temperature was that the magnesium treatment ladle had not been used prior on the day of the experiments and the temperature of the ladle was low. The time it takes from the magnesium treatment to the last mould poured is 18 minutes. In this time the temperature in the automatic pouring device that is not heated decreases to 1,268 ºC. This temperature would normally be considered as much too low and cold runs would definitely be expected. The experiments proved, however, that this was not the case. No cold runs were found, and in fact it was not possible afterwards to tell the difference between the castings from the beginning and the end of the experiments.

6.3 Reduction in poured weight
Results from the layouts can be seen as cast in Fig.7. The weight reductions are summarized in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Traditional layout</th>
<th>Streamlined layout</th>
<th>Weight reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total poured weight</td>
<td>19.7 kg</td>
<td>15.5 kg</td>
<td>4.2 kg</td>
</tr>
<tr>
<td>Weight of gating system</td>
<td>5.6 kg</td>
<td>4.5 kg</td>
<td>1.1 kg</td>
</tr>
</tbody>
</table>

It was found that the poured weight of the traditional layout is 19.7 kg and the poured weight of the streamlined layout is 15.5 kg. This means a total reduction in poured weight of 4.2 kg. The weight of the gating systems, meaning the layouts without the castings and the feeders, was found to be 5.6 kg for the traditional layouts and 4.5 kg for the streamlined layouts. So the weight reduction for the gating systems is 1.1 kg.

6.4 Handling of the as-cast layouts
A parameter in the evaluation of how well a layout performs in the production is how easy it is to remove the feeders and the gating system from the casting. Especially it is important
that operations are necessary to remove feeders. In the case study here where the traditional layout is being cast, the gating system itself is easily removed. The gating system is often but not always seen to break off in the shake out. If the gating system does not break off, it obviously takes an additional operation. The removal of the feeders is more difficult. The feeders need to be cut off. They are positioned on a round surface, which makes it more difficult to remove them without damaging the valve housing than if it had been on a flat surface.

Removing gating system and feeders in the streamlined gating system in this case study is a bit more complicated. The use of round fan gates has the effect that the gating system does not break off and hence needs to be cut off. The removal of the feeders is more or less the same as for the traditional layout. So in total, in this example the cost of using the streamlined gating system is that a possible operation of breaking off the gating system has been replaced by the operation of cutting off the gating system. Beside this the cost should be the same for the two layouts. Had the fan gates been flat, it would also have been possible to simply break off the gating system in the streamlined gating system as well.

6.5 Machining of the castings

Normally with the traditional gating system the castings would be heat treated prior to machining. This is done to achieve more uniform material properties so that the difference in especially the hardness of the material is not too large. This is important for reducing the tooling cost at the machining workshop. In this project the aim is to design gating systems so that the temperature field in the castings after mould filling is more uniform than with the traditional gating system. In this way the material properties will be more uniform and it will not be necessary to have the castings heat treated. To see if this was the case, the castings from the streamlined gating system were machined with no heat treatment at the workshop at Dania for evaluation. The following was reported from the workshop: During the turning process of the two ends, the wear on the tooling was increased by 15–20% having the same operation time compared with the traditional heat treated castings.

The conclusion for this part of the experiment was that using the streamlined gating system heat treatment is no longer necessary. The extra cost from the increase tool wear during the turning process is much less than the cost of heat treatment and hence does not make the heat treatment economical viable.

7 Conclusions

A gating system for a valve-housing was designed using the principles for streamlined gating systems and the result was investigated and compared to the result of a traditional gating system. It was proven that the weight of the gating system excluding feeders was reduced from 5.6 kg to 4.5 kg. This reduction in poured weight of the gating system of 1.1 kg indicates the amount of the reductions in poured weight that can be expected in other similar examples. One part of the weight reduction is due to the difference in the placement of the ceramic filter from the traditional layout to the streamlined layout, but the major part is due to the weight reduction in the runner system itself. The experiments also proved possibilities of reducing the pouring temperature by 100°C and of avoiding the need of heat treating the castings.

The energy saved per mould in this vertical layout is seen in Table 2. Only the weight reductions in the gating systems are used. The value for the heat treatment is based on all three valve housings in the layout being heat treated.

Table 2 The energy saved for the two layouts per mould

<table>
<thead>
<tr>
<th></th>
<th>Vertical layout</th>
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<tbody>
<tr>
<td>Energy saved for melting</td>
<td>1.31 kWh</td>
</tr>
<tr>
<td>Energy saved for heat treatment</td>
<td>4.40 kWh</td>
</tr>
<tr>
<td>Energy saved in total</td>
<td>5.71 kWh</td>
</tr>
</tbody>
</table>

When the moulds for the vertical layout is produced on a DISAMATIC that produces 350 moulds an hour, the total energy saved per hour for both melting and heat treatment becomes 2,000 kWh and per eight hour work day 16,000 kWh. The price of 1 kWh in Germany is approximately 0.1 EUR leading to savings of 1,600 EUR per 8 hour workday. Seen in this perspective the potential for saving energy and hence money in the foundries is substantial.