Automatic Optimization Technology Solve the Problem of Gas Porosity in Complex Casting Parts

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***Abstract* - Automatic optimization of artificial intelligence is a hot topic today. However, how to apply such technology to general industrial enterprises application is more interesting. This paper introduces the application of artificial intelligence techniques in the gating system design of high pressure die casting, make it fully automatic optimization, detailing its basic principle, application methods and techniques.**

***keywords* - Artificial Intelligence, Cast-Designer, Casting Simulation, Evolutionary Genetic Algorithm, Flow Path Optimization.**

I. INTRODUCTION

In the case of high pressure die casting, if there is not good enough vacuum system, the gas entrapment and gas porosity will become very often and serious defects, especially for the casting parts with complex shapes. This is also the most painful problem for casting engineers, how to find a better solution to balance the economy and the quality of the product is very important.

The solution to this problem is nothing more than a few: a) equipped with a good enough vacuum system and setup well. This can reduce the gas inside the mould; also solve the gas entrapment problem. However, add the vacuum system will make the mould structure more complex, also more experience in the production; b) we can improve the casting systems, such as the gating systems, the overflow systems and the venting system. Optimize the flow direction and flow pattern of the molten metal so that the gas moving in the direction of the overflow and venting channel, thereby reducing internal gas residues and avoiding gas entrapment. In this way, there is no need to increase the complexity of the mould, and can maintain the same production efficiency. But on the other hand, it also asks the design engineers have better design skills and more knowledge. c) Combine the above a) and b).

The popularity of Computer Aided Engineering (CAE) technology provides a great convenience for optimizing the casting system such as the gating system, overflow system and venting system, allowing the user to free up from the physical trial and error, and to obtain better economy and timeliness. But even the CAE method, it still cannot solve the design problem, the typical method of CAE is still: a) According to the physical model and conditions to generate numerical simulation model and perform simulation; b) Analysis the simulation results and raise up the solutions for the existed defects; c) Modify the original CAD data like gating, overflow and venting in the CAD system, and re-generate a new simulation model and perform simulation again, one by one, until a satisfied result.

This process is undoubtedly feasible and effective for the simple casting products and only finding one single variable. But if the parts geometry are complex and multiple influencing variables, the difficulty will be increased fast in the exponential level, even if many rounds of repeated simulations are performed, the results are still not necessarily satisfactory. The most common phenomenon is that the CAE simulation technology can help to find the defects of casting process, even match the actual casting process, but how to solve the problems are often helpless.

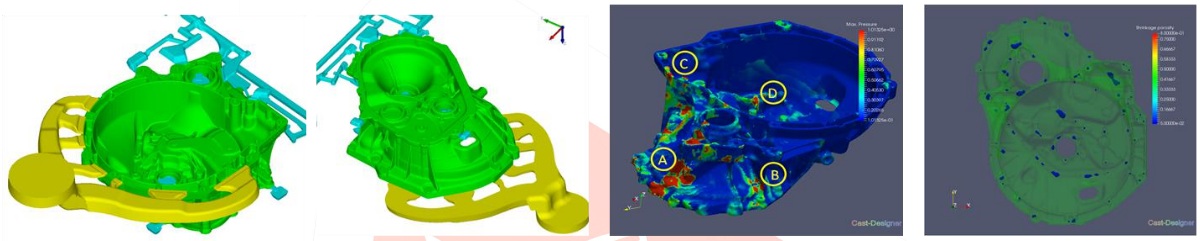
Recently, this technology has been a great breakthrough. Automatic optimization technology has been applied to the industrial reality. The so-called automatic optimization, that is, the computer system can modify the parameters automatically for the casting system such as gating system, overflow system and venting system, and set up the CAE model and perform the CAE simulation, then analyze the simulation results automatically and submit to the optimizer solver to find the next parameters for the next step, until obtain a satisfied result. This can be understood as a branch of artificial intelligence, which involves a lot of core technologies, such as:

a. The full parametric design of the casting system, including the gating system, overflow and venting system. If it is gravity casting, it also includes the riser, feeder and chill design;
b. Automatic meshing generation and mesh assembly technology;
c. Automatic CAE model generation, includes the parameters setting and perform CAE simulation;
d. Automatic result analysis techniques. In the case without programming, the user can extract and analysis the various results, as more as possible. The results analysis should also contain a degree of logical analysis;
e. Automatic optimization techniques to search and analyze the simulation results, and make decision for the next step automatically. At present, the mature optimization techniques include genetic algorithm, particle swarm optimization, artificial neural network, multi-objective optimization, fuzzy mathematics and so on.

Therefore, in order to achieve the above objectives, not only single CAD design software or single CAE simulation software can be achieved, and a full solution from the design to analysis to optimize is strongly required. At this moment, very few software can achieve this, but the Cast-Designer of C3P software is one good example. In this paper, we will demo a typical auto part, in CAST-DESIGNER software, to illustrate the principle of the entire automatic optimization process, practice and application.

II. Project Background

Figure 1 (a) & (b) are an auto part with the original designed gating system, overflow and venting system. It is clear, in the design of the runner has been considered the flow distribution of the main runner and sub-runners, the cross section area of runner already under control. In the casting process of this part, it was only using ordinary venting, no additional vacuum system. Figure 1 (c) & (d) shows the CAE simulation results, the flow result. The figure uses the statistics of the maximum gas pressure to characterize its gas entrapment. The red contour represents a larger gas pressure, and the blue area indicates that the filling is perfect and the green is between the above two. From the results, it is clear, in the regions marked in the figure A, B, C and D, are obvious gas entrapment behavior, which is actually the defects in the physical casting parts. In particular, the volume of entrapment gas at the region A was quite big, also located at the end of the product, there are big defects in the actual part. Also, the gas entrapment in the region C also leads to filling defects. Compared with A and C, the defects in region B and D are relatively minor, and the final quality requirement in B and D was not so important, so we need not pay special attention. However, the defects in region A and C must be resolved; otherwise the casting part will not be judged as unqualified. In the existing process, the failure rate as high as 40%.



(a) (b) (c) (d)

Fig 1 (a) The Auto part and Gating, (b) Overflow and Venting system, (c) The CAE simulation result of gas entrapment, distributed in the A, B, C, D, etc., where A is particularly obvious defects ,(d) CAE simulation of the shrinkage porosity defects

In Figure 1 (d) we have shown the shrinkage porosity result of the simulation. The main source of the shrinkage defects is caused by non uniform wall thickness and non uniform mass distribution. Optimize the geometric structure of the part is the first choice to solve the shrinkage problem, followed by the optimization of water cooling channels, gating system and control the mold temperature also have some help to the shrinkage porosity, but not very obvious. In this case, the size and distribution of shrinkage porosity was within the acceptable limits. So there is not much discussion about the shrinkage porosity in this paper.

In the following sessions, we attempt to use automatic optimization techniques to improve and avoid the problem of gas entrapment by optimizing the gating system to control the metal flow direction and mass distribution.

III. Optimization objective and criteria

To Set an automatic optimization model is not so complicated, just need to do few steps. First of all we need to define the optimization objective and the use of mathematical language to express it; this is the core of the optimization. The objective could be a single target or multiple targets; however with the increase of the number of optimization targets, the difficulty level of the optimization calculation is also exponentially increasing. It is very simple if we set specific physical quantities as optimization objective, such as volume, shrinkage porosity volume, temperature of the given point, liquid fraction, surface area, etc. But if you need to describe the flow pattern, the gas entrapment and some more complex process, you need to pay more time to consider how to set the optimization objective. Usually, for a complex physical process, require different physical quantities of matching and mutual computing, and sometimes also contain some logical relationship.

After define the optimization objective, and then define the input variables that affect the optimization objective. This variable may be a variable that affects the geometric parameters, or a variable that affects the boundary condition parameter. Same as the objective, the input variable can be a single variable or a number of variables, which also contains an unlimited number of intermediate variables. Again, with the increase in the number of input variables (except the intermediate variables), the calculation amount and difficulty level of the optimization is also increased in the exponential level.

In practical applications, we recommend that the input of the original variable less than 3, the optimization objective is also less than 3, so you can get a better calculation speed and effectively. If the problem is too complex, you can split it into several subprojects to optimize.

How to set optimization objective and develop optimization criteria is the key to automatic optimization. In the previous, the research level software was often asking the user to write some complex subroutines to describe the optimization goals and the development of optimization criteria. But this is only suitable for specific issues, could not really apply to industrial practice.

Because it is not practical for engineers to write programs in their daily work, and computer personnel who can write the program often do not understand the actual engineering problems.

In CAST-DESIGNER, users can customize formulas, expressions, and complex logical relationships by themselves. There is no different from the normal mathematical formulas. In this way, through the extraction of the resulting variables and mathematical processing, you can easily customize the optimization objective and criteria. Regards the input variables, the user can define some the original variables and unlimited number of intermediate variables with mathematical relations, and the casting system design is fully integrated to the simulation system with fully parametric. And the optimizer could drive the above all automatically.

Setting the optimization parameters

In this case, we first reconstruct the gating system in CAST-DESIGNER and determine the association relationship of the input parameters.

a. On the basis of the original design, at the rear end of the runner R1, we add a sub-runner R3, and retain the original two main runners R1 and R2. Which SR1-1, SR1-2, and SR1-3 are sub-runners attaching to R1, the cross sectional area is maintain the original design ratio. SR2-1, SR2-2, SR2-3, SR2-4 are sub-runners connected to R2, and the cross sectional area also maintains the original design ratio.

b. Set a resource variable parameter K1 to characterize the ratio of the initial cross-sectional area of R1 to R2, so that K1 = SR1 / SR2. And the acceleration ratio of the whole system is constant, that is, SR1 + SR2 is a constant. When K1 changes, the initial cross sectional area of R1 and R2 is also changed accordingly, that is, the gating system with different distribution ratio is generated. SR1-1, SR1-2, SR1-3, SR2-1, SR2-2, SR2-3, SR2-4, which is attached to R1 and R2, are also adjusted and changed.

c. Set another parameter K2 to represent the ratio of the initial cross-sectional area of R3 to R1, so that K2 = SR3 / SR1. Thus, K2 can control the starting area of sub-runner R3. In particular, in CAST-DESIGNER, we give K2 a special definition, when K2 <0.2, the sub-channel R3 is not generated. This can be achieved whether to generate R3 and the section area of R3 in fully automatic control.

For the data range of K1 and K2, we set the following:

K1: 0.80 to 1.40, in the accuracy of 0.025.

K2: 0.05 to 0.35, in the accuracy of 0.05.

Figure 2 (a) shows the gating system used for optimization and the specific parameters setting.

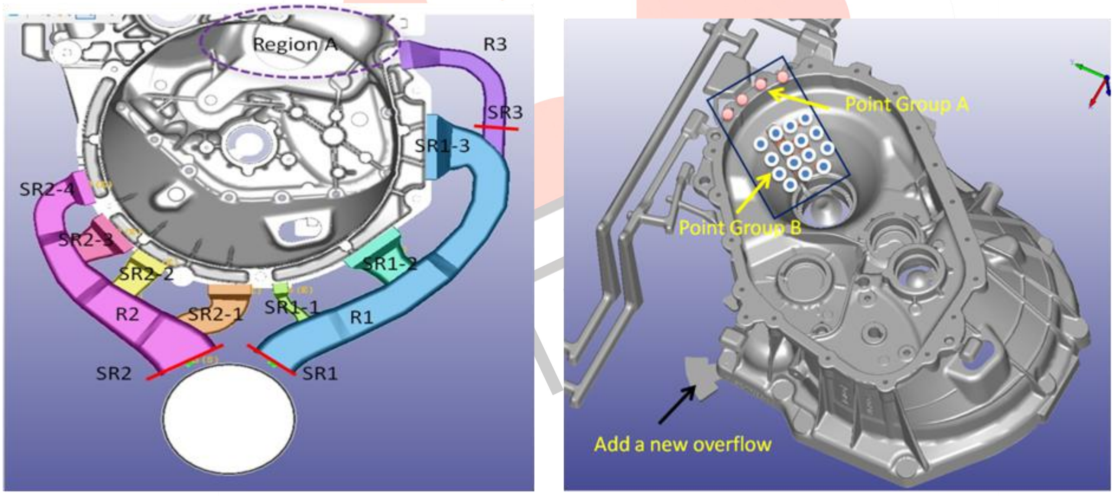


Fig 2(a) Automatic optimized gating system diagram, R3 is a new runner to improve the flow for region C, and the system will optimize the initial cross-sectional area ratio of R1 and R2. (b) To develop optimization goals, define point set A near the overflow and point set B near the gas entrapment region. The merits of the design are evaluated according to the difference between the filling times of point set A and B.

Optimization Criteria

By trial calculation, we found that by modifying the ratio of K1 and add the sub-runner R3, the defects at region C of Figure 1 (c) has been basically solved, especially the presence of sub-runner R3 significantly improves the velocity vector at region C. So the following main optimization goal is set at the defect A. We set the control point set A and the point set B, to obtain result of the simulation to evaluate the design. Where the point set A is four points, which are distributed in the area near the overflow (as shown in Figure 2 (b)); the point set B is 15 points, distributed in a large range (where the final gas entrapment region), it is used to detect the existence and distribution of gas.

Setting optimization goals requires good predictability because different gating system can cause changes in the size and location of the final defect, so that a given position point cannot be used as an analysis object, but a point set should be used. The set of points should not only be able to reflect the defects themselves, but also should have sufficient results of the difference. This is the focus and difficulty of the whole optimization. For actual casting, it is usually appropriate to select the casting defects and the surrounding area.

If the average filling time of point set A is T1, and the average filling time of point set B is T2, then

$\triangle$ T = T2-T1

Since the filling time is usually very small, in order to enlarge the difference, we make

$\triangle$ T = 1000 • (T2-T1)

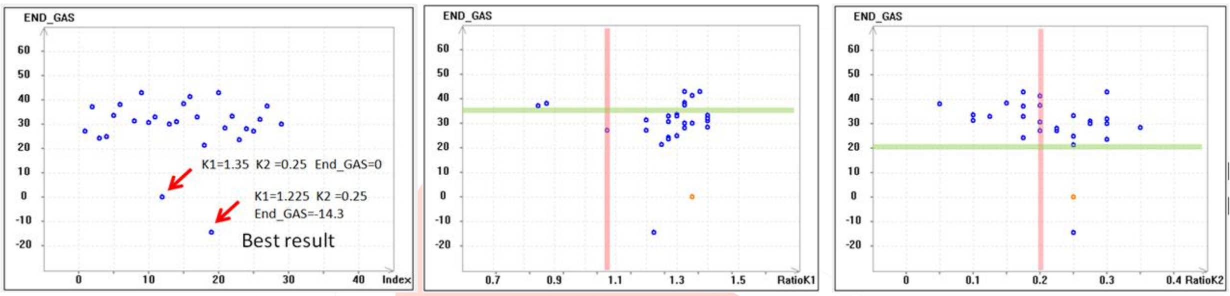
The expression of $\triangle$ T is clearer, but the value of $\triangle$ T is only the relative meaning of the number, there is no absolute meaning. It is clear, the smaller $\triangle$ T, then the filling results are ideal,

If $\triangle$ T <0, indicating that there is no gas entrapment. Fill in the first fill set B, and then fill the point set A.

If $\triangle$ T> 0, indicating the existence of gas entrapment, and the smaller the value that the degree of gas entrapment is low. While the larger the value, then the more serious the gas entrapment.

IV. Result

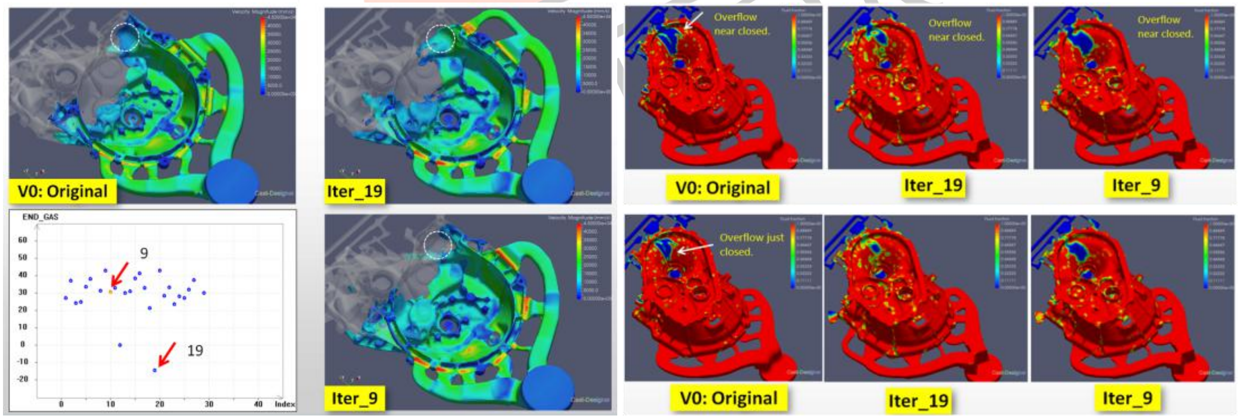
After running 30 iterations, the optimized results are shown in Figure 3. According to the above discussion, the smallest $\triangle$ T (we named END_GAS, the end gas volume) for the best results, we select the two best results, and marked on the figure. One of which is END_GAS was -14.3 and the other one is END_GAS was 0.



(a) (b)

Fig 3 (a) Result of automatic optimization, run 30 iterations (b) relationship between optimization results and parameters K1, K2

Try to analysis the optimization results to check the affection of parameters K1 and K2. We found if K1> 1.2, the results were significantly better than the other case (Figure 3 (b)); and the result is always better if K2> 0.2, means with the additional runner R3. But regardless of K1, or K2 and the results are not related in linearly. We compare the flow result of the following 3 cases, the best 19th iteration, the 9th iteration which is not good and the original design plan. It is obvious that add the sub-runner R3 can improve the filling speed of the defect region C, the filling velocity is much balance in iteration19 and avoid the mis-run problem (Figure 4).



(a) (b)

Fig 4 (a) Results of Comparison of different iterations the contour shows the velocity distribution, (b) Results of Comparison of different iterations with original design plan

Now we compare the result of iteration 19 and the iteration 9, to compare with the original design plan of the gas entrapment problem before overflow close and just close the overflow. Because after the overflow is closed, the gas is quite difficult to push out. Obviously, the iterations 19th are involved in the least gas, followed by the original design plan, and the gas entrapment volume of the iterations 9th is more serious. It is clear that the different gating system causes a completely different filling result.

In this case, the gas entrapment in iterations of 19th is not completely eliminated, but there is a very big improvement over the original design plan and could be able to meet the industrial requirements.

One thing need highlight, in the result analysis, in iteration 19th, the END_GAS value was negative, means no gas entrapment existed, but the simulation result show there is still some gas inside. Why? This is due to the sampling point setting. In this model, we have selected a total of 15 sampling points for the use of gas areas, but in the process of averaging and calculation of data, may be covered up or ignored. The solution is to adjust the number and location of the sampling points. On the other hand, the optimization still requires a certain margin, if the result is too narrow, for industrial production is very unfavorable.

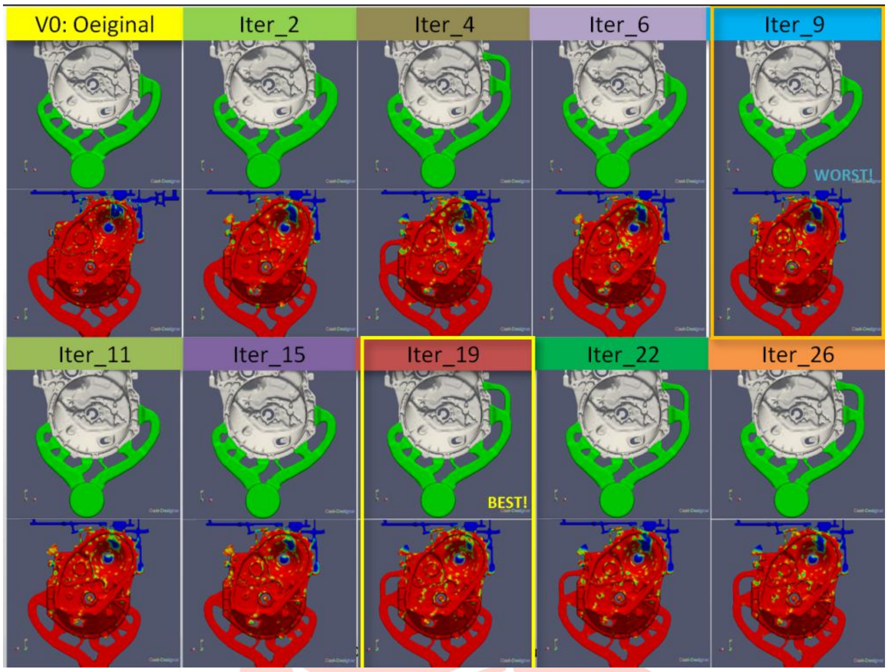


Fig 5 Select 10 iterations of the optimization result compare the severity of gating system to gas entrapment

In Figure 5, we show the result of 10 different iterations. With different runner systems, the gas entrapment level is also different. The beauty of automatic optimization is that users do not need to view and analyze the results one by one, and the system can guide the next step of parameter selection according to the results of the history until the optimal result is found.

In this example, the above optimization has optimized a total of 30 iterations and has not converged. But the calculation has reached the fifth generation of genetic, so the results already could be used. We use 8 CPU / Core in Intel I7 CPU for DMP parallel computing, the modeling and simulation time of a single model has been adjusted to only 40 minutes, so all the calculation takes roughly 24 hours. In fact, because the casting part was quite complex, the wall thickness is very thin, the real calculation of the model should be more fine. It is necessary to enlarge the calculated population and more for the better results too. In this way, for this level of industrial problems, usually 2 to 3 days of calculation time is necessary. Form the software side, in order to short the calculation time more effectively but retain enough computing accuracy, the next step is the direction of parallel optimization technology.

Finally, we can load the designed CAD data of iteration 19th; check the details in Cast-Designer (Figure 6). The user can do some fine-tuning, also possible to adjust some simulation parameters for a more detail simulation to check the final result.

On the other hand, the user can also export the design to other CAD systems, for mould design or manufacturing processing.

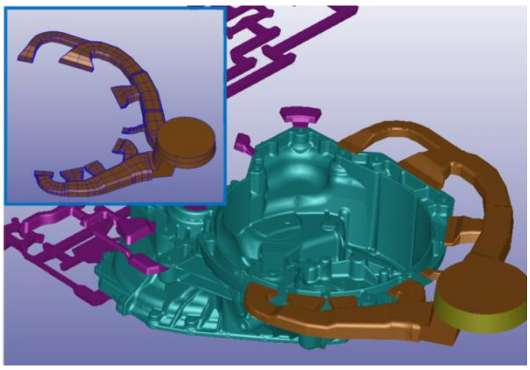


Fig 6 the CAD data of the final optimization gating system (the result of iteration 19th)

V. Conclusion

The automatic optimization of the casting system has been progressively entered into our real industry. With this new generation of artificial intelligence technology, we can effectively integrate CAD modeling, geometric optimization, CAE simulation, automatic analysis and decision-making together, and directly serve to the foundry industry. This could greatly enhance the design capacity and improve the competitiveness of the enterprises.

How to build an effective optimization model is the key to the whole project, where there is a need for a deep understanding of the physical issues, but also need to understand some of the basic concepts and techniques of optimization.

Today's optimization is no longer limited to simple parameters and simple shape optimization, but can be applied to any CAD changes; while the optimization of the study point is no longer a simple direct mathematical variables (such as shrinkage volume, gas content, etc.), but more representative of the actual physical phenomena of casting, such as flow imbalance, gas entrapment and other factors.

VI .ACKNOWLEDGMENT

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