SIMULATION OF THE KAPLAN ROTOR HUB CASTING AND COMPARISON WITH THE EXPERIMENTAL RESULTS

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ABSTRACT

The paper presents the results of a numerical simulation on the hub of a Kaplan turbine rotor and it aims to obtain a casting technology through the efficient-rendering of the feeder role, the orientation of the thermal front in view of displacing the casting defects to the desired areas, the diminishing of these defects and the reduction of the liquid metal quantity. All these advantages lead to reduced costs of casting and of the subsequent processing.

KEYWORDS

Turbine, numerical simulation, casting, test.

1. INTRODUCTION

Casting has developed in time, as it started as an art form and has become a high-tech manufacturing process. Today a large quantity of knowledge is available, covering the influence of the casting and solidification parameters upon the casting profess. This led to the development of modern simulation software that, together with the casters' practical knowledge, rendered the process more intelligible and more controllable than before.

MAGMASOFT [2] is simulation software providing the designer and the caster an instrument helping to rapidly and efficiently test a wide range of option and to select the optimum combination for the improvement and optimisation of the casting process. The traditional casting tests, expensive, time-consuming and delay-causing, are much diminished. From the beginning of manufacture one attempts to avoid the reject cast parts and to assure the finite product quality. Within the elaboration of a MAGMASOFT casting project it allows the creation of several versions containing different variants of the casting system, so that its improvement is done only through the modification of the casting process geometry and parameters, the analysis of results, their comparison and the selection of the optimum solution. This principle is based on the idea that the improvement of the casting system can be achieved not only through a single calculation, but through several calculations. A new version of the project can be created through the conversion of a previous variant of the project, preserving the common data, assuring thus the saving of time. In view of optimising the casting of the rotor hub part one used the MAGMASOFT software. This software is useful for the reduction of the time gap between the reception of the offer and the homologation of the optimised technology, assuring a superior quality level and a minimum consumption of material and energy. Two major goals were aimed at, i.e.:

- The increase of the cast part quality
- The reduction of the liquid necessary for the semi-product manufacture [3]

In order to reach these goals, we focused on:

- the optimisation of the hub casting technology; first one conceived a classical technology with an annular feeder covered by an insulating plate, one single casting leg and the modification of the casting velocity; thus one simulated 12 variants; among these, we present only variants 01 and 12.

- the simulation of the classical technology and the design of a new optimised technology. The parallel simulation of the two technologies.

The use of the MAGMASOFT software for the simulation of a rotor hub part simulation, i.e. the optimisation of the hub rotor technology, imposes the following main mandatory stages:

- pre-processing of the start initial data of the simulation;
- calculation of simulation with the selection of the adequate solver (simulator) ;
- post-processing with the presentation of the simulation results.

2. THE PRE-PROCESSING OF THE SIMULATION INITIAL DATA

The pre-processing of the simulation initial data imposes the following mandatory steps:

- One processes the hub drawing with the help of a CAD software or with the help of the pre-processor incorporated into the simulation software;
- One conceives a preliminary part technology and one models it on the computer;
- One introduces all the CAD data into the MAGMASOFT pre-processor, figure no. 1, assigning them also the specific material classes.

Figure no. 1 Drawing of the hub designed in CAD and imported into the Magma

Then one defines the components of the casting system according to the material classes. The component of the casting system defined according to the material classes is in our case the following:

- Cast Alloy – the alloy to be cast, steel make GS 20Mn5;
- Insulation – insulating material;
- Feeder – feeder, steel make GS 20Mn5;
- Gating – casting grid, steel make GS 20Mn5;
- Inlet – the liquid metal jet to the grid entry, steel make GS 20Mn5.

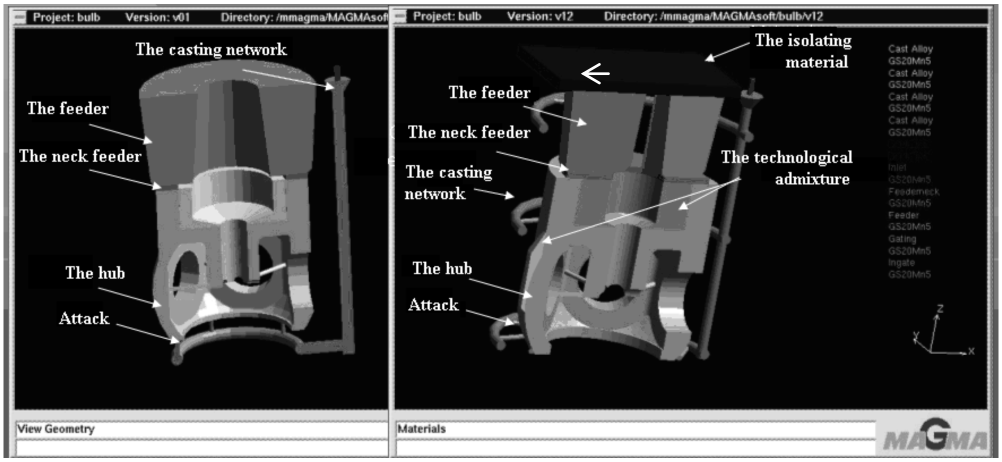
All these components of the casting system, classified depending on the material classes, are automatically presented by the software in the right side of the screen with the specific denominations, differing through the colours assigned to each class of materials. This denomination allows the identification of components within the casting process, monitoring the function of each component in this process.

For variant 12 one designed larger diameters in the hub area and at the inner upper part of the rotor, due to the technological addition, which does not appear in variant 01 (figures no. 2, 10, 11). The design with the technological addition leads to the increase of the wall thickness.

Then one generates the CAD geometry mesh [1]. In order to effect the filling and solidification simulation we need a geometry meshing, the operation being almost entirely automated. There are several meshing options:

- automata (one sets the maximum number of elements) ;
- standard (one manually sets certain meshing parameters);
- advanced I and advanced II (the parameters are set by groups of materials).

The minimum thickness of the part in the present case is considered to be the inlet, i.e. the diameter of the liquid jet form the ladle exit to the grid entry (figure no. 2).



Variant 01 Variant 12

Figure no. 2 Definition of the material groups

3. CALCULATION OF THE SIMULATION

3.1. Introduction of the parameters of filling and solidification simulation

- One sets the materials and the conditions of the simulation initiation (STEEL GS 20Mn5 according to the DIN/EN 10213-2 standard) [5] ;
- One introduces the coefficient of the heat transfer between the component materials of the casting system; [4]
- One introduces the filling parameters:
    - time (or debit or pressure)
    - one sets the information stocking conditions;
- one introduces the solidification parameters:
    - time or conditions of simulation ending;
    - one establishes the information stocking conditions.
- One launches the simulation execution.

3.2. Calculation of simulation with the selection of the adequate solver (simulator)

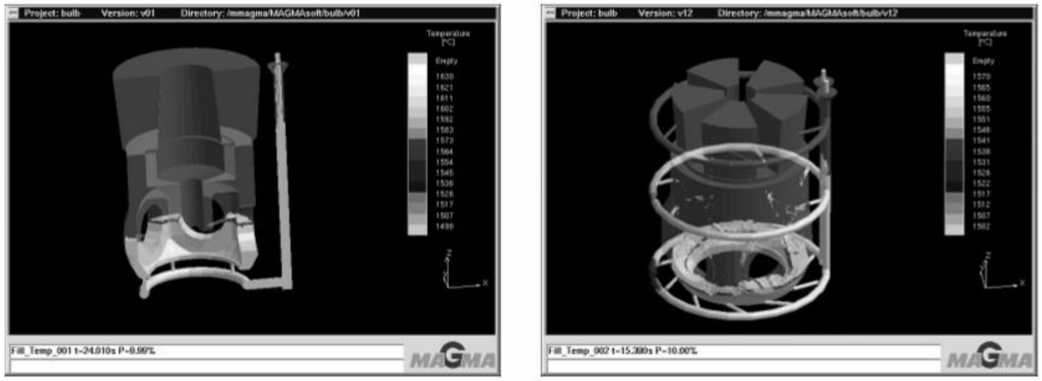
After having introduced the filling and solidification parameters one hits the START command, having the possibility to visualise the partial results, to stop the process at the desired moment, to modify certain parameters and to continue the filling and solidification simulation. Thus:

- One starts the simulation, introducing the concrete material data, their properties and the initial casting conditions;
- After simulation one interprets the results with the help of the post-processor, and according to the results obtained one modifies the technology and one repeats the simulation.

In our case one conceived also a classic technology with annular feeder and one single casting leg ; following this analysis one conceived a new optimised technology.

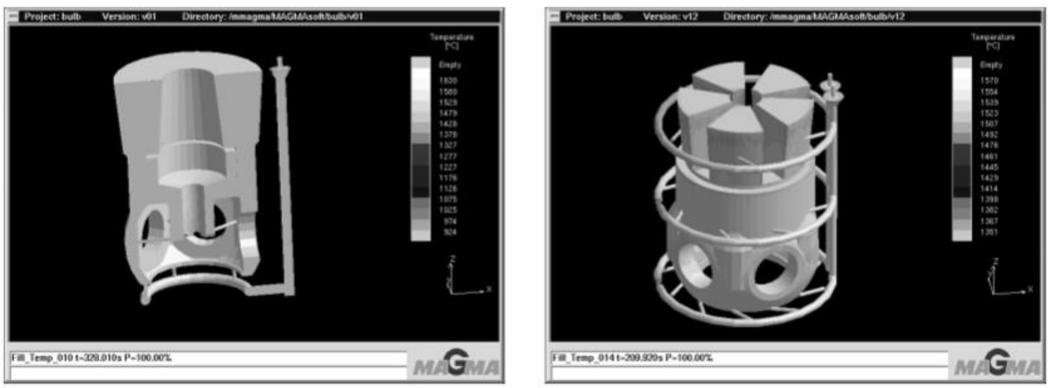
4. POST-PROCESSING WITH THE PRESENTATION OF THE SIMULATION RESULTS

Figures no. 3 and 4 shows the visualisation of the hub filling according to temperature:



Variant 01 Variant 12

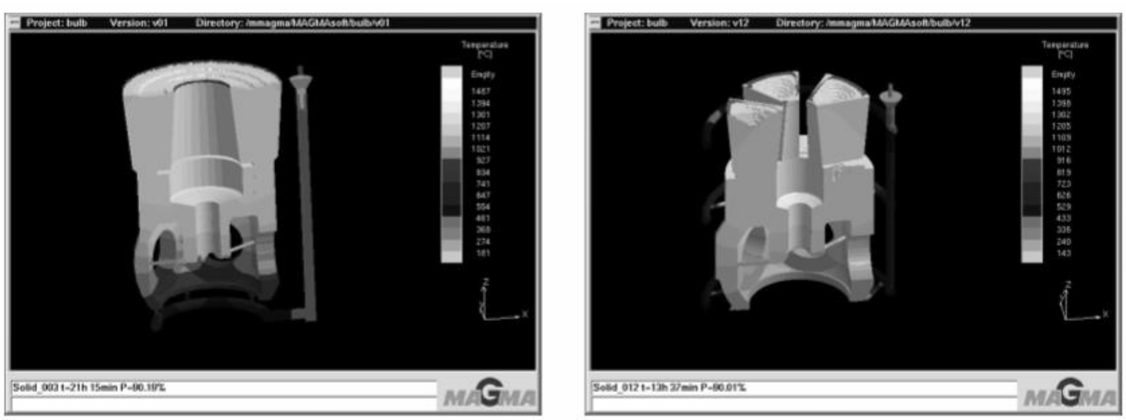
Figure no. 3 The variation of temperature during the ladle filling at 10% of the volume



Variant 01 Variant 12

Figure no. 4 Temperature variation during the ladle filling at 100% of the volume

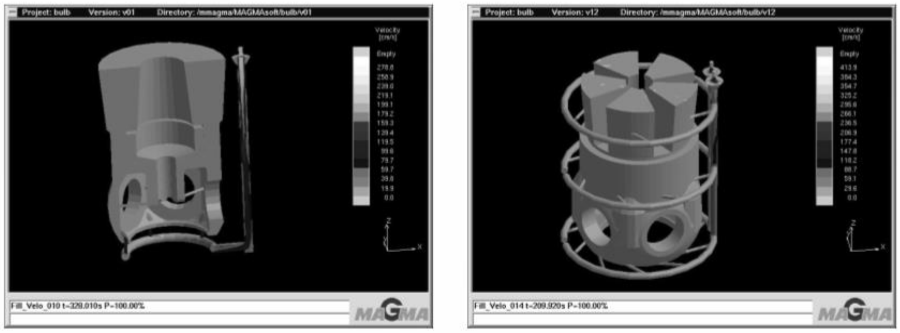
Figure no. 5 show the visualisation of the hub filling according to temperature:



Variant 01 Variant 12

Figure no. 5 Temperature variation in the 100% - solidified part

Figure no. 6 show the visualisation of the hub filling depending on velocity:



Variant 01 Variant 12

Figure no. 6 Visualisation of the hub filling in the 100% according to the casting velocity

The analysis criteria of solidification and of the simulation results are presented in table no. 1:

Table no. 1

Criterion	U/M	Criterion	U/M
LIQTOSOL – passing from liquid to solid	S	FEEDING – ladle filling quality	%
SOLTIME – solidification time	cm	POROSITY – position of the casting defects	%
HOTSPOT – hot spots	s	VELOCITY – casting velocity	cm /s

The liquid-to-solid passage area, LIQTOSOL, is one of the criteria used in order to determine the delay of time for the passage of the part from liquid to solid state, i.e. the solidification time, figure no. 7. The maximum time delay in this case exceeds 23 hours. This criterion represents the time necessary for certain areas to cool from the liquidus temperature to the solidus temperature and is measured in seconds. The faster to cool are the casting grid and the part-ladle contact surface. The hottest area remains that around the geometric centre of the sphere, which will influence the hotspot position.

The last area to solidify, HOTSPOT, figure no. 8. Using the HOTSPOT criterion one can determine the isolated areas with residual liquid at all moments during solidification. With the help of this criterion, measured in seconds, one may determine the maximum time after which there are still areas with melt residues, in other words the hottest area of the part where there is still liquid. The last area to solidify occurs in the centre of the part and is represented in the lightest colour, and it solidifies after 84296 seconds. One remarks that the thermal centre of the part coincides with the geometric centre of the sphere. The hotspot position influences the shrinkage position rendered through the porosity criterion, criterion including all the casting defects. With the help of this criterion one can anticipate the casting defects, their size and position in the part.

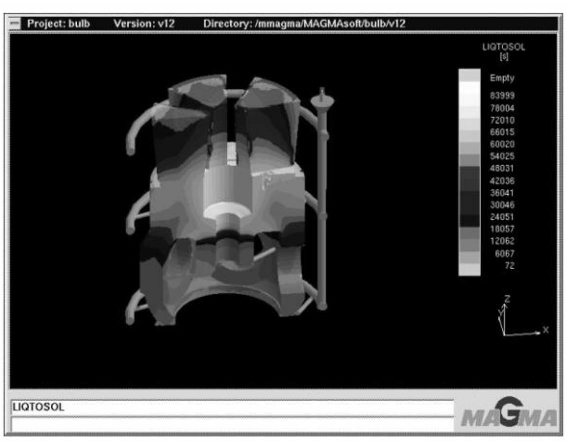


Figure no. 7 Presentation of the LIQTOSOL criterion, passage from the liquid to the solid phase in (s).

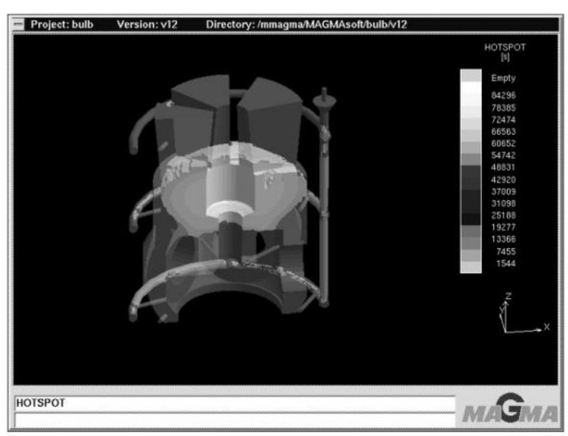


Figure no. 8 Presentation of the hotspot criterion (hot spots), the last area to solidify [s]

Visualisation of the action of the hub feeding with material from the feeder, FEEDING, represents the quality of the part feeding (the filling degree of the ladle hollow) and is in fact the reverse of porosity, i.e. the metal share at the end of the part solidification, Figure 9. The measuring unit is in (%) (according to the colour scale) 100% feeding corresponding to 0% porosity and vice-versa.

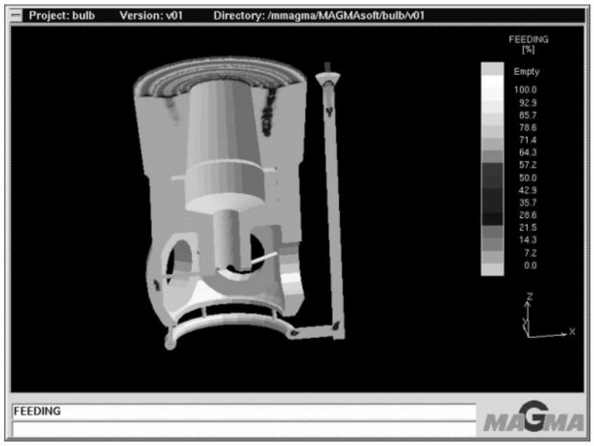


Figure no. 9 Position of casting defects presented through the feeding criterion

The porosity in the part, POROSITY: using the porosity criterion one can visualise the porosities in the part, as it shows the porosity share at the end of solidification, figures no. 10 and 11. The measuring unit is in % (colour scale). The hollows and the porous regions are also shown in white. The software renders the position of the casting shrinkage and blows in the part. The casting defects are placed within the feeder, very few in the part body, which is also proved through the previous FEEDING criterion.

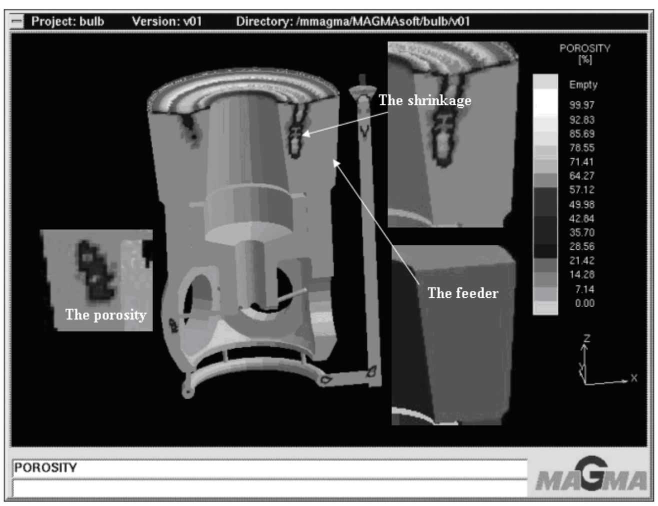


Figure no. 10 Presentation of the casting defects through the porosity criterion

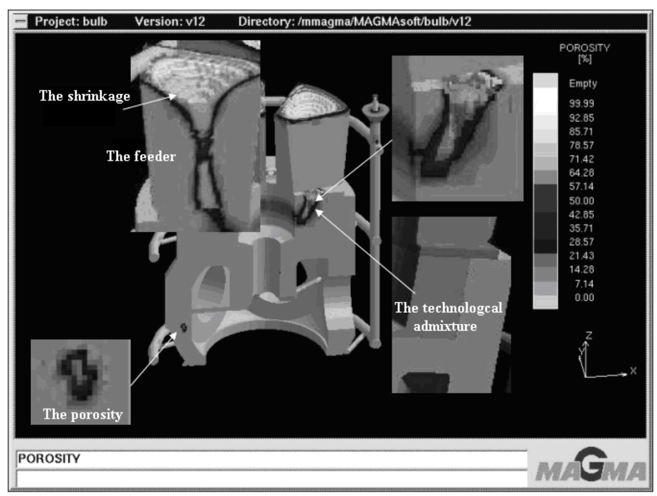


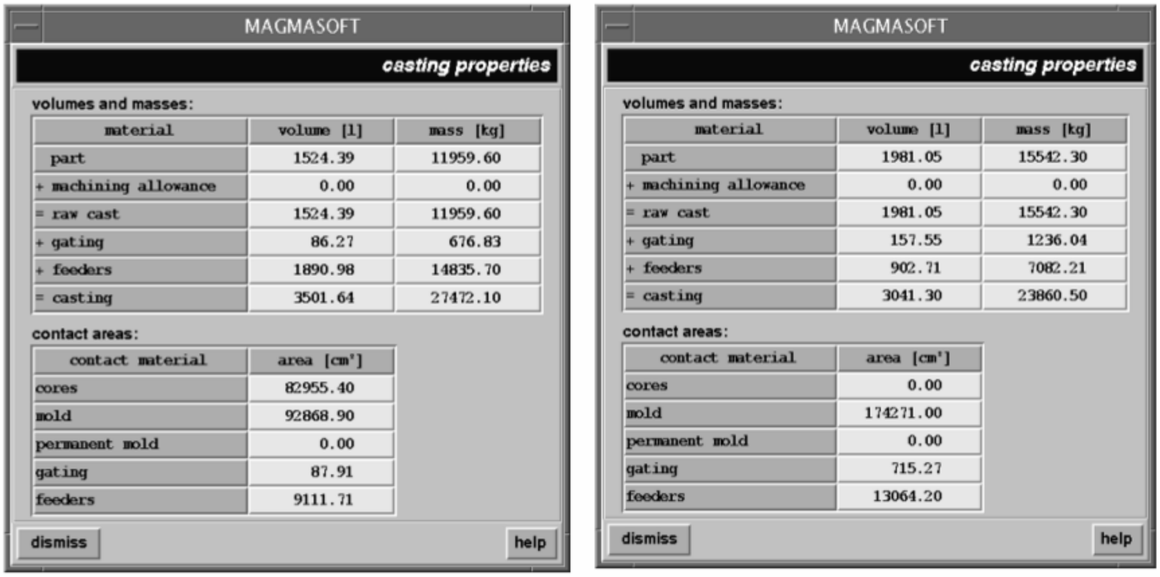
Figure no. 11 Detailed presentation of the casting defects through the porosity criterion

5. CONCLUSIONS

Following post-processing the following optimisations resulted, in comparison with the experimental results:

- The weight was reduced by 3.6 tons as shown in figure no. 12;
- One succeeded in orienting the thermal front towards to desired direction, on the feeder where the technological addition plays the feeder's part;

- After the effective hub casting one remarked the occurrence of the porosities in the areas simulated by the software, i.e. in the feeder;
- The porosity defects were eliminated in their majority, through the reduction of the filling velocity from 2700 cm/s variant 01, reaching an optimum value in version 12, that of 4133 cm/s;
- The feeder is efficient, and the technological addition contributes to this efficiency (figures no. 2, 10, 11);
- One reduced the liquid quantity compared to the initial technology with annular feeder, from 27472 kg to 23860 kg, i.e. a 3600 - kg material saving;
- One brought improvements through the elimination of porosities in the windows' area (figure no. 13).



MAGMASOFT

casting properties

volumes and masses:

material	volume [l]	mass [kg]
part	1524.39	11959.60
+ machining allowance	0.00	0.00
= raw cast	1524.39	11959.60
+ gating	86.27	676.83
+ feeders	1890.98	14835.70
= casting	3501.64	27472.10

contact areas:

contact material	area [cm²]
cores	82955.40
mold	92868.90
permanent mold	0.00
gating	87.91
feeders	9111.71

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MAGMASOFT

casting properties

volumes and masses:

material	volume [l]	mass [kg]
part	1981.05	15542.30
+ machining allowance	0.00	0.00
= raw cast	1981.05	15542.30
+ gating	157.55	1236.04
+ feeders	902.71	7082.21
= casting	3041.30	23860.50

contact areas:

contact material	area [cm²]
cores	0.00
mold	174271.00
permanent mold	0.00
gating	715.27
feeders	13064.20

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Figure no. 12 The volumes and weights of the components of the material classes after casting

Figure no. 13 The gross part after the removal of the feeders

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