SIMULATION TOOLS – "NG" : PRACTICAL APPLICATION OF NEXT GENERATION NUMERICAL OPTIMISATION TO HPDC CASTING PROCESSES

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Abstract

In this paper, the leveraging of casting process simulation to design and process optimisation tools will be discussed. Optimisation is done by the integration of a universal mathematical optimisation tool into a program for casting process simulation. The basic scheme of a general design optimisation process is explained. Some advantages and particularities in application and controlling of genetic algorithms are described. Industrial examples for the die casting process are presented to illustrate the application of this approach. Further examples show that through the coupling of simulation and optimisation tools this concept can be addressed to virtually any optimisation concept of almost any casting or geometrical parameter.

Introduction - Optimisation of Casting Processes

It has been a foundrymen's dream over many decades to receive tools that enable him to move away from the classic approach of trial and error and to be able to come to a compromise solution in no time. Experienced staff members are in a certain view also considered as such 'tools' since they know – by experience – how to optimise a casting process. On the other hand sophisticated IT – systems which are based on empirical as well as thermal and physical relationships are such tools used nowadays.

Such systems work in today's foundries very reliable when it comes to make sound decisions based on sound data. However the planning and execution of casting processes are not yet part of such 'sound decisions' since too many variables influence the soundness of a casting.

Even up to today many process steps in the total process chain of development of castings are not using reliable control instruments or tools due to the fact that rules and guidelines are missing. Quite often any step in optimising is not fully or even not at all reproducible. Quite often intuition, creativity, and the willingness to compromise is being asked: such demands cannot be fulfilled by IT-systems, human nature is the key factor for success.

The decisions for optimising a casting process must usually be done under time constraints. Many "trial & error loops" are not permitted. That is the main reason why experienced foundry engineers take their decisions based on own observations, own experience and reliable conclusions.

Many foundries utilise casting process simulation tools on a regular basis. Such tools provide valuable information for sound decision making on one side and are used for process documentation on the other. Here as well trial and error is the key to success – however in case of an 'error' only a virtual casting was spoiled, no raw material wasted, no tool has been cut and most important no production loss was accumulated. For a complete version of one simulated situation an ordinary working day is usually invested.

The ever increasing development of computing power and storage capacity delivers daily high performance PC's. With computers in the value range of €100k or more utilizing parallel computing technologies HPDC projects are able to be calculated within minutes. This is state-of-the-art technology. Over night for example one can simulate and calculate numerous versions in almost unlimited configurations. However it takes of course time to define each version and the user must evaluate the results achieved.

The advantage gained by extremely short calculation times can only be used if the computer re-defines versions based on evaluated results achieved from the previous version. Basically two different approaches are possible for such an ides:

First, there are rules and knowledge based systems available (so-called „Expert"-systems) that can optimise the casting process based on the internally stored data and rules. To apply such a system clearly identified step by step relationships between main cause and main result must exist. This is however not the case in regards to the high-pressure-die-casting (HPDC) casting process as this process is too fast moving in order to apply any thumb-rules.

Second, there is the possibility to utilise natures law of the survival of the fittest - which has been manifested in Darwin's theorem – for formulating a genetic numeric algorithm that allows variables more or less to be created by luck and where „fit" or survivable variables will be carried forward to the next generation.

Via the integration of software for casting process simulation with such optimisation algorithm (figure 1) a computer based optimisation tool is created that automatically is able to define variables and optimise the casting process. Certainly such system is able to provide optimal solutions for the HPDC casting process too.

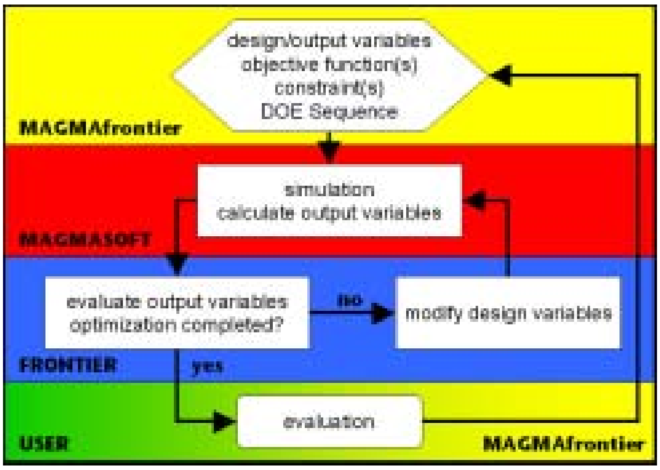

Figure 1: *Schematic flow chart of a computer based optimisation routine via integration of software for casting process simulation (here MAGMASOFT) and a generic optimisation software (here modeFrontier), based on the first statistical evaluation of the starting sequence.*

Following this initial sequence all subsequent iterations will carried out with individually defined casting process parameters. After each cycle an automatic evaluation takes place after which the next version is defined following genetic principles according to Darwin's law.

Optimisation strategy: Multi Objective Genetic Algorithm

When designing and developing HPDC – castings and casting processes a huge number of optimisation goals must be taken into consideration. For casting itself cavity filling, effective feeding as well as local mechanical properties must be considered just as much as the residual stresses and load factors under operational conditions. Finally the manufacturing specifics must be considered throughout the whole manufacturing process.

Basically incorporating a computer based optimisation technique allows the user to follow various goals at the same time. Hence only an optimisation technique that is capable of doing as such will be successfully used. Such a technique is described with **MOGA,** Multi Objective Genetic Algorithm. It belongs to the group of so-called "genetic algorithms". This algorithm is very useful especially in regards to solving casting technique related questions because it allows defining both design parameters as well as process parameters. In addition it allows defining boundary conditions for geometric boundaries as well as boundaries that maintain within the physical laws for all other variables and optimisation goals.

With MOGA one can optimise complex, non linear relationships within the casting process. The algorithm follows in principle the same Darwin defined laws of evolution of life. Through inheritance, mutation, selection and adaptation a new generation of individuals is created of which only the fittest survive. (Figure 2).

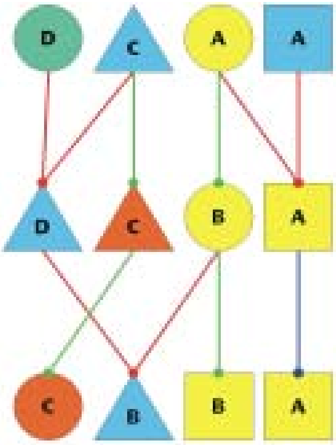

Figure 2: *The principle of development according to genetic laws in 3 steps: The individuals differentiate itself according to the characteristics like Letter, Shape, and Colour. The genetic laws are Inheritance (red lines), Mutation (green lines) and Selection (blue lines). Through inheritance at least one characteristic is being combined, through mutation a characteristic is changed and through selection the characteristic don't change and survive.*

In case of a single optimisation goal , e.g. finding „a good design", a sufficient number of individuals of generation with a sufficient number of generations should be used. If however more optimisation goals are defined you may receive various "good solutions". In this case a so-called "pareto-Set" is created and includes all designs that are good since none of the calculated designs dominates in all optimisation goals.

This however does not mean that the selected solution is the best. In reference to the optimisation goals defined they only represent the best compromise. On the other hand it cannot be 100% concluded that there isn't any solution that would fulfil the optimisations goals in full. This method is providing the user various advantages, as it provides support in the evaluation of non-linear very complex relationships, which are existing especially in high-pressure-die-casting processes.

Optimisation Goals in High-Pressure-Die-Casting Processes (HPDC)

A useful approach in the development of numeric optimisation is the correct definition of the casting process problems and their importance towards quality. Considering the casting itself shrinkages, gas-porosity and distortions are mentioned by foundry men at first. If the casting consumer is being asked, other items like tolerances and local casting properties become relevant.

Basically it can be stated that the optimisation goals defined in the numeric optimisation are the same than in the practical daily work. Prerequisite for a numeric optimisation is the fact that all physical relationships are considered via casting process simulation at first and quantifiable results are available from this work.

With the nowadays available criterion functions a vast variety of applications for numeric optimisation can be achieved.

Practical Applications

<u>Optimisation of Gating Designs</u>

When designing a die casting tool the design for the runner system plays a paramount role. Many casting defects are caused by insufficient gating design. Some of these casting defects are:

- Gas-porosity and gas-entrapment due to turbulent flow behaviour,
- Cold runs due to insufficient melt control in the main runner,
- Shrinkage porosity due to material accumulations and insufficient feeding in the pressurisation phase.

Many times the task of designing the runner is not done with the necessary care. Although HPDC castings have become more and more complex, their gating and runner design are in most cases kept on a fairly simply level. Such designs have been created based on simple considerations like easy de-gating or easy to mill on the die, however not taking flow properties and behaviour as key points. The optimisation process of designs created in such a way are usually based on assumptions about the problem and no knowledge about the real facts, hence revisions are not done in radical steps as they are prohibitively expensive.

Again a “trial and error” approach is followed; hence a numerical optimisation of the gating and runner design seems to be an ideal case. In the following an example is explained where the optimisation goal defined was the absolute minimisation of air-entrapments in the runner system.

The 3D CAD data in a parameterised format was used and with the given plunger speed no air entrapment should be created. After providing a range of „start designs“ for the „first generation“ calculated through the genetic algorithm, each subsequent simulation of filling and the evaluation of results - keeping in view the optimisation goal - was done automatically. The evaluation criterion used was “air over pressure” which again is described in a mathematical formula and shall lead to a minimum. Through the rules of the genetic algorithm of inheritance, mutation and selection (refer to the above paragraph) new parameter combinations (design variants) are created and only the fittest are surviving for the next generation. Via the calculation of various generations using various design variants and parameters a relative optimal result can be achieved (Figure 3)

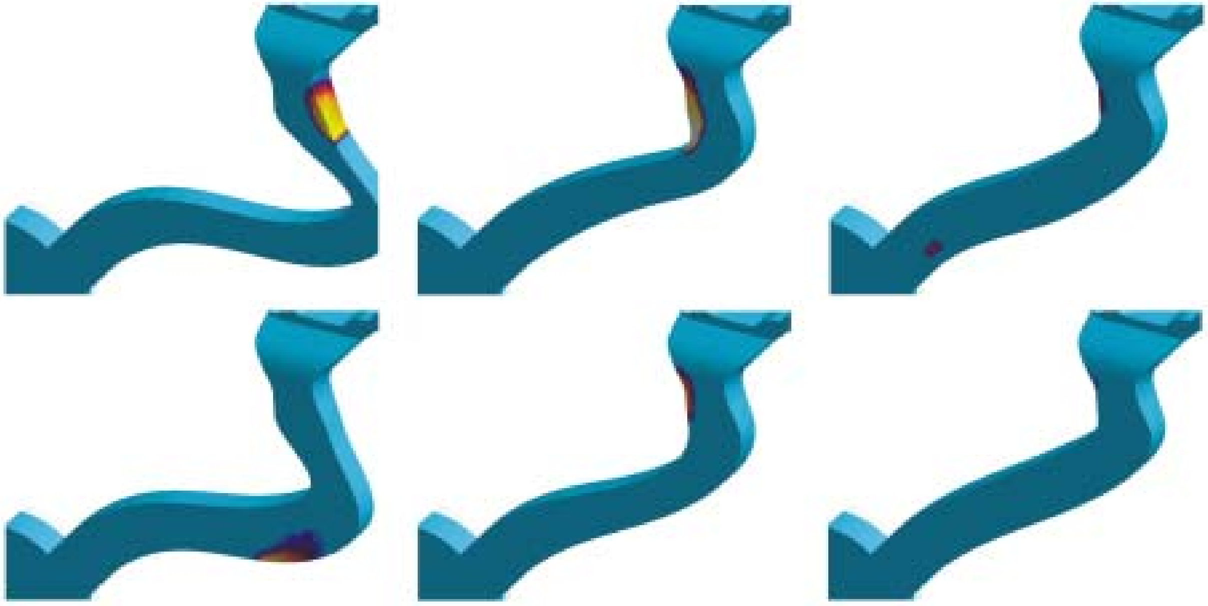

Figure 3: *Various design variants of gating designs for a casting that were considered for numerical optimisation. Depicted are six design variants that are checked out of 257 Versions. Design goal is to avoid air entrapment in the runner system. The position of the shot-sleeve and the angel for in-gate were defined as fixed boundary conditions. The rest was free for modification between bisquit and in-gate. Coloured areas indicate air entrapment of certain magnitudes The best variant (bottom right) is free of any air entrapment in the runner system..*

The numerical optimisation delivers gating and runner design that are customised to the individual casting process situation. Results achieved are basically free from any “experience” – motivated results and expectations. Hence, solutions can emerge which are not expected at all and look different on in comparison with solutions based on experience.

Such an optimisation goal could in principle be enhanced by defining a directional solidification towards the bisquit. In addition the volume of gating system could be reduced. And if the casting itself is included in the optimisation goal the air entrapment can be reduced in the part as well via variations of the ingate position and runner design.

<u>Minimisation of Porosity due to Shrinkage</u>

In many die-casting parts shrinkage porosities create a problem. Sometimes they are accepted as they seem to be not critical, however in many cases they do represent a problem when it comes to mechanical loads and or machining of the part. Shrinkage porosity always occurs when material is accumulated and thick walled areas are designed which cannot be pressure fed. Such thick walled areas quite often required due to functional design considerations. If design changes aren't followed there seem to be little chances to avoid such shrinkages. One solution might be local squeeze pins. /1/.

In the subsequent case study the dimensioning of such a squeeze pin is discussed that shall be used to squeeze – feed the thick walled areas in a casting part. (Figure 4). Such systems - in case they do not work with the first shot - have to be optimised using extensive and costly trial and error approaches.

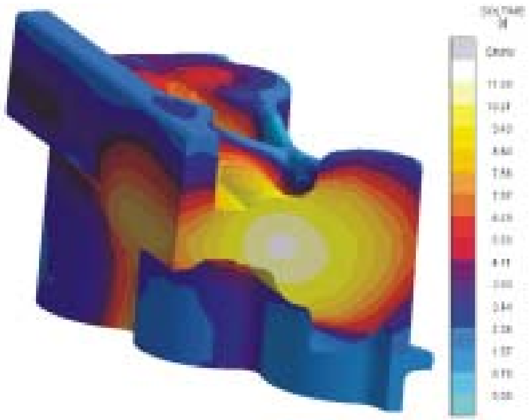

Figure 4: *Local Solidification time (SOLTIME) of a HPDC casting is showing a Maximum in the thick walled area. Here a strong shrinkage can be expected. Since pressure feeding is impossible a local squeeze solution is required..*

For the numerical optimisation the local feeding criterion can be utilised in order to visualize the macroscopic shrinkage which can be seen in x-rays. The genetic algorithm works in principle in the same way as described above and will find at the end of each version the minimal squeeze volume that is required to create a sound casting.

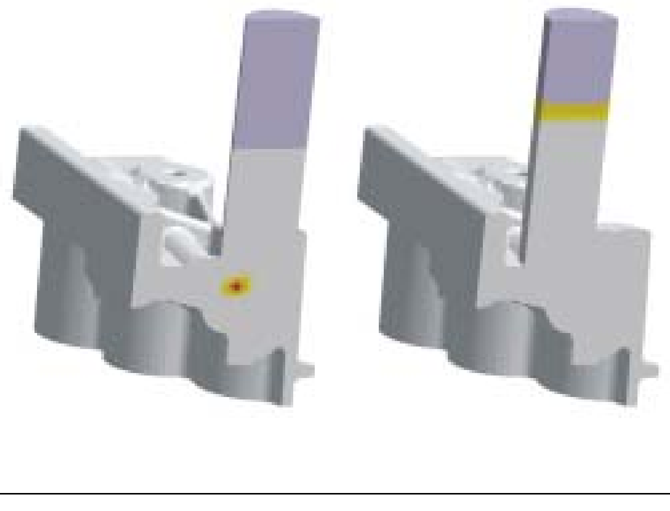

Figure 5: *Utilizing the feeding criterion function a local squeeze system can be visualised that has been found via numerical optimisation. A good design is depicted on the right hand side whereas a similar design depicted on the left is showing some rest porosity. It is understandable how important a local squeeze system can be and how difficult it is to design one.*

<u>Increase of Tool / Die Lifetime</u>

Tool Lifetime is one the key-factors in HPDC economics. Aside from erosion related problems also the cyclic temperature changes resulting in residual stresses are the ruling factors that influence tool lifetime. Low residual stresses are achieved when the temperature distribution is even. This means that if it is possible to optimise the tempering system of a tool, hence being able to reduce residual stresses, the tool lifetime can be enhanced.

The tempering of a tool can be optimised using traditional try and error approaches. In this way it is customary to create as many tempering channels as possible and via a trial production each and every channel is activated with various cooling / heating media and temperatures. Certainly such a procedure is costly and time consuming and can lead to success in case it is executed in a structured way with proper documentation.

The following example is showing such an optimisation of a tempering system of a tool. Here the optimisation goal was to create an even temperature distribution at lowest possible level. The casting itself is a housing bracket with an even material wall thickness of 3 mm. The exception is on the lower area where a wall thickness of 10 mm is required for stability purposes. In this area the ingate is mounted on the casting for extensive pressure feeding in the third phase. On the other hand extensive heat is being introduced here as well which again has to dissipate into the tool. Optimising the tempering system and considering the cyclic changes including spraying and blowing of the tool surface resulted in an even temperature distribution (Figure 6 and 7). In addition as a side result a reduction in solidification time and die casting cycle was achieved.

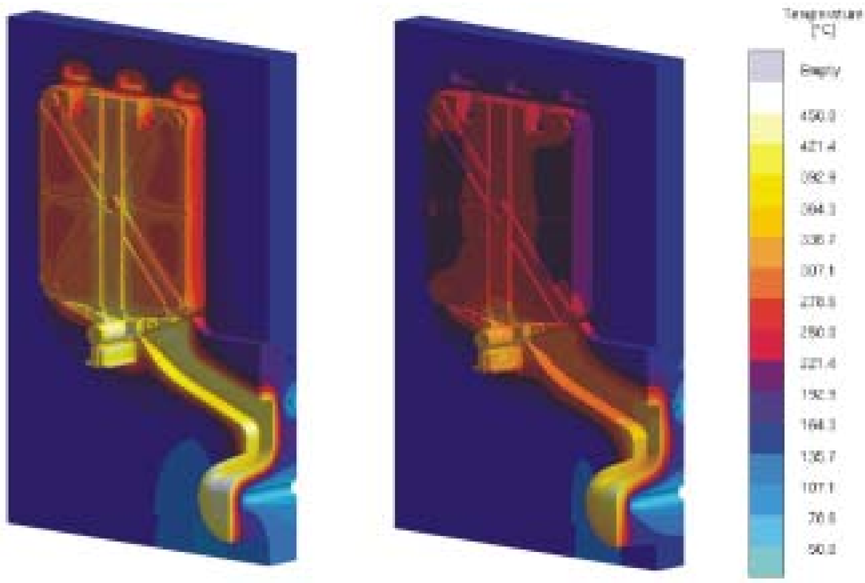

Figure 6: *Tool temperatures immediately before spray and blow takes place (left) and the same time spot after optimisation (right). Through optimisation the temperature gradients and temperature levels are lowered. This is important for the minimisation of residual stresses in the tool.*

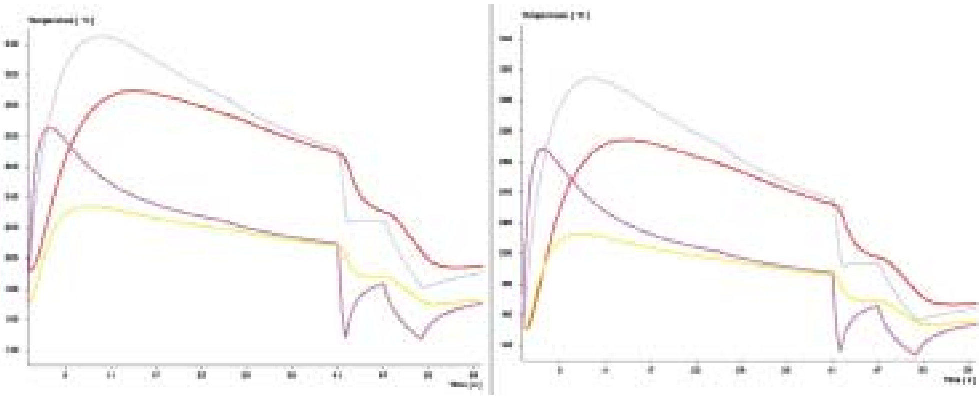

Figure 7: *Tool temperatures during a casting cycle before (left) and after (right) optimisation. The cooling curves show clearly the lowering of the peak temperatures the gradients and overall temperature levels..*

Summary

With the ever increasing complexity and complex functionality of castings especially in HPDC the demands for casting processes are increasing as well. While process planning and pre-production takes place many time- and cost intensive optimisation iterations have to be done. Numerical casting process simulation of filling and solidification is more and more substituting expensive tool changes and also trial productions via computerised engineering approaches. Most of the nowadays used optimisation techniques are based on classical trial and error. The "next generation" of optimisation tools combined with simulation are now doing this process automatically. The final result is not only a 'simulated' checking of a version but already an optimised result of the casting process which the user can implement. In this way simulation of classical casting processes and evaluation of the results are achieved.

With this paper 3 different optimisation projects have been introduced. Optimisation of gating and runner systems, optimisation of shrinkage porosity and optimisation of tool lifetime were documented. In all three projects and optimised „compromise" with 100% optimisation goal achievement was found in the same way as it could have been done using traditional methods.

It is certainly possible that in the very near future such computerised optimisation processes and technologies are utilized in the foundry. Computerised optimisation is however not replacing the engineers on site which have to work out process design and mass production optimisation. Their risk is however minimised as the increasingly more demanding environment is asking higher level results. In addition the new task of computerised optimisation is leading to exact definitions of optimisation goals and an increased understanding of the complex relationships in the casting process.

Nevertheless not all tasks in a foundry can be resolved and optimised using this technology, but further developments will lead into that direction. However wherever a clear optimisation goal can be defined and an appropriate model can be established, an optimised result can be achieved. Today's computer technologies are able to calculate one version plus optimisation in 15 minutes for a simple task and a few hours for a more complex one, hence it is suitable to follow further the path of developing computerised optimisation technologies.

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