Algorithm for calculating parameters of mold temperature controller

Hong Liu, Danqi Pan*, and Zheqi Jiang
College of Mechanical Engineering, Zhejiang University of Technology, Hangzhou, China

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°C. 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

* Corresponding author: pandanqi@outlook.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).
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 \([0, \beta]\), and the time domain of the similar model after transformation is \([0, \alpha \beta]\). 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 \([0, \alpha \beta]\).

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

\[
\begin{align*}
    t &= \alpha t \\
    u_{i_i} &= \alpha u_i \quad (i = 1, 2, 3) \\
    \rho_{f1} &= \rho_f / \alpha \\
    c_i &= \alpha c
\end{align*}
\]

In these formulas, \(\alpha\) is the similarity transformation coefficient, \(t\) means time, whose domain is \([0, \alpha \beta]\). And \(u_{i_i} \quad (i = 1, 2, 3)\) are the three components of the water velocity in coordinate direction, \(\rho_f\) 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 \(\beta\), 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 \( \beta \). This requirement can be expressed by a mold temperature equation:

\[
|T - T_m| \leq \varepsilon \quad (t_1 \leq \alpha \beta)
\]

(5)

Where: \( \varepsilon \) 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 \( \varepsilon \) and \([u_a, u_b]\) 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 \([0, \beta]\) the similarity transformation is applied to obtain similar model, and mold temperatures \( T_a, T_b \) corresponding to the velocity \( u_a, u_b \) are gotten by solving the similar model.

3) If \( \text{abs} \left( \frac{T_a + T_b}{2} - T_m \right) < \varepsilon \), then \( u_m = \frac{u_a + u_b}{2} \), go to step 5;
   If \( T_a - T_m > 0 \), \( \beta = \frac{\beta}{2} \), back to step 2;
   If \( T_b - T_m < 0 \), \( \beta = \frac{\beta}{2} \), back to step 2;
   If \( T_b - T_m > 0 \), \( T_a - T_m < 0 \), then \( u_{b1} = \frac{u_b + u_a}{2} \), calculating \( T_{b1} \);
4) If \( T_{b1} - T_m > 0 \), \( u_{b2} = \frac{u_{b1} + u_a}{2} \), back to step 2;
   If \( T_{b1} - T_m < 0 \), \( u_{b2} = \frac{u_b + u_{b1}}{2} \), 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 \( u_m \) and flow rate \( A_{um} \) of hot water are obtained easily under the condition of giving the heating time \( \beta \) and expected mold working temperature \( T_m \).

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

![Flowchart of algorithm](image-url)

**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 the 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 °C, ambient temperature 25 °C, hot water temperature 90 °C, heating time β = 1800s, the length of mold water pipe is about 2.2m, and the section area of water pipe is A = π × 25mm².

Demand: under the condition of giving the heating time β it’s expected to heat mold to working temperature 88 °C, i.e., Tm = 88 °C = 361.15K, give out flow rate 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 [ua, ub] are given, ε = 0.1, [ua, ub] = [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 Ta and Tb corresponding to water flow velocity ua, ub 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 ua = 1m/s, temperature of measuring point Ta = 357.993K, Ta - Tm = -3.157<0, see Figure 2.

   Water velocity ub = 4m/s, temperature of measuring point Tb = 361.252K, Tb - Tm = 0.102>0, see Figure 3.

3) According to the step 3, take water velocity ub1 = (ub + ua)/2 = 2.5m/s, calculating Tb1, temperature of measuring point Tb1 = 360.795, Tb1 - Tm = -0.355<0, see Figure 4.

4) Take water velocity ub2 = (ub + ub1)/2 = 3.25m/s, calculating Tb2, temperature of measuring point Tb2 = 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 um = 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 × 10⁻⁴m³ = 0.2847 × 10⁻³m³. And the mold temperature after heating at um is 88.1 °C using the fast algorithm.

![Fig. 2. Numerical result at step 2 for um=1.](image)
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.
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 difficult. 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.

References
1. Z. Y. Xie, S. Q. Chen, L. J. Tan, etc. Study of temperature distribution of mold under temperature gradient in rapid heating process [J]. China Plastics (2019), 33(4), 59-65. (in Chinese)
2. K. Wu, H. Zhou, B. L. Wang, etc. Numerical Simulation and experiments of a new rapid mold heating method for rapid heat cycle molding [J]. Engineering Plastics Application (2017), 45(2), 77-81. (in Chinese)
3. K. Wu, H. Zhou, B. L. Wang, etc. Effect of gap on thermal response efficiency in heating process of RHCM [J]. Engineering Plastics Application (2017), 45(7), 73-79. (in Chinese)
4. J. G. Li, H. Liu, K. Lin, etc. Theory and experimental research on the multiple source heat conduction inversion of the polymer curing reaction mould heating system[J]. Journal of mechanical engineering (2016), 52(14), 174-181. (in Chinese)
5. J. C. Wang, L. Chen, G. L. Wang. Research on thermal response analysis of electric heating rapid thermal cycle injection mold [J]. Mold Technology (2013), 6, 6-12. (in Chinese)
6. T. D. Li, Z. Y. Shen, Jia Yadong, etc. Study on optimization of heating system of electric-thermal variable-temperature injection mold[J]. Plastic Industry (2019), 47(01), 51-55+78. (in Chinese)
7. Yuk-Jae Kwon, Hong-Kyu Kwon. Computer aided engineering (CAE) simulation for the design optimization of gate system on high pressure die casting (HPDC) process. Robotics and Computer-Integrated Manufacturing (2019), 55, Part B, 147-153.
8. F. Wittemann, R. Maertens, L. Kärger, F. Henning. Injection molding simulation of short fiber reinforced thermosets with anisotropic and non-Newtonian flow behavior. Composites Part A: Applied Science and Manufacturing (2019), 124, Article 105476.
9. W. Rossine, M. Souza, N. Bouaanani, A. E. Martinelli, U. T. Bezerra. Numerical simulation of the thermomechanical behavior of cement sheath in wells subjected to steam injection. Journal of Petroleum Science and Engineering (2018), 167, 664-673.
10. H. Liu, P. P. Jia. Method of rising simulation efficiency for tube bends [J]. Computer Simulation (2015), 32(10), 234-238. (in Chinese)
11. Y. Chen, H. D. Cai. Numerical simulation analysis of thermo-mechanical coupling of injection mold for GPS navigation shell [J]. Plastic Industry (2020), 48(12): 96-100. (in Chinese)
12. H. Liu, H. J. Chen, F. Chen, etc. Fast Algorithm for Heating Injection Mold by Water [J]. Journal of Physics: Conference Series, 042018 (2020.11)