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CAST-DESIGNER: A New Approach towards Casting Production Optimization

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ABSTRACT: In Casting, the rate of production and the quality of the parts produced in mass production process depends on cycle time. The cycle time of a part can be reduced by reducing the cooling time. The cooling time can be achieved by the uniform temperature distribution in the moulded part which helps in quick dissipation of heat. At the same time, the mould temperature should be maintained a uniform distribution to minimum the part warping and extend the die life time. This paper describes the analytical study of the mould cycling optimization and the cooling channel control during the mass production, a new casting production optimization method has been introduced.

KEYWORDS: Cast-Designer, Die-casting, Die-cycling, Gravity casting, KBE, soft computing.

I. INTRODUCTION

Die cycling is essential for high pressure die casting or gravity die casting since the same die is used repeatedly to produce many thousands of castings. It is important to maintain die temperatures for each and every casting because the temperature cycles can cause warping in the die pieces themselves, which will lead to dimensional instabilities in the cast parts.

The different phases of a casting's thermal cycle involve complex physics, because the speed of the fluid is always changing as it proceeds through each section of the die. Conduction and convection are both present in the molten metal, complicating the determination of liquid-to-metal heat transfer coefficients. Moreover, it is no simple matter to subdivide the production cycle into well-defined steps to come up with average properties for these effects.

With Cast-Designer cycling simulation, the temperature distributions resulted from the combined effects of die heating (during filling and solidification), spraying and air blow-off, and the cooling channels and inserts can be accurately and efficiently predicted.

An optimized die cycling time can not only save production time to increase the production rate, but also improve the part quality and extend the mould life time. The cycle time is possible to adjust in the workshop by operator, but how to find the best number is always quite difficult, and it is the major topic of this paper.

II. RELATED WORK

Optimization method and challenge

a. Numerical simulation (hard computing) and the major problem

More and more casting simulation software has the die cycling simulation capability, it can predict the die temperature distribution for each cycle, also can predict the affection of cooling channel to die temperature. However, numerical simulation is a 'What you put and what you get' process, it only can answer the questions with the known conditions, but not the known result.

The major drawbacks of traditional numerical simulation are:-

- Very long time to generate the CAE model, since the cooling channel and the full mould must be considered.
- Very longer CPU time for the simulation, since 5 to 10 cycles should be considered for a stable cycling.
- 'What you put and what you get' process, the user input the condition to check the result, but not the revise side. So the user must make many tests with some trial and error.

- Result analysis is not simple. For example, the user doesn't know how about the contribution of one cooling channel to the specific points.

There are many studies focus on this field, but very few success stories reported so far.

b. Soft computing

The term which is used in computer science is Soft computing. Soft computing having featured of inexact solutions to computational hard tasks such as the solution of NP-complete problems. There is no any other known algorithm which can find out an exact solution in polynomial time. Soft computing having features of tolerant of imprecision; uncertainty, partial truth, and approximation. These features are different from conventional (hard) computing.

We can differentiate soft computing from possibility. If we don't have enough information to solve any problem at that time we can use Possibility. But soft computing is slightly different than this; we can use soft computing when we don't have enough information about the problem itself.

Neural networks (NN), Support Vector Machines (SVM), Fuzzy logic (FL) and Evolutionary computation (EC) are the components of soft computing. Now a day the main problem regarding casting process optimization is it has not enough sample data for optimization and special for complex model.

c. Mathematic optimization

From some set of available alternatives regarding with some criteria, Mathematical optimization is a best element. An optimization problem consists of maximizing or minimizing a real function in a simple case. We can choose the input value systematically from an allowed set and then used the value for computing the value of the function. Mathematic optimization which includes finding the best available values of some objective function given in a defined domain. It includes a variety of different types of objective functions as well as different types of domain.

There are many mathematical optimization methods existed in the market, and with success in product design and other field. However, for casting process optimization, also the sample data for optimizing is the biggest problem. It is possible to combine the numerical simulation for cycling and mathematical optimization together, but the too longer simulation time is totally not affordable. For example, for one casting part, you need 10 to 20 days to prepare the sample data, and then start the optimization.

d. Combine KBE and numerical simulation

To solve the casting process optimization problem, C3P Software has developed a new method for optimizing. Combining the KBE method and numerical simulation method together, it can achieve a full automatic optimization and much fast converge than tradition optimization method, since it doesn't need the sample data.

KBE defines as Knowledge-Based Engineering on the basis of digital knowledge models. The knowledge representation techniques are used to create the computer interpretable models which give results of knowledge modelling. The knowledge models enable engineers to specify requirements or create designs on the basis of the knowledge in such models which can be further imported in and/or stored in specific engineering applications. The developments of knowledge models are generally system dependent.

Bridge knowledge management and design automation are roles of the KBE. Knowledge processing has played a successful role in engineering. Cast-Designer CPI based on FEM technology with very powerful function in mesh generation and outstanding mesh assembly capability for full mould. Thanks of the FEM technology, Cast-Designer can use the mixture meshes for the casting and mould.

It is well known that the hexahedron element had the better flow analysis result than the tetrahedron element for casting part, but thermal analysis result was almost similar. Also, the tetrahedron element still has many advantages if applied to the mould meshing. For example,

a) Save model size. The tetrahedron element is easy to have a big element ratio than the hexahedron elements. It is well known that the volume of the mould is much larger than the casting part, to build a node connect mesh, the FDM type mesh need waste lots of elements in the mould. With tetrahedron element, we can use quite smaller element number for the mould and save the model size. In other words, such technology will help a higher element ratio of casting part to full mould elements numbers.

b) Good geometry description for cooling channel and other components. The cooling channel diameter is usually smaller compared with the full mould size. The tetrahedron element generated from the surface triangle element can have a good geometry description in the high curved area.

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c) Good thermal analysis capability. The tetrahedron still has a good result for thermal simulation.
d) Save CPU time. Since the mould size is economic, so the CPU time of simulation is also saved. This is very useful for the cycling simulation, since 5 to 10 cycles is necessary for a stable thermal analysis.
With the innovative technology, the full mould meshing and assembly could be carried out easily and it has been done in Cast-Designer in one button. There is a lot of innovation, technology behind the button. One of them is the re-mesh technology. After build the Volex model of the mould, we need make re-mesh operation to recover the surface mesh.

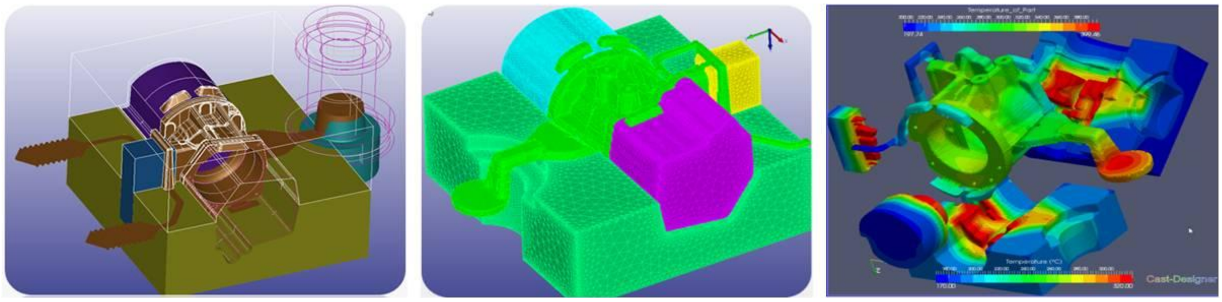


Fig.1. Mesh technology of Cast-Designer

	Elements	Nodes	
Casting Part	87235	117336	Hexahedron
Slider-1	28173	8269	Tetrahedron
Slider-1	89883	24345	Tetrahedron
Slider-1	66832	18613	Tetrahedron
Sleeve	134728	37502	Tetrahedron
Movable Die	206523	55997	Tetrahedron
Fix Die	164375	44993	Tetrahedron
Total	777749	307055	Tetrahedron
Effective Ratio	11.2%	38.2%	

Table.1. the mould assembly performance of Cast-Designer

III. METHODOLOGY

Cast-Designer Production

The Casting Production module is specially designed for the process optimization during the mass production to achieve the best productivity and cost rate, as well as the product quality. There are so many headache problems in such process and must be answered by the production engineers, such as,

- Thermal Balance: it can help smooth out the hot spots and prevent soldering.
- Do not over cool any portion of the die, to maintain a reasonable temperature during the full production cycle
- Uniformity temperature across the die surface, it is very useful to maintain the flatness of parts.
- Begin to shorten cycle times without creating thermal extremes.
- Monitor the die / cooling line performance
- Document die heat-up performance as a function of number of shots
- Confirm simulation and solidification studies

Casting Production optimizes the cooling channel and production cycle, to maintain a reasonable mould temperature. Also, Casting Production is fully automatic and easy to use.

a. Heat balance and cycle wizard

The cycle wizard help user to predict the best cycling time base on the thermal balance. The means the heat transferred in from the hot liquid metal should be equal to the heat transfer out from the cooling channel and mould surface.
The user need define the basic information of the casting part, the mould and cooling system, then the system will calculate the cycling time and production rate automatically. The cooling system information includes the media temperature, flow speed and channel length and diameter. Please note, this value has been just base on the heat balance and did not consider any work process condition, so it is usually shorter than the actual one. The user can adjust the heat affection rate to balance the cycling time.

b. Process Layout

One full thermal cycle includes all the steps for producing one cast part. This cycle can be divided into homogeneous sub-steps that are performed sequentially; the more sub-steps identified, the more accurate the corresponding simulation results. For this experiment, the thermal cycle was divided into several different segments. These sub-steps comprised:

Stage-I, Starting the cycle and filling the casting part

Stage-II, Open moulds and ejects part

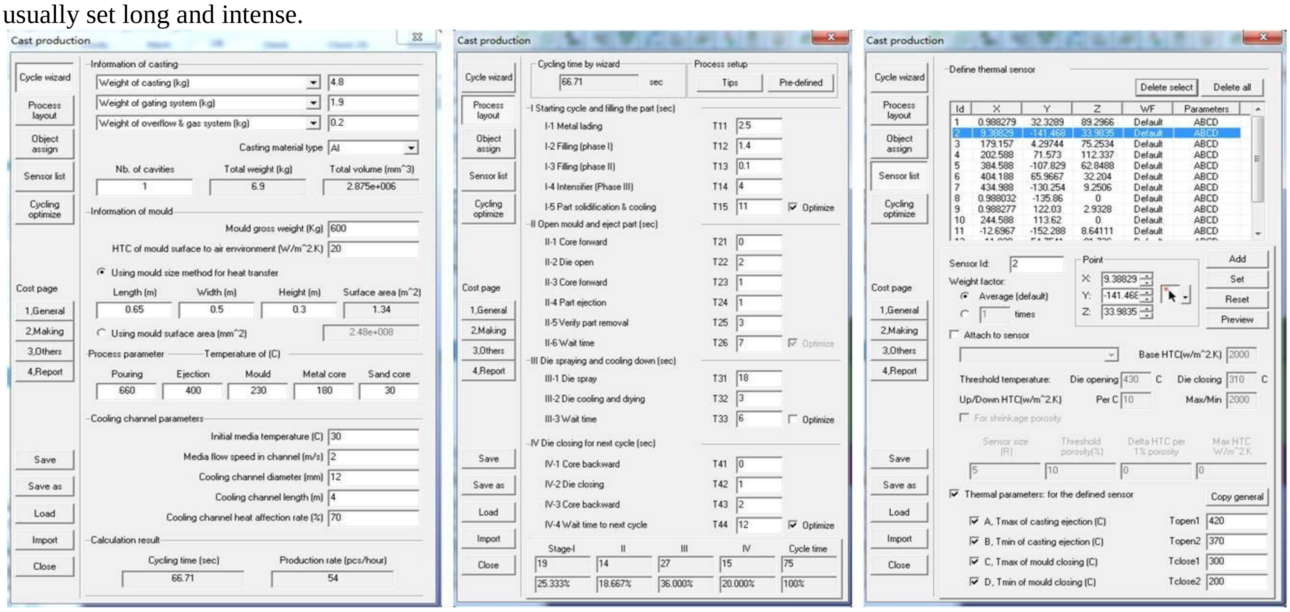
Stage-III, Die spraying and cooling down

Stage-IV: Die closing for next cycle

All above operations has been summarized to the process layout page. The user can define it with the guide of tips or wizard. The layout page based on the high pressure die casting process, but also could be used for other process, such as low pressure die casting and gravity die casting etc.

c. Die spraying

In order to cool the die cavity and to lubricate it to aid part removal, Die spraying is the necessary operation. If the die temperature in the die for aluminium alloys rises too high, there will soon occur soldering in the hottest places. If there is not enough lubricant in the spraying water or if there is too much lubricant then the casting will stick to the cavity or Part will stick too. So, according to the requirements, the spraying time and intensity are going to be selected. If there are shapes with a large surface area compared to the die material volume under the surface then the spraying time is usually set long and intense.



(a) (b) (c)

Fig.2.Cast-Designer (a) Production cycling wizard (b) Production layout (c) Sensor define

d. Die cooling and drying

In order to secure as small moisture content inside the die, Die cooling and drying is needed. Porosity problems are caused by the Moisture. If the drying and cooling time is the longer then causes more difficulties in spraying the die cavity. The cooling time has to be as long as 6 – 8 seconds in some cases.

e. Total casting cycle length

In total the casting cycle length may vary from approximately 30 seconds up to 1 minute 30 seconds. The most influential details are:

- Largest casting wall thickness
- spraying efficiency and the degree of difficultness in spraying
- Core movement device efficiency
- Robot movements efficiency
- Overall efficiency in the equipment

The system can optimize the following parameters of the process: T15: part solidification & cooling time; T33: wait time when the mould was opened; T44: wait time when the mould was closed. For T33 and T44, the user can select one only.

f. Sensor define

To run the optimization, the user must define some sensor on the model. During the calculation, the solver will check the data of the sensor, and then make the action plan for the next step. So, Sensor is the nose of the optimization.

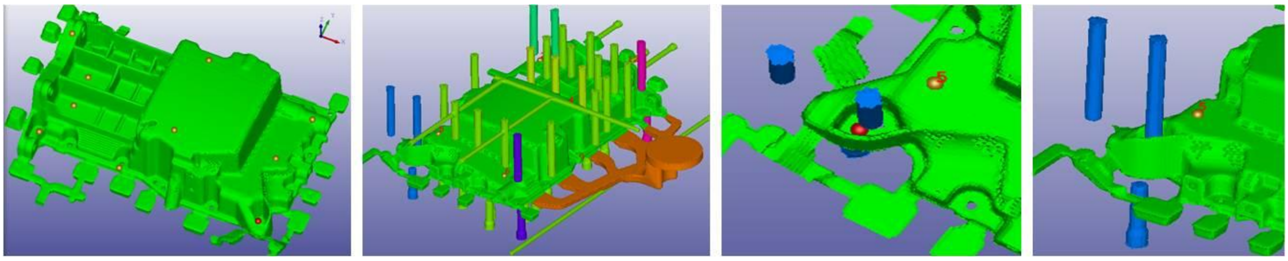
Define the sensor is very simple; the user selects one point from the model and define the thermal parameters of the sensor. The main parameters of the sensor include,

- Maximum temperature of casting ejection: define the maximum temperature before part ejection. Above this temperature, the part was not stiff enough and easy to damage by ejection. For aluminium alloy, 400 degree could be considered as a reference.
- Minimum temperature of casting ejection: sometimes, if the temperature of the casting part was too low, then the ejection force will be increased a lot, so we can define the minimum temperature before part ejection. It could be applied to the region with higher ejection force.
- Maximum temperature of mould closing: define the maximum temperature when closing the mould for the next cycle. A higher temperature will affect the solidification of the casting part; also bring big affection of the mould life time.
- Minimum temperature of mould closing: define the minimum temperature when closing the mould for the next cycle. A balance mould temperature is useful to maintenance a good part quality.
- Main casting ejection: min solid factor ratio (%): define the minimum solid factor ratio in the main casting before ejection. This is a global parameter to apply to the whole casting part.

g. Attach sensor to cooling channel

Moreover, the sensor can attach to the cooling channel, and then optimize the HTC automatically. This function is very useful for the complex cooling system since the user does not know how to set the exact value for the channels.

The user need separate the cooling surface at first; it will be linked to the sensor point. Then make the standard definitions in Cast-Designer CPI in a standard HTC value. The cooling surface could be one channel or several channels. General speaking, the linked cooling channel can affect the assigned sensor result directly, so it should be quite close.



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

Fig. 3. Cast-Designer (a) Production sensor defines (b), (c) & (d) Define sensor attached to the cooling channel

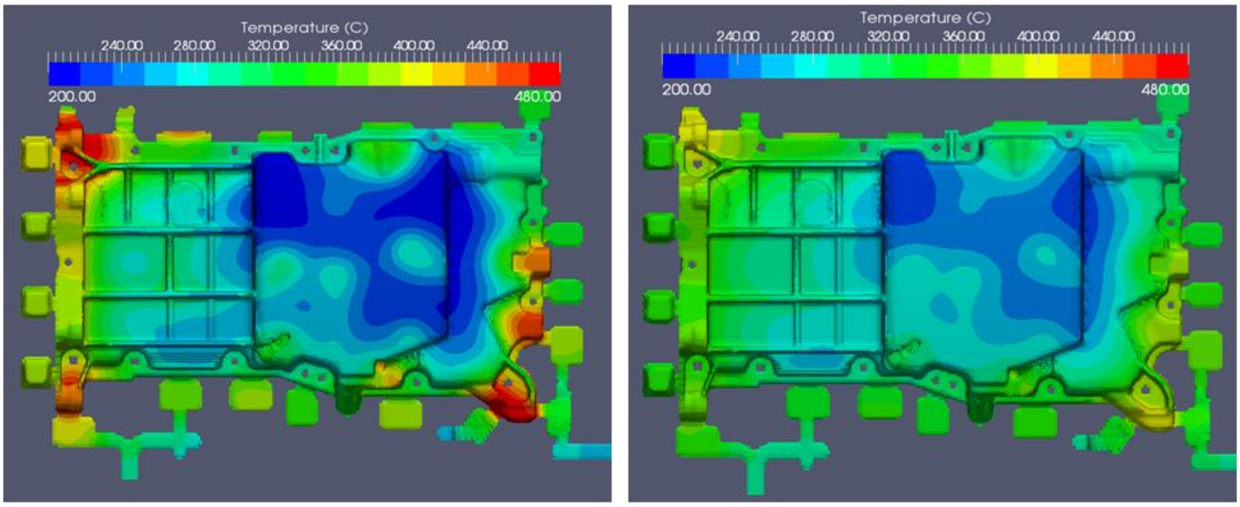
IV. EXPERIMENTAL RESULTS

The optimization is fully automatic and easy to use, all parameters can be saved to file to reuse in the later. The optimization solver will call the model generation and Cast-Designer CPI solver automatically. The user can define the boundary conditions and simulation cycles, same as normal cycling simulation.

For each iteration, the system will report the optimized result, such as the new mould opening time, mould closing time and total cycling time. The file optimization result will be output in the Project_iter_i_Report.txt file. The format is similar as below.

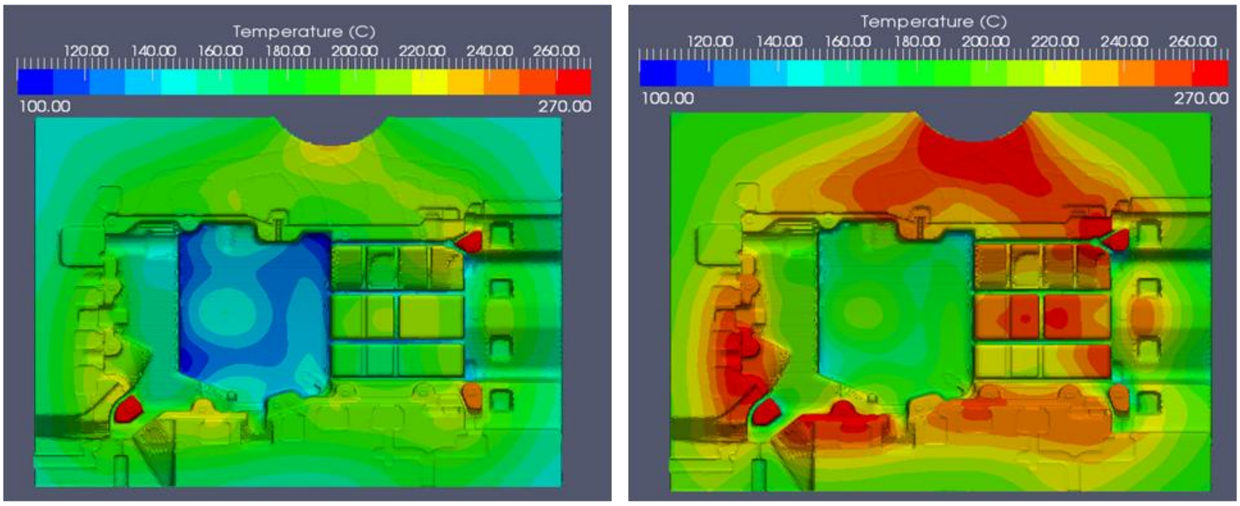
```
***  CYCLING DATA  ************************************************
I, Start cycle and filling part (sec)
I-1  Metal lading                     T11          2.5
I-2  Filling (phase-I)                T12          1.4
I-3  Filling (Phase-II)               T13          0.1
I-4  Intensifier (Phase-III)          T14          4
I-5  Part solidification & Filling    T15          8.92125    <OPT>
--------------------------------------------------
                                 Subtotal         16.9212    25.6319
II, Open mould and eject part (sec)
II-1  Core forward                    T21          0
II-2  Die open                        T22          2
II-3  Core forward                    T23          1
II-4  Part ejection                   T24          1
II-5  Verify part removal             T25          3
II-6  Wait time                       T26          7          <OPT>
--------------------------------------------------
                                 Subtotal         14         21.2069
III, Open mould and eject part (sec)
III-1  die spary                      T31          18
III-2  Die cooling & dry              T32          3
III-6  Wait time                      T33          6
--------------------------------------------------
                                 Subtotal         27         40.899
IV, Open mould and eject part (sec)
IV-1  Core backward                   T41          0
IV-2  Die closing                     T42          1
IV-3  Core backward                   T43          2
IV-4  Wait time to next cycle         T44          5.095      <OPT>
--------------------------------------------------
                                 Subtotal         8.095      12.2621
                       Total cycling time         66.0163

**  SENSOR LIST  **********************************************
```

Fig.4.Cast-designer Optimization Result



(a) (b)

Fig.5. (a) Casting temperature before optimization, (b) Casting temperature after optimization



(a) (b)

Fig .6. (a) Mould temperature before optimization, (b) Mould temperature after optimization

V. CONCLUSION

1) A new approach to optimize the casting production cycling time has been developed based on the numerical simulation and KBE system. Compared with the traditional numerical simulation method, it was ten times faster and the result was very easy to understand.
2) This method has been integrated to the Cast-Designer software and has been validated by industrial models. In the example of this paper, with 3 iterations, the cycling time could be reduced from 86 seconds to 66.1 sec, or save 23.1% .
3) The optimized cycling plan with better cooling system arrangement could balance the mould temperature and reduce the difference of highest temperature and lowest temperature, then extend the die life time.

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