PREDICTING AND ELIMINATING DEFECTS IN INVESTMENT CASTINGS USING COMPUTER SIMULATION

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ARTICLE TAKEAWAYS:

- Computer simulations make good rigging design fast, thorough and highly accurate
- Learn about the 5 steps in the design process

INTRODUCTION

Computer simulation makes it possible to synthesize elements of good rigging design into a general method that is fast, thorough and highly accurate. And, because of the automation involved, this tool allows new foundry engineers to effectively design casting process methods.

The design process consists of these steps:

- Simulation of the 'Naked' Casting
- Gate Sizing and Feeding Design
- Rigging Geometry Creation
- Verification via CFD/Solidification Simulation

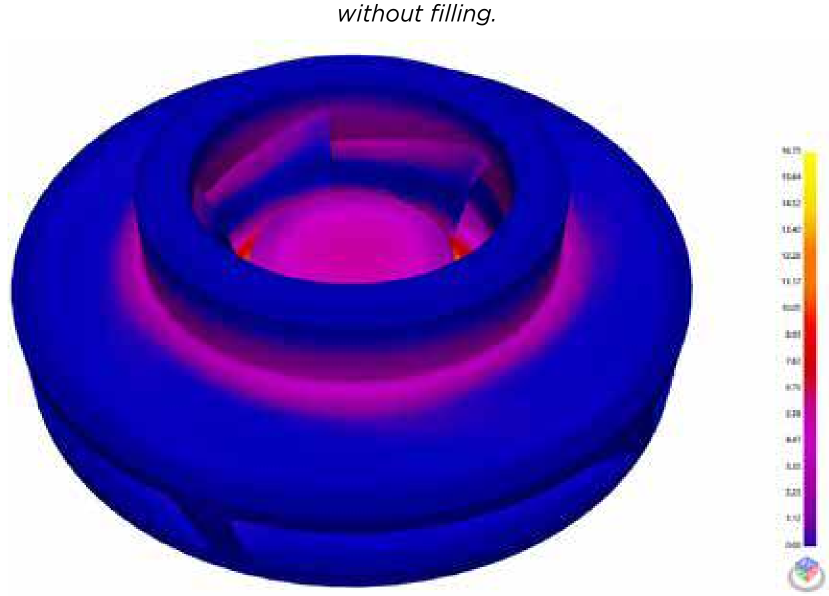
'NAKED' SIMULATION

The first step in the rigging process is to run a simulation of the part 'naked'; without any rigging system. Simulation shows the effects of part geometry on the overall solidification. Filling analysis is typically not done, providing extremely rapid results, and can point out preferred gate locations which promote directional solidification.

All that is required for the initial simulation is a casting model, normally provided by the customer in the STL file format, and basic process details such as casting alloy, shell material/ thickness, pouring temperature and shell pre-heat temperature. Our example of a commercial part is an impeller casting. Unrigged simulation results are shown in **Figure 1**.

Once the unrigged simulation is complete, solidification data is converted to thermal modulus information, and feeding zones are determined. In this case, two zones are predicted; one on the top and one on the bottom of the casting. By plotting the higher modulus areas, we can find the preferred gate attachment points. The feeding zones and last points to freeze on each zone are shown in **Figures 2 and 3**.

__Figure 1:__ STL model of an impeller casting. 'Naked' simulation results, without filling.



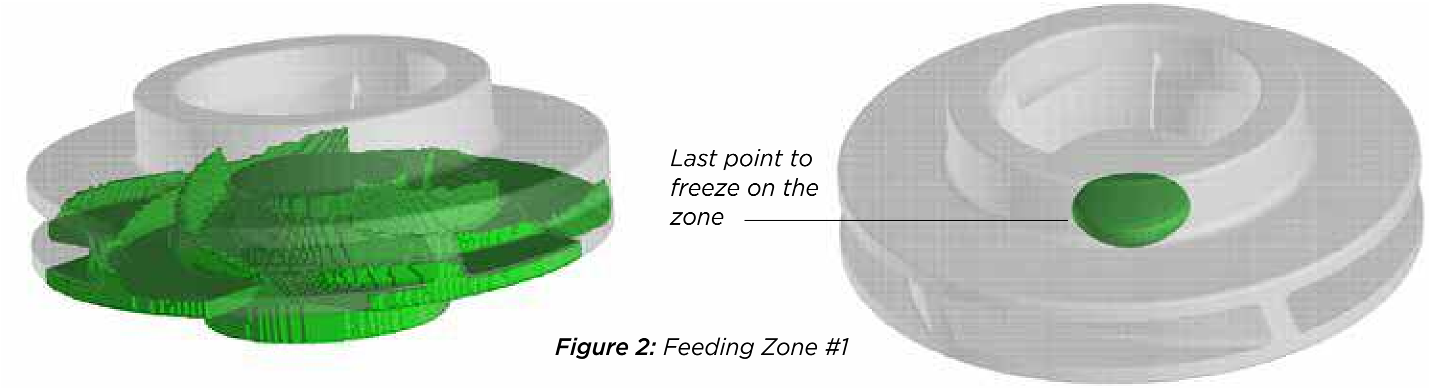


Figure 2: *Feeding Zone #1*

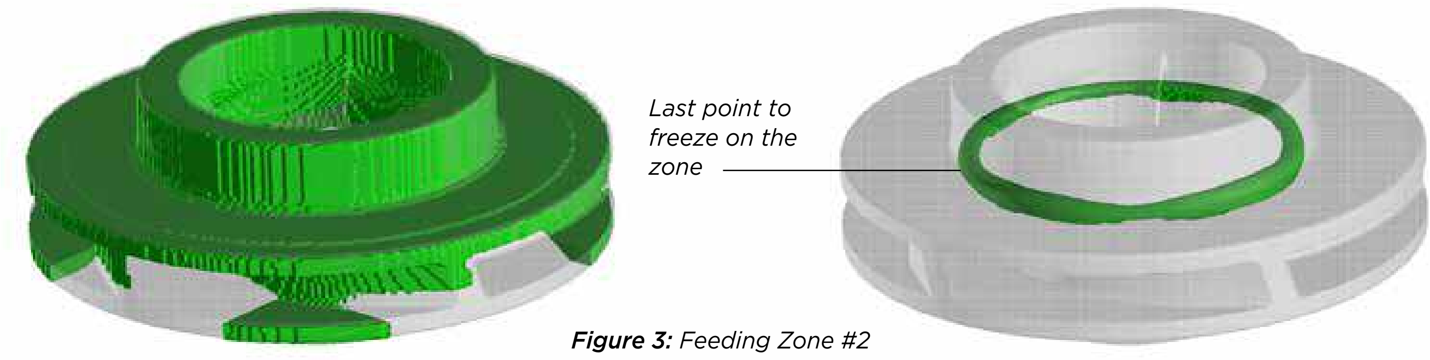


Figure 3: *Feeding Zone #2*

GATE AND FEEDER BAR DESIGN

Gate and Feeder Bar sizes for each feeding zone are calculated using the thermal modulus. This takes into account not only casting alloy and shell material, but also the solidification dynamics of the specific situation, including the use of insulating materials such as Kaowool or Fiberfrax wrapping.

Guidelines for gate and feeder bar sizing are given in **Figure 4**.

Once we know the maximum modulus in the feeding zone, we can calculate the appropriate size for a tapered gate, as well as feeder bar dimensions that will adequately feed that part of the casting. This calculation is done in the Riser Design Wizard, which was originally developed to calculate cylindrical risers for the sand-casting process. However, it provides good information for investment castings, too. An example of the wizard screen is shown in **Figure 5**.

Gate and Feeder Bar Sizing

- From the Riser Design Wizard, calculate the maximum modulus of the feeding zone.
- The 2-D modulus of the casting end of the gate will be equal to the maximum modulus.
- The 2-D modulus of the feeder bar end of the gate will be 1.2 times the maximum modulus.
- The 2-D modulus of the feeder bar will ALSO be 1.2 times the maximum modulus.
- For a square cross-section, the modulus is the edge length/4.

Figure 4: *Gate and Feeder Bar Sizing*

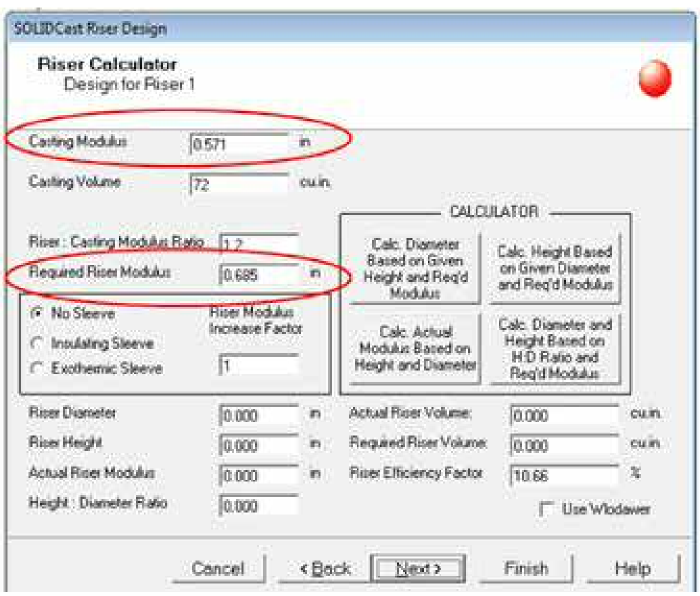


Figure 5: *Modulus data is used to size both the tapered gate and the feeder bar.*

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MODELING THE RIGGING SYSTEM

Gate and feeder bar calculations take only a few minutes to perform. Rigging components can be created in CAD or in the simulation software itself. Items that will be used for more than one casting, such as a standard size of pouring cup, can be created in a component format, and re-used as needed, saving considerable time in the model creation phase. If a library of gating components is developed and used, the entire rigging design process, from loading the unrigged model to having a fully rigged geometry ready for verification simulation, can be as short as 30 minutes or so.

DESIGN VERIFICATION USING CFD AND SOLIDIFICATION ANALYSIS

With the rigging system in place, a full Computational Fluid Dynamics (CFD) analysis is performed to predict and visualize mold filling. This also provides the most accurate temperature distribution in the casting and mold, which provides the best solidification analysis. In addition to temperature analysis, CFD can provide velocity information. It is important to keep metal stream velocities low during filling, to minimize chances for splashing and re-oxidation defects.

Filling analysis is automatically followed up with solidification analysis, using a combined thermal and volumetric calculation. This technique not only predicts poor directional solidification but provides the most accurate analysis of macro-shrinkage due to lack of volumetric feeding from the rigging system.

In many cases, the design portion of the analysis can be done in an hour or less. Verification simulations, using full CFD analysis, can be done typically in about two hours to overnight, depending on computer processor speed and available memory, casting complexity and materials cast. In general, thinner walled castings require more computation time, and materials with higher thermal conductivities, such as aluminum and copper, will also take longer to simulate, all things being equal.

One of the things that feeding zone analysis does NOT tell us is the effect of metal flow. In this example, the foundry decided to invert the casting and gate on the top of the solid boss, hoping that the filling process would create temperature gradients for directional solidification. The initial design is shown in **Figure 6**.

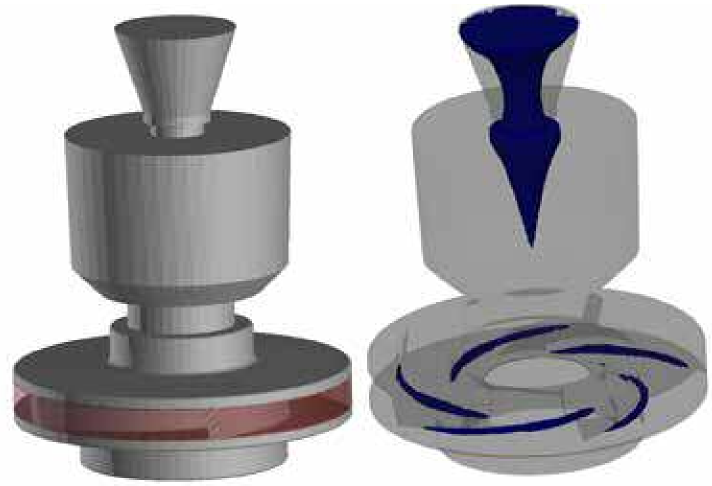

Figure 6: *Initial rigging design and Material Density plot, showing areas of poor feeding.*

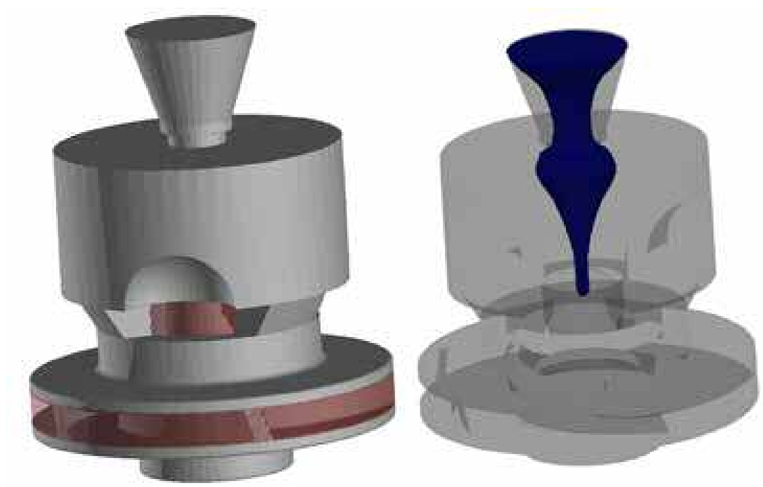

Figure 7: *Improved feeding by inverting the casting, adding multiple gates on the flange.*

Unfortunately, filling did not have the desired effect, and there were isolated areas in each vane. The foundry then flipped the casting over and provided multiple gates into the top flange. The revised model and results are shown in **Figure 7**.

This example shows clearly why it is important to verify the rigging design with a full simulation, including fluid flow analysis. It is impossible for 'rules of thumb' to take into account all the variables and dynamics of a process as complicated as the filling and solidification of castings. However, those rules can help us get to a good rigging design much more quickly than by simple trial and error.

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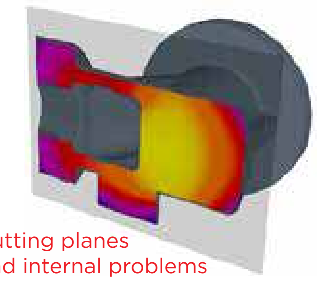
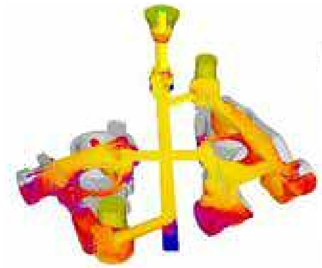
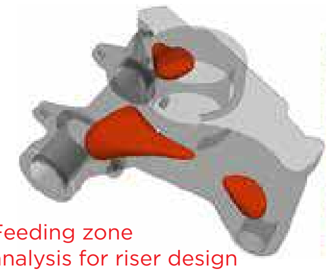


Cutting planes
find internal problems



CFD-based fluid flow analysis



Feeding zone
analysis for riser design

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