Algorithm for calculating parameters of mold temperature controller

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Abstract. In the problem of mold heating proper parameters of mold temperature controller are important for mold temperature, but the parameters are hard to calculate for numerous computing amount, and simulating its state during heating is also difficult for there is a limitation for flow velocity of hot water that simulating will be failure when large velocity. To solve this problem the paper presents an algorithm based on the fast algorithm for heating injection mold by water. A mold temperature equation is established, and the dichotomy method based on the fast algorithm as a core is used to numerically solve the mold temperature equation. The first step of this process is to construct a similar model having the same solution with the original model of the mold heating problem. The similar model is obtained by similarity transformation to the original model. The second step is to solve the similar model, which is fast than solving the original model. The third step is to find solution of the mold temperature equation meeting the heating conditions. An example is given to show that parameters of mold temperature controller are easy to calculate.

Keywords: Mold temperature controller parameters, Fast algorithm, Mold heating, Similarity transformation.

1 Introduction

Mold heating is a necessary step for injection production. The suitable mold temperature is 80~90℃. Before the injection production it needs to be heated to the temperature higher than ambient temperature. The common ways to heat mold are electric heating, oil heating and water heating. For electric heating the power of the electric heating rod, the distance between rods and the longitudinal distance on the cavity, surface temperature response rate and surface temperature uniformity are the main factors to the mold temperature [1]. The influence of the gap between the electric heating rod and the mold mounting hole are studied about the heating efficiency of the mold [2, 3]. The thermal response curves of the mold surface for different gaps are obtained through three-dimensional transient heat transfer simulation analysis and experimental verification. The contact condition between the electric heating rod and the mold is improved by filling a

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thermal fluid between the electric heating rod and the mold. And Simulation and experimental research show that this method heating efficiency is effectively improved.

An inverse problem of the heat source strength of the mold electric heating system is studied [4], and a multiple sources inversion algorithm for the heat conduction of the mold heating system is put out. It takes a single cavity and reaction curing mold as an example to show that this multiple sources inversion algorithm is effective and reliable. For electric heating injection mold two-dimensional and three-dimensional thermal response analysis model are used to obtain the thermal response law and temperature distribution law of the mold cavity surface during the heating process and the cooling process [5]. And it discusses the influence of mold structure, heating rod and mold material on mold thermal response efficiency and temperature uniformity. In the process of electrothermal rapid variable temperature injection molding the constant mold surface temperature is important [6], and the influence of different heating rods' heat flux density on the mold surface temperature is analyzed. It gives out the criteria about heat flux density of the heating rod for improving the uniformity of mold surface temperature.

Yuk-Jae Kwon etc. [7] studied the design of aluminum alloy die-casting die by the CAE method, effectively optimized the die-casting system, and improved the design efficiency of aluminum alloy die-casting. Florian etc. [8] put out a new simulation method for reaction injection molding after studying the injection molding simulation about short fiber reinforced thermosets with anisotropic and non-Newtonian flow behavior. Wendell Rossine etc. [9] used numerical simulation to study the thermo mechanical behavior of cement sheath in wells subjected to steam injection, and provided a good guide to its forming parameters. Combined coordinate translation with mass scaling Liu Hong etc. [10] put forward an equivalent method for simulation of forming process for tube bends, it could not only greatly raise simulation efficiency, but also has enough analysis precision. Chen Yun etc. [11] analyzed the entire set of injection molds for the car GPS navigation shell by thermal-mechanical coupling numerical simulation using Moldflow and ANSYS Workbench software.

Liu Hong etc. [12] proposed a fast algorithm for water heating simulation of injection molds. Simulating mold heating, one of the problems is that the amount of calculation is large because the size of the mold channel is much smaller than that of the mold resulting in a very dense grid. The other is the boundary condition limitation that the water velocity cannot be too large; otherwise the algorithm is prone to failure and error. The fast algorithm effectively solves these problems.

Water heating has now become main stream in recent years, and water heating equipment, mold temperature controller is the ideal equipment for mold heating and water recycling. The parameters of water heating include water temperature, velocity and flow rate. To heat a specific mold, it needs to determine the heating time for the mold to reach a given temperature under the specific conditions of water temperature and velocity. Relying on experience and experiments in the past, the method is simple but requires repeated trials and the error of the results is large. Aiming at this problem, this paper applies the fast algorithm [12] to the parameter calculation of mold temperature controller. It gets the parameters of mold temperature controller by solving mold temperature equation.

2 The fast algorithm

In the fast algorithm of mold water heating [12] a similar model is established through similarity transformation of the original model of the mold heating problem, and it is simulated fast to obtain the mold temperature after water heating. The procedure of fast algorithm for water heating simulation of injection mold is as follows:

1) Similarity transformation for basic equations of fluid motion in time domain.

2) Similarity transformation for basic equations of mold heat conduction.

3) Similar calculation for fluid flow velocity and density, solid specific heat capacity to get similar model, and then simulation for similar model.

The main point is similarity transformation to establish a similar model. The core is as follows. The first step is time domain transformation, the time domain of the original model is [0, β], and the time domain of the similar model after transformation is [0, αβ]. The second step is governing equation transformation; the basic equation of fluid motion describing the flow velocity of heated water and the basic equation of heat conduction describing the heating of the mold are similarly transformed. And the last step is solving similar models in the time domain [0, αβ].

The above steps could be carried out simply by completing the following calculation.

$$t_1 = \alpha t \tag{1}$$

$$u_{1i} = \alpha u_i \ (i = 1,2,3) \tag{2}$$

$$\rho_{f1} = \rho_f / \alpha \tag{3}$$

$$c_1 = \alpha c \tag{4}$$

In these formulas, α is the similarity transformation coefficient, t means time, whose domain is [0, αβ]. And $u_{1i} \ (i = 1,2,3)$ are the three components of the water velocity in coordinate direction, ρ_f represents the density of water, c represents the specific heat capacity of the mold.

In order to facilitate the distinction in the transformation calculation, the subscripts f and g respectively indicate fluid and solid variables, and the variables of the similar model are subscript 1 to distinguish the variables of the original model. The density of solids and the thermal conductivity of fluids and solids in similar models remain unchanged.

If the similarity transformation coefficient is less than 1, the time domain of the similar model becomes smaller and the water flow velocity becomes smaller, the solution of the similar model not only improves the stability of the analysis, but also greatly reduces the amount of simulation calculation.

3 Algorithm for parameters of mold temperature controller

The above fast algorithm has very good application prospect in mold design and production. This paper gives out an algorithm for calculating parameters of mold temperature controller. After mold design the parameters of mold temperature controller are needed to choice because the efficiency of mold heating depends on the water pipe layout in mold and the parameters of mold temperature controller.

Because pipe diameter for mold heating water is much smaller relative than mold size the water flow could be considered as one dimensional flow, the direction of velocity vector of the water is the pipe direction, and vector mode uses *u* representation.

The parameters of mold temperature controller are mainly water velocity, water temperature and outlet section area of water pipe of mold temperature controller. For selection of mold temperature controller the known conditions are: ambient temperature T_h, water temperature T_s, mold initial temperature T_0, mold working temperature T_m, heating time β, and outlet section area A of water pipe. The problem is to give out the water

velocity u (denoted by u_m) for heating mold from T_0 to T_m within β. This requirement can be expressed by a mold temperature equation:

$$\left|T - T_m\right| \le \varepsilon \quad (t_1 \le \alpha\beta) \tag{5}$$

Where: ε is permissible error, $T \propto u, \beta, A$. Because analytic solution is difficult to get, trial calculation is commonly used way. But as mentioned above it needs great amount of calculation, leading to solving difficult. Based on the fast algorithm for heating injection mold by water [12], improvement of calculation efficiency makes the solving possible. On this basis the paper gives out an algorithm for calculating the parameters of mold temperature controller.

Analysis process:

1) According to the velocity ranges of hot water for mold temperature controller permissible error ε and [ua, ub] are given. Several points on mold surface are chosen as measuring points and takes arithmetic mean of their temperatures as mold temperature.

2) In the heating time domain [0, β] the similarity transformation is applied to obtain similar model, and mold temperatures Ta, Tb corresponding to the velocity ua, ub are gotten by solving the similar model.

3) If abs（（Ta+ Tb）/2-Tm）<ε, then um= (ua+ ub)/2, go to step 5;

If Ta-Tm>0, β= β/2, back to step 2;

If Tb-Tm<0, β= β*2, back to step 2;

If Tb-Tm>0, Ta-Tm<0, then ub1= (ub+ ua)/2, calculating Tb1;

4) If Tb1-Tm>0, ub2= (ub1+ ua)/2, back to step 2;

If Tb1-Tm<0, ub2= (ub+ ub1)/2, back to step 2;

5) Giving out analyzing results: flow velocity, flow rate of hot water, and mold temperature. That is, for specific shape of injection part, mold size and water pipe layout the flow velocity um and flow rate Aum of hot water are obtained easily under the condition of giving the heating time β and expected mold working temperature Tm.

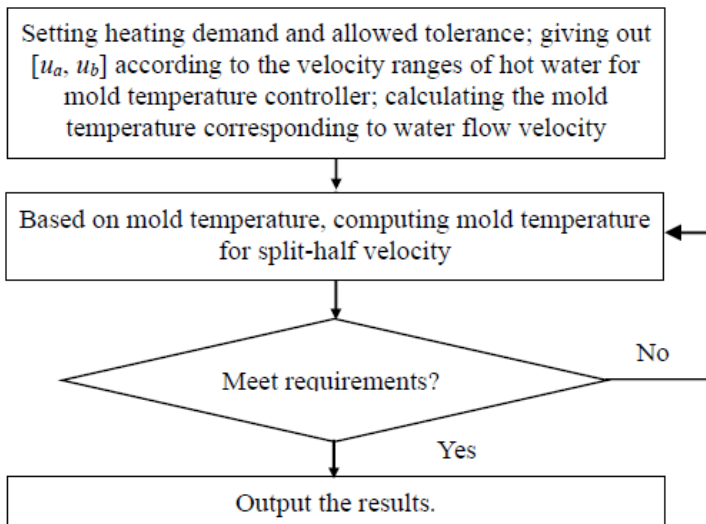Procedure of parameters calculation for mold temperature controller is shown as in Figure 1.

Fig. 1. Procedure of parameters calculation for mold temperature controller.

4 Specific implementation examples

The following example is used to further illustrate the effectiveness of above algorithm. The example is parameters calculation of mold temperature controller for water heating. Without above algorithm such calculation couldn't be carried out for large water velocity.

The problem is described as follows: 295 mold, mold initial temperature 25℃, ambient temperature 25℃, hot water temperature 90℃, heating time β=1800s, the length of mold water pipe is about 2.2m, and the section area of water pipe is A=$\pi\times$25mm^2.

Demand: under the condition of giving the heating time β it's expected to heat mold to working temperature 88℃, i.e., T_m=88℃=361.15K, give out flowrate of hot water.

Analysis process:

1) The length of mold water pipe is rounded to 2m. According to the velocity ranges of hot water for mold temperature controller the permissible error ε and [u_a, u_b] are given, ε=0.1, [u_a, u_b] =[1,4] m/s;

It chooses a point (0.097,0.021)m on mold surface as measuring point and takes its temperature as mold temperature, See the circle in Figure 2.

2) On the heating domain [0, β]=[0, 1800]s the fast algorithm is applied to calculate mold temperatures T_a and T_b corresponding to water flow velocity u_a、 u_b after transformation. According to experience requirements, that is, the water flow velocity should be less than 1, taking the similarity transformation coefficient α=1/6.

Water velocity u_a=1m/s, temperature of measuring point T_a=357.993K, T_a-T_m=-3.157<0, see Figure 2.

Water velocity u_b=4m/s, temperature of measuring point T_b=361.252K, T_b-T_m=0.102>0, see Figure 3.

3) According to the step 3, take water velocity u_{b1}=(u_b+ u_a)/2 = 2.5m/s, calculating T_{b1}, temperature of measuring point T_{b1}=360.795, T_{b1}-T_m=-0.355<0, see Figure 4.

4) Take water velocity u_{b2}=(u_b+ u_{b1})/2 =3.25m/s, calculating T_{b2}, temperature of measuring point T_{b2}=361.079K, see Figure 5.

Because (361.079+361.252)/2-361.15=0.0155＜0/1=ε, so water velocity is 3.625m/s.

5) Analysis result.

According to the feasible water velocity u_m=3.625m/s, obtained after above calculating, the flow rate of hot water for mold temperature controller is given out as: 3.625×π× 25×10^{-6}m^3 = 0.2847×10^{-2}m^3. And the mold temperature after heating at u_m is 88.1℃ using the fast algorithm.
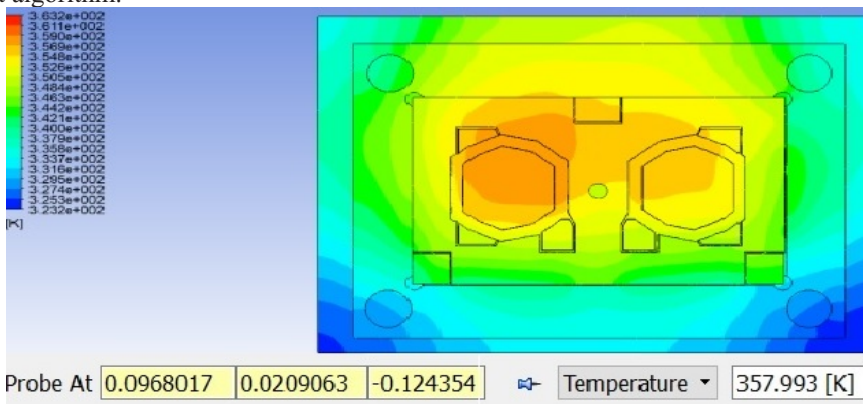

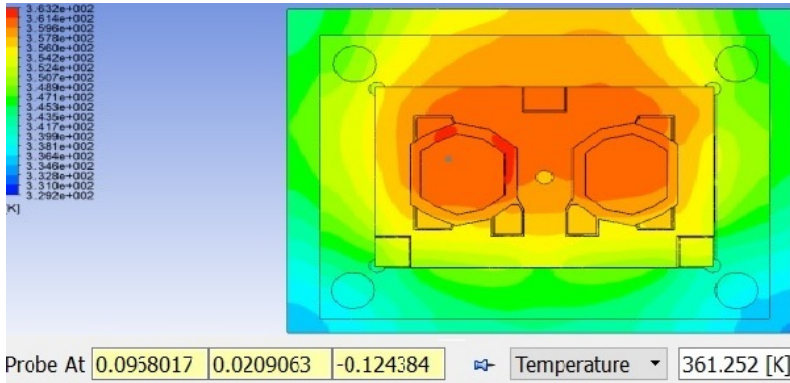**Fig. 2.** Numerical result at step 2 for u_a=1.

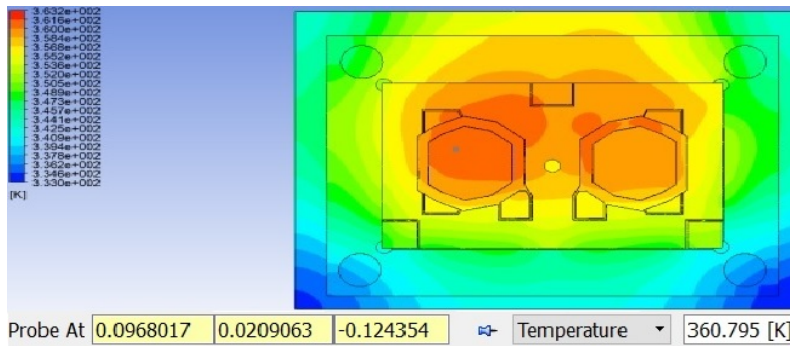**Fig. 3.** Numerical result at step 2 for u_b=4.
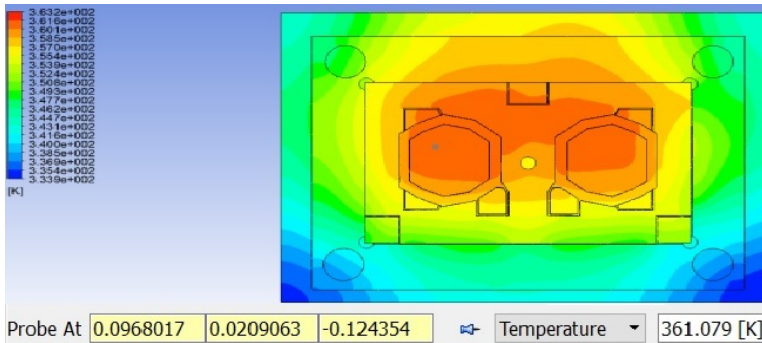

Fig. 4. Numerical result at step 3.

Fig. 5. Numerical result at step 4.

5 Conclusions

Since the simulation of the working state of the injection mold temperature controller involves the mathematical problem of fluid-solid coupling the huge amount of calculation makes the choice of parameters of the mold temperature controller difficulty. This paper proposes an algorithm for calculating the parameters of the mold temperature controller based on the fast algorithm of mold water heating. The example shows that the calculation for parameters of mold temperature controller is simple and convenient, and it has good engineering practical value.

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