

Furnace Temperature Curve Model Based On Partial Differential Equation

Chenjuan Zhu, Yutong Song, Wenyuan Sun*

(Mathematics Department, Yanbian University, Yanji, China)

*Corresponding author

Abstract: In the production process of all kinds of electronic products such as integrated circuit board, the temperature setting of each temperature zone of the reflow furnace and the setting of the passing speed of the conveyor belt are very important to the quality of the electronic components heated in the reflow furnace. The temperature change of welding area is analyzed and studied by mathematical method in order to reveal the law of temperature change of welding area and provide theoretical basis for the study of optimal furnace temperature curve. In this paper, the mathematical model is established by the heat conduction equation, and the temperature change of the welding area is analyzed, so as to obtain the optimal temperature setting of each temperature zone and the furnace passing speed of the conveyor belt under certain conditions.

Keywords: heat conduction equation, partial differential equation, nonlinear programming

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I. Introduction

After the circuit board installed with electronic components is heated in the reflow furnace, the electronic components will be automatically welded to the circuit board. In this process, the quality of the product is closely related to the temperature of each temperature zone of the reflow furnace and the passing speed of the conveyor belt. The furnace temperature curve is the curve of the central temperature of the welding area changing with time. We can use mathematical methods to analyze and study the mechanism model to obtain the optimal temperature of each temperature zone and the passing speed of the conveyor belt, so as to obtain the optimal furnace temperature curve.

II. Establishment of heat conduction equation

In the process of studying the temperature change of welding area, the way of heat transfer should be defined first. Heat conduction is the most important way of heat transfer, ignoring the influence of heat radiation and heat convection, only considering the temperature effect of heat conduction on electronic components. When considering the establishment of the model, we establish the differential equation of heat conduction process according to the heat conduction equation.

2.1 Temperature distribution model based on heat conduction problem

When the temperature of the object is different, heat is transferred from high temperature to low temperature by conduction. The experimental results show that the thermal conductivity Q of the object per unit time is directly proportional to the heat conduction area a and temperature T . Fourier's law of heat conduction is

$$q = A\lambda \frac{T - T_0}{\delta}$$

. From the macroscopic point of view, due to energy conservation, the energy of reflow furnace is transferred to the heat of electronic components. Therefore, the differential equation of heat conduction can be obtained by combining Fourier law with energy conservation, and the relationship is :

$$\begin{cases} \frac{\partial T}{\partial t} = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \\ T(0) = T_0 \end{cases}$$

2.2 Fitting temperature changes of electronic components

After the temperature of each temperature zone and the speed of conveyor belt passing through furnace are determined as specific values, the temperature of welding area center in some positions is measured by temperature sensor, and the experimental data are obtained. We will use piecewise function to fit the data in the

experiment. We use five sections: low temperature zone 1-5, low temperature zone 6, small temperature zone 7, $T_i(t)$, $i = 1,2,3,4,5$ small temperature zone 8-9, low temperature zone 10-11 and furnace back zone. Let be a function of the temperature of the electronic component with time.

III. Solution of partial differential equation

Combined with the heat conduction equation, using MATLAB software, and mainly using the quantitative relationship given by the experimental data, we can get the following functions to represent the temperature change relationship of electronic components with time.

$$\begin{cases} T_1 = 113232 \times e^{-0.00479t} - 1162e^{-0.0073t} \\ T_2 = 0.003472 \times t^2 - 0.8817 \times t + 214.6 \\ T_3 = -0.004614t^2 + 3.103t - 262.1 \\ T_4 = -0.004828 \times t^2 + 3.095t - 249.2 \\ T_5 = 4134 \times e^{-0.009012t} - 2.242 \times 10^{10} \times e^{-0.06764t} + 2 \end{cases}$$

By using quadratic function and exponential function piecewise fitting, the function curve of each section is obtained under the condition of constant temperature in each temperature zone and the conveyor belt passing through furnace speed of 70cm/min.

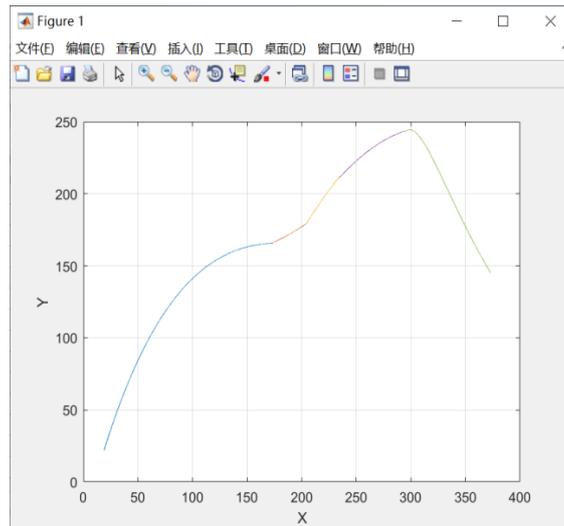


Figure 1 Fitting function of experimental data

Through qualitative analysis, it can be found that the curve first rises and then decreases. The heat conduction process is caused by the temperature difference between different objects. In the preheating zone, constant temperature zone and reflow zone, because the temperature of the reflow furnace is higher than that of the electronic component, the temperature of the element keeps rising until the end of the reflow zone. At this time, the temperature reaches the maximum value, which is consistent with the data in the experiment. Because the temperature of the cooling zone is far lower than that of the element, the temperature of the electronic component is It will decrease exponentially until it reaches a stable state and no heat conduction is carried out.

Draw the dynamic diagram of heat conduction analytical solution by MATLAB, the initial state and the end state:

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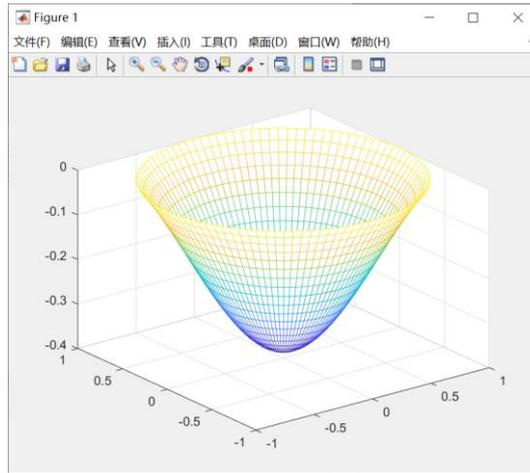


Figure 2 Initial state of heat conduction

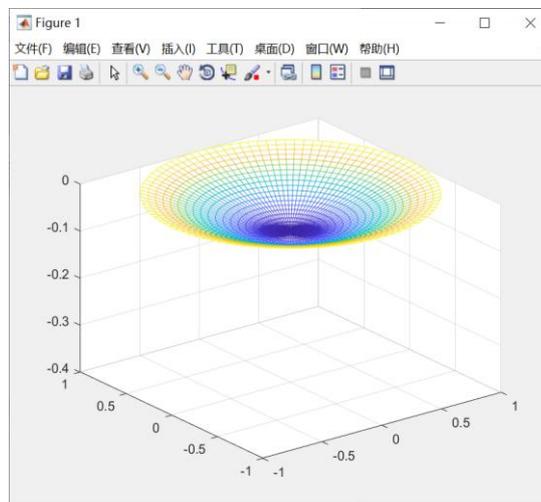


Figure 2 End state of heat conduction

IV. Solution of optimal furnace temperature curve

When the set value of each temperature zone and the passing velocity of conveyor belt have changed, the fitted equation can still keep the same characteristics. In the welding process, the time when the temperature in the center of the welding area exceeds 217 °C should not be too long, and the temperature in the temperature zone should not be too high, otherwise the electronic components will be damaged if they are in high temperature for a long time. Since the temperature of the cooling zone remains constant (= 25 °C), but because the temperature setting of the temperature zone has changed in the previous process, and the temperature change should be a stable and smooth curve, the temperature change function of the welding area with time in the cooling zone should be K times of the original basis (coefficient correction factor).

We can get the temperature change of electronic components with time:

$$\begin{cases} T_1 = T_1'(6.469e^{-0.3353\frac{t}{v}} - 6.64e^{-0.511\frac{t}{v}}) \\ T_2 = T_2'(0.087\frac{t^2}{v^2} - 0.3165\frac{t}{v} + 1.101) \\ T_3 = T_3'(0.0962\frac{t^2}{v^2} - 6.924\frac{t}{v} - 1.115) \\ T_4 = T_4'(-0.0928\frac{t^2}{v^2} + 0.8496\frac{t}{v} - 0.977) \\ T_5 = T_5'(4134e^{-0.63081\frac{t}{v}} - 2.242 \times 10^{10} \times e^{-4.7348\frac{t}{v}} + 2) \end{cases}$$

T_i' , $i = 1,2,3,4$ is the unknown set temperature of each temperature zone, v is the furnace passing speed of conveyor belt.

At this time, the time t_1, t_2 corresponding to 217 °C and peak temperature is the lower limit and upper limit of integration respectively. In the furnace temperature curve, the area covered from 217 °C to peak temperature is S, then the following is true.

$$S = \int_{t_1}^{t_2} T_{4,N} dt = \int_{t_1}^{t_2} T_4 (-0.0000189t^2 + 0.012t - 0.977) dt$$

In essence, the model is an optimal solution. The maximum allowable speed of conveyor belt passing through the furnace should be determined under the condition of satisfying the normal operation of each temperature zone of the reflow furnace. And the temperature change range should not be too large, otherwise the electronic components will be damaged, and the temperature rise slope should be kept at 0-3, that is:

$$0 \leq \frac{dT_i}{dt} \leq 3, \quad i = 1,2,3,4$$

In the same way, the slope of temperature drop is kept at - 3-0, that is:

$$-3 \leq \frac{dT_5}{dt} \leq 0$$

And meet the known process limits, We can solve this nonlinear programming problem according to the function relation. According to the constraints of process boundary, we can establish a nonlinear programming with s as the objective function:

objective function: $\min S$

constraint condition:
$$\begin{cases} 0 \leq \frac{dT_i}{dt} \leq 3, \quad i = 1,2,3,4 \\ 3 \leq \frac{dT_5}{dt} \leq 0; \\ 60 \leq T_3^{-1}(190) - T_1^{-1}(150) \leq 120; (8) \\ 40 \leq T_5^{-1}(217) - T_4^{-1}(217) \leq 90; \\ 240 \leq T_{\text{峰值}} \leq 250; \end{cases}$$

Therefore, we use MATLAB to solve the programming problem numerically, and obtain the optimal furnace temperature curve, the set temperature of each temperature zone and the passing speed of conveyor belt.

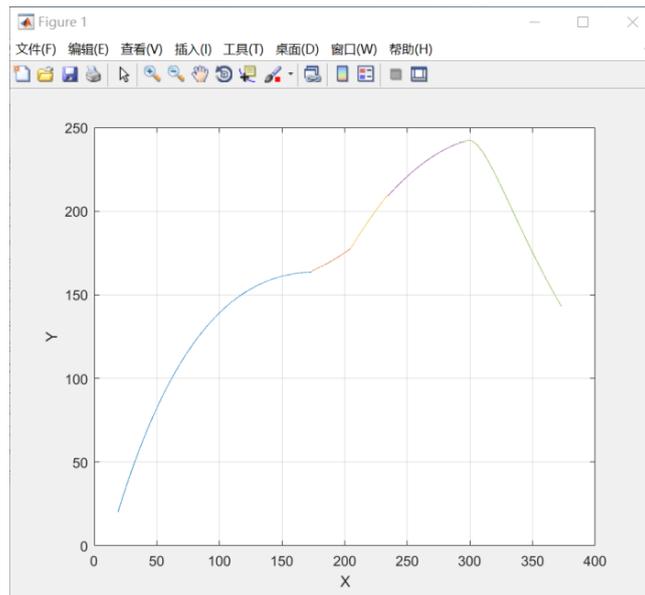


Figure 4 Optimal furnace temperature curve

V. conclusion

It is very important for the quality of electronic components to study the optimal temperature of each temperature zone of the reflow furnace and the speed of the conveyor belt passing through the furnace, and to study the furnace temperature curve under these conditions. However, it is difficult to study the temperature of each part of the reflow furnace that meets the process requirements. In this paper, through mathematical methods, using the heat conduction equation to establish the model, and using MATLAB to solve, to determine the temperature of each temperature zone of the reflow furnace, which is conducive to the design of process conditions. It is hoped that this paper can provide some help for the production and research of electronic components.

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