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Research on Furnace Temperature Curve Control Based on Genetic Algorithm

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Abstract: *Electronics are widely used in everyday life, and in the production of electronic products various electronic components need to be soldered to printed circuit boards. With the miniaturization of electronic components, traditional soldering methods cannot be completed. Reflow soldering technology can be used to complete the printing of tiny electronic components, and in this process, it is critical to the quality of the product to maintain the proper process temperature for each part of the reflow soldering. In this paper, how to achieve temperature control in this process is studied and solved by establishing a mathematical model about differential equations. First, by analyzing the heat transfer of air in the reflow oven, it is found that the air in the oven satisfies the heat transfer equation. Secondly, the temperature of the small temperature zone in the base data is used to obtain the temperature distribution in the furnace at steady state. Again, the temperature of the temperature zone and the speed of the conveyor belt are determined so as to achieve the minimum target area. By constructing the model of genetic algorithm, the area minimization is used as the fitness function. Finally, in this paper, we make the images on both sides from 217℃ to the peak temperature as symmetrical as possible. For this problem, we can still build the fitness function by genetic algorithm to solve it.*

Keywords: *Furnace temperature profile; finite difference method; heat conduction equation; fixed-step search method; genetic algorithm*

1. Introduction

First, in this paper, the heat transfer equation is obtained from the data related to the temperature variation of the center of the welding zone with time in a particular case. Using the known temperature of each small temperature zone using the heat transfer equation to obtain the temperature distribution of the furnace temperature with distance. Then, using the heat conduction differential equation model corresponding to the conditions of the problem, the temperature corresponding to each moment is found by the finite difference method and the image of the temperature variation of the center of the weld area over time is plotted.

Next, the maximum conveyor overheating speed that satisfies the process boundaries is found by using the fixed-step search method. All the values to be searched are substituted into the model to obtain the temperature variation curve for each conveyor belt speed, which is compared with the process limits and the speed values that do not meet the process limits are removed to find the maximum conveyor belt speed that meets the conditions.

Again, we solve the problem by building a model of genetic algorithm, using the magnitude of the value corresponding to the constant integral of the covered area as the fitness function. The furnace temperature profile corresponding to a specific case is obtained, and the adaptation function is minimized on the basis of satisfying the process limits, i.e., the area of the corresponding region is minimized.

Finally, based on the fact that more cases can be obtained through variational propagation, the corresponding cases are obtained through decoding and substituted into the model so as to obtain the corresponding furnace temperature profile. The problem is solved by establishing an adaptation function of size as the sum of the squares of the differences of the temperature change rates of the corresponding moments on both sides, using a genetic algorithm thus.

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2. Assumptions

We use the following assumptions.

(1) Assume that the thermal conductivity of the welded area does not vary with time and ignore the effect of time on the thermal conductivity of the welded area.

(2) Assume that the effect of heat radiation is ignored in this question.

(3) Assume that no heat loss occurs during the exchange of gas temperatures in the furnace.

(4) Assume that the air temperature within the small temperature zone remains constant and that there is little interaction between the temperature zones.

(5) Assume that the boundaries of the welded object can be quickly brought into agreement with the ambient temperature when it enters the temperature field.

3. Symbol Description

Description and explanation of the symbols used in this article are shown in Table 1.

Table 1: Description and explanation of the symbols used in this article

Symbol Name	Description and explanation of the symbols
a	Product of coefficients in the heat conduction equation
λ	Thermal conductivity
ρ	Density
C_P	Constant pressure heat capacity
u	Temperature
ω	Optimal number of codes
h	Step size for fixed-step search
θ	Population fitness function
t	Time
T_{out}	Weld object boundary temperature
T_{in}	Welding center area temperature
v	Belt speed of conveyor belt
q	Heat flow density
λ_i	The number in the first position of the binary code

4. Model construction and solving

4.1 Mathematical modeling of the temperature variation pattern in the welding area

There are three forms of heat transfer, namely: heat radiation, heat conduction, and heat convection.

Heat conduction refers to the phenomenon of energy transfer through microscopic vibrations, displacements and mutual collisions of molecules, atoms and electrons inside an object when there is a temperature difference between different objects or inside the same object. Heat conduction is the main mode of heat transfer from solids. In fluids such as gases or liquids, the process of heat conduction often occurs simultaneously with convection[1]. The heat conduction equation is expressed through Fourier's law of heat transfer as follows.

$$q = -\lambda \frac{dT}{dx} \tag{1}$$

Thermal radiation, objects due to the temperature and radiation of electromagnetic waves, known as thermal radiation. All objects with a temperature above absolute zero can produce thermal radiation, the higher the temperature, the greater the total energy radiated. The spectrum of thermal radiation is a continuous spectrum, wavelength coverage from 0 to ∞ in theory, the general thermal radiation mainly

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by the longer wavelength of visible light and infrared radiation propagation. The expression of thermal radiation can be calculated by this law.

$$E = \varepsilon\delta T^4 \tag{2}$$

Thermal convection is a heat transfer process in which relative displacement of masses within a fluid occurs. Since the parts of the fluid are in contact with each other, in addition to the thermal convection due to the overall motion of the fluid, there is also an accompanying heat transfer due to the motion of the microscopic particles of the fluid [1].

The basic formula for convective heat transfer is Newton's law of cooling, which describes the process of heat exchange between a fluid and the surface of an object.

$$q = h\Delta T \tag{3}$$

(1) Temperature distribution inside the furnace under steady state condition

When the reflow furnace starts working, the air temperature inside the furnace will reach stability quickly in a short time. Since the gap between the pre-furnace area, post-furnace area and small temperature zones is not made special temperature control, and their temperature will be influenced by the nearby small temperature zones. Therefore, it is necessary to use the heat conduction equation to obtain the temperature distribution of the furnace temperature with distance after each temperature zone reaches steady state at the set temperature.

During the start of the reflow furnace operation, the air temperature inside the furnace is transformed from non-steady state to steady state. In this process, we need to utilize to the one-dimensional heat transfer equation, which can be expressed as [2].

$$a = \frac{\lambda}{\rho C_p} \tag{4}$$

$$\frac{\partial u}{\partial t} = \frac{\lambda}{\rho C_p} \times \frac{\partial^2 u}{\partial x^2} \tag{5}$$

The second-order partial derivative of temperature with respect to distance is equal to , which means that when the temperature inside the furnace is stable, the temperature varies linearly with distance or remains constant. For each location within the small temperature zone the temperature remains constant, and for the gap region and the front domain of the furnace, the temperature is linear with distance. The relationship between temperature and distance in the furnace at steady state can be expressed as Figure 1.

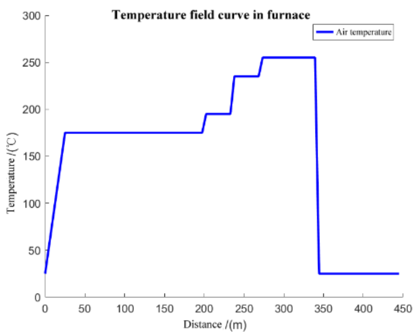

Figure 1: Distribution of air temperature inside the furnace with distance

(2) Solving the parameters of the heat conduction equation

In step 1 we obtained the heat conduction equation to plot the distribution of air temperature with distance in the furnace after reaching steady state. Assuming that the boundary of the welded object can quickly reach the same temperature as the ambient temperature, only the conduction from the boundary of the welded object to the center of the weld needs to be considered in this problem. Using the air temperature after reaching the steady state with the time provided in the annex with the temperature of the corresponding welding area as the boundary condition and the initial value condition, solving the above heat conduction equation (3) equation for a yields[3].

$$\begin{cases} \frac{\partial u}{\partial t} = a\frac{\partial^2 u}{\partial x^2} \\ u(x_0, t) = T_{\text{out}} \\ u(x_{\text{end}}, t) = T_{\text{in}} \\ u(x, t_0) = T_0 \end{cases} \quad (6)$$

The basic idea of solving heat transfer problems numerically is to discretize the continuous physical quantities in time and space at each node and solve the numerical solution of the physical quantities by the finite difference method. In this paper, the above model is discretized using the display difference format. The temperature distribution of the first time layer can be obtained from the temperature of the first time layer. After the above discretization[4], we get.

$$\begin{cases} \frac{u(x_i, t_{i+1}) - u(x_i, t_i)}{\Delta t} = a\frac{u(x_{i+1}, t_i) - 2u(x_i, t_i) + u(x_{i-1}, t_i)}{\Delta x^2} \\ u(x_0, t) = T_{\text{out}} \\ u(x_{\text{end}}, t) = T_{\text{in}} \\ u(x, t_0) = T \end{cases} \quad (7)$$

(3) the law of temperature change in the soldering area

First of all, the use of small temperature zone set temperature can be found in the furnace temperature field of the law of change, so as to obtain the entire temperature distribution in the current situation, that is, the board boundary temperature. Then the same use of the finite difference method, the above solution can be substituted to find the temperature of the center of the welding area, you can get as Figure 2.

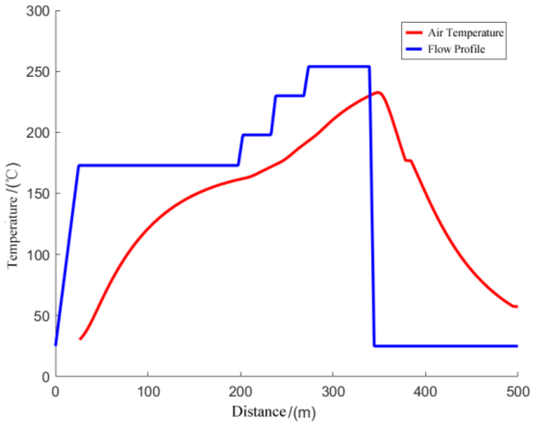

Figure 2: Plot of furnace temperature curve versus air temperature with distance

Among them, small temperature zone 3 midpoint temperature 129.3137 °C, small temperature zone 6 midpoint temperature 166.1564 °C, small temperature zone 7 midpoint temperature 181.1102 °C, small temperature zone 8 end at the center of the welding area temperature 213.1684 °C.

4.2 Maximum permissible conveyor speed through the furnace

(1) Processing of process boundaries

Table 2: Process boundary related data

Boundary Name	Lowest value	Highest value	Unit
Slope of temperature rise	0	3	℃/s
Slope of temperature drop	-3	0	℃/s
Temperature rise in process of 150 ℃~190 ℃ time	60	120	s
Temperature greater than 217 ℃ for a period of time	40	90	s
Peak temperature	240	250	℃

Table 2 provides the temperature variation requirements during the heating of the welded part, which

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can only make the final product of the required quality if the process limits are met.

For peak temperature screening, the peak of the weld part temperature profile can be compared with the peak temperature provided in the table.

For the screening of temperature rise slope or fall slope, the absolute value of the slope size of the temperature curve of the welding part can be judged.

For temperature time screening, the time difference in the process can be obtained by recording the time when the temperature changes at a specific value and subtracting the two recorded times, and comparing this time difference with the data in the table to eliminate the speeds that do not meet the process limits, leaving the speed values that meet the conditions[5].

(2) Fixed-step search method

The fixed-step search method is then used to search all positions to find the maximum overheating speed.

$$q=p+n\,h \tag{8}$$

Through this search, we find the maximum conveyor speed of 78cm/min to meet the process boundary.

4.3 Peak temperature covered by Temperature and conditions corresponding to the minimum value of area

Since the temperature has an up and down range of 10 ℃, the total variation range is 20. The variation interval of velocity is 65-100, and there are 36 cases. We need to encode all the cases, assuming that the upper limit of the one-dimensional variable range is , and the lower limit is , and the optimal number of codes is . We can obtain the following equation.

$$\omega = \log_2(b-a) \tag{9}$$

By solving the equations, we obtain the optimal number of codes corresponding to 5 and 6. Finally, a total of 26 codes are needed to represent all the cases encountered in this problem after combination. In turn, the codes that cannot be used are removed by lethal means.

Generate population: randomly generate 50 26-bit binary codes, we call any one of them an individual in the population, where the 26-bit binary code indicates a situation, and each of the first five digits indicates the size of the adjusted temperature, and the last six digits indicate the size of the conveyor belt's over-burning speed.

Mating: Any two individuals are selected from the previously randomly generated individuals, and the crossover operation probability is used to decide whether to.

Then a crossover bit is randomly found on the code and the codes of both ends of the two individuals are swapped to output a new individual.

Mutation: The mutation probability is used to decide whether to mutate or not (1 is yes, 0 is no), then a random mutation bit is found on the code, and the codes are swapped.

Then a random variant bit is found on the code and its code is changed (01 mutation) to make a new individual. The current best adaptation and the average adaptation are recorded for the new generation of individuals, and the current best coding style is recorded.

Through this process, a gradual cycle is performed until the optimal solution is output. The small temperature zones are set at 178 ℃, 202 ℃, 230 ℃, 259 ℃ , and the conveyor belt speed is 87cm/min.

4.4 Make the graph corresponding to both sides of the peak temperature as symmetrical as possible

In order to achieve a graph that is as symmetrical as possible on both sides of the peak temperature, the absolute values of the rate of change of the temperature at the symmetrical positions on both sides of the peak temperature need to be as identical as possible. The smaller the difference between the absolute values of the rates of temperature change, the more similar the trend of the two sides is. Through the idea of differentiation, we can understand that when the slope at any moment is the same, the final curve is also the same.

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Suppose the peak temperature is T_f, the corresponding moment is t_f, and 217 ℃ corresponds to a time of t_c, Δt denoting the range of symmetric regions.

$$\Delta t = t_f - t_c$$

$$G(t) = \frac{dT}{dt}. \tag{10}$$

$$\theta = \int_0^{\Delta t} \left| G\left(t_f + t\right) - G\left(t_f - t\right) \right| dt.$$

Changing the fitness function can be used for the solution of the problem. By decoding, the corresponding case is obtained, and the case is substituted into the model in problem one, and the current optimal solution is finally obtained by judging whether the process boundaries are satisfied and using the fitness function to filter the different cases. The solution is obtained for the small temperature zones set up as 179 ℃, 198 ℃, 234 ℃, 251 ℃, and the conveyor speed is 83cm/min.

5. Conclusion

First, the model developed in this paper can be solved more accurately under the current assumptions by using the traversal method. Secondly, this paper simplifies the coefficients in the heat conduction equation, which reduces the computational difficulty of the model. Finally, the genetic algorithm model developed in this paper is smaller for the problem, which effectively shortens the processing scale of the problem. However, the model in this paper uses the idea of traversal for the solution of the problem, which takes longer time.

The problem studied in this paper is how to achieve temperature control during the work of reflow soldering, in order to ensure the quality of the final product. In the process of soldering electronic components to a circuit board, the temperature at the center of the solder needs to meet the process limits. However, the most difficult part of reflow soldering is the setting of the reflow temperature profile. Previously, much of this work has been controlled and adjusted through experimental testing. The model developed in this paper can be used to set the temperature profile for reflow soldering, but it can also be used to control and set the temperature profile for other similar processes.

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