International Core Journal of Engineering
Volume 7 Issue 1, 2021
ISSN: 2414-1895
DOI: 10.6919/ICJE.202101_7(1).0013

Study on Optimization of Furnace Temperature Curve of Rewelding Furnace

Wenbo Qin, Liang He, Rui Li

College of Science and Management, Chengdu University of Technology, Chengdu, 610051, China.

Abstract

In the production of electronic products, how to optimize the furnace temperature curve of the rewelding furnace has become a hot issue in the industry. For the production process, we first set up the differential equations under different temperatures in different temperature zones according to the settings of different temperatures in different temperature zones of the reflow oven and use particle swarm optimization algorithm to obtain the thermal conductivity of the circuit board in the heating process and the thermal conductivity of the circuit board in the cooling process k_0. Finally, we obtained the temperature of small area 3, 6, 7 and the right margin of zone 8. On this basis, aiming at the specific temperature conditions, we first establish the constraint equations, and then, under the condition of constraints, we use Monte Carlo simulation to get the value of the maximum velocity of the conveyor belt transmission element.

Keywords

Heat conduction model; Particle swarm optimization; Monte Carlo simulation.

1. Introduction

Along with the continuous development of electronic information technology, people's demand for electronic products is increasing. As time goes on, people have had higher and higher requirements for the precision of electronic products, and on account of electronic products becoming more and more sophisticated, each process in producing electronic components must be close to the optimal to ensure the product yield. In the manufacturing of some electronic components, such as integrated circuit boards, in order to weld the electronic components to the circuit board, they need to be heated in a reefer. Meanwhile, there exist many small temperature areas in the reflow oven, and they can be divided into preheating area, constant temperature area, reflow area and cooling area[1]. By controlling the temperature of the small temperature area, many problems such as component burst, warped parts and PCB delamination bubbling can be solved[2]. Therefore, in the heating process, people must rigorously control the temperature of components in order to ensure the quality of products. Hence, it is of great importance to study the heating temperature of the element in the reflow oven.

To solve the problems, we need to control the time spent of the electronic components heated in the reflow oven, as well as the speed of the conveyor belt, so that the electronic components in the reflow oven can be optimized under the condition that all constraints are met.

2. Experiment Conditions

According to the factory production requirements, the products in the reflow furnace need to meet the conditions in table 1.

In the specific production, in addition to meeting the above constraints, the conveyor belt in experiment 1 passes through the furnace at a speed of 78cm /min, and the temperature values in each

ISSN: 2414-1895 DOI: 10.6919/ICJE.202101_7(1).0013

temperature area are 173 C (1~5 in the small temperature area), 198 C (6 in the small temperature area), 230 C (7 in the small temperature area) and 257 C (8~9 in the small temperature area) respectively. In experiment 2, the temperature values in each temperature region were 182 C (1~5), 203 C (6), 237 C (7) and 254 C (8~9) respectively.

Table 1. Constraint condition

Boundary conditions	Minimum	Maximum	Unit
Slope of temperature rise	0	3	ºC/s
Slope of temperature drop	−3	0	ºC/s
During the heating process, time when the temperature is between 150 ºC and 190 ºC	60	120	s
Time when the temperature is greater than 217 ºC	40	90	s
Peak temperature	240	250	ºC

3. Model Establishment

There are three ways of heat transfer: heat conduction, heat convection and heat radiation. Since the peak temperature of reflow soldering is 200 ℃ ~ 250 ℃, the electromagnetic wave generated at this temperature can transfer less heat, so the thermal radiation can be ignored; at the same time, the direct contact area between the air and the circuit board wall in the reflow furnace is very small, so the thermal convection can also be ignored. So we only need to consider the effect of heat conduction mode on the electronic components passing through the reflow furnace. At the same time, due to the small volume of electronic components, they can be regarded as particles. Therefore, the model is a one-dimensional heat conduction equation model with displacement only.

3.1 The heat conduction equation and Fourier experimental law

From the heat conduction equation and Fourier experimental law, we get that the relationship between the heat passing through unit area and the rate of temperature drop per unit time is $q = -a\frac{\partial u}{\partial s}$, ‘a’ is called thermal conductivity and ‘u’ is called heat value. At the same time, according to the relationship between the temperature and the heat of the particle, we can know $\frac{\partial T}{\partial t} = \frac{a}{\rho c} . \frac{\partial^2 T}{\partial t^2}$, the time is when the particle is in the heating area.

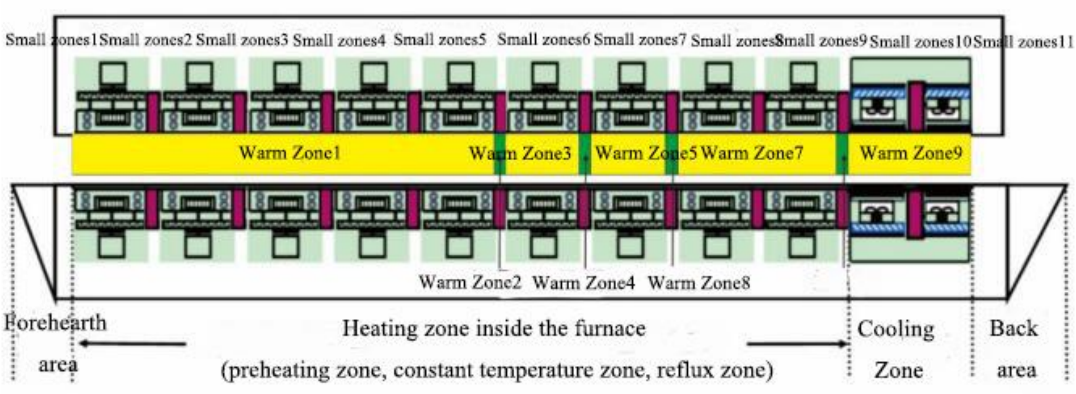
According to Newton's law of cooling, when the medium surface is inconsistent with the ambient temperature, the heat released by the medium per unit area per unit time is directly proportional to the temperature, so that the ratio is called the heat transfer coefficient, which can be expressed as k_0, and $\frac{\partial T}{\partial t} = k_0(T - \theta)$, θ is the temperature of the surrounding environment

3.2 Experiment 1: temperature change model of welding area

After listing the temperature changes in the heating and cooling process (equation 3, equation 4), we can start to establish the temperature change equation of the welding area, and then solve the optimal solution of the parameter sum.

Since the specific heat capacity and density are constant when the temperature is constant, we only consider the relationship between temperature and time of welding center. Therefore, for different temperature regions, we first partition the temperature, and take the average temperature of the two small temperature regions around each gap as the temperature of the gap region. According to the conditions of the title, the place with the same temperature (small temperature zone and gap) is regarded as a new temperature zone, and based on this, a zonal heat transfer model is established.

ISSN: 2414-1895
DOI: 10.6919/ICJE.202101_7(1).0013



Picture 1. Schematic diagram of partition heat transfer model

According to equation 4, there is an equation between the temperature of printed circuit board and its time in a new zone named $\frac{\partial T_i}{\partial t} = \frac{a}{\rho c} \cdot \frac{\partial^2 T_i}{\partial t}(1 \le i \le 9)$, and there is a connection condition among the nine new temperature regions, that is, the temperature of printed circuit board at the end of the new temperature zone is the same as that at the initial end of the new temperature zone:

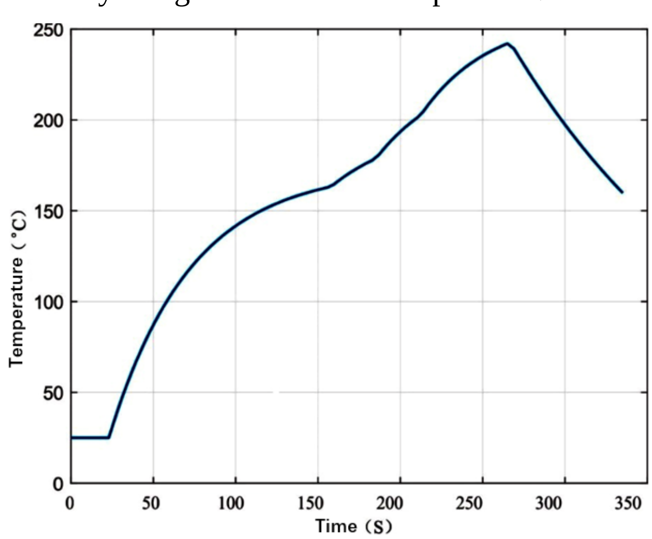
$$T_{i-1}(end) = T_i(start)(2 \le i \le 9)$$

Next, we use the particle swarm optimization algorithm to solve the parameters. When the thermal conductivity a=0.0112 and the thermal conductivity coefficient $k_0 = 0.0035$, the solution is optimal. After substituting the parameters into the equation, we use difference instead of differential to obtain the temperature at the middle point of small temperature zone 3, 6 and 7 and the temperature at the end of small temperature zone 8.

Form 2. The temperature at which the center of the welding area is located at the specified position

Site name	Position coordinatesx_i/cm	Central temperature/°C
The midpoint of small temperature region 3	111.25	130.99
The midpoint of small temperature region 6	217.75	169.75
The midpoint of small temperature region 7	253.25	189.09
The end of small temperature region 8	304	224.93

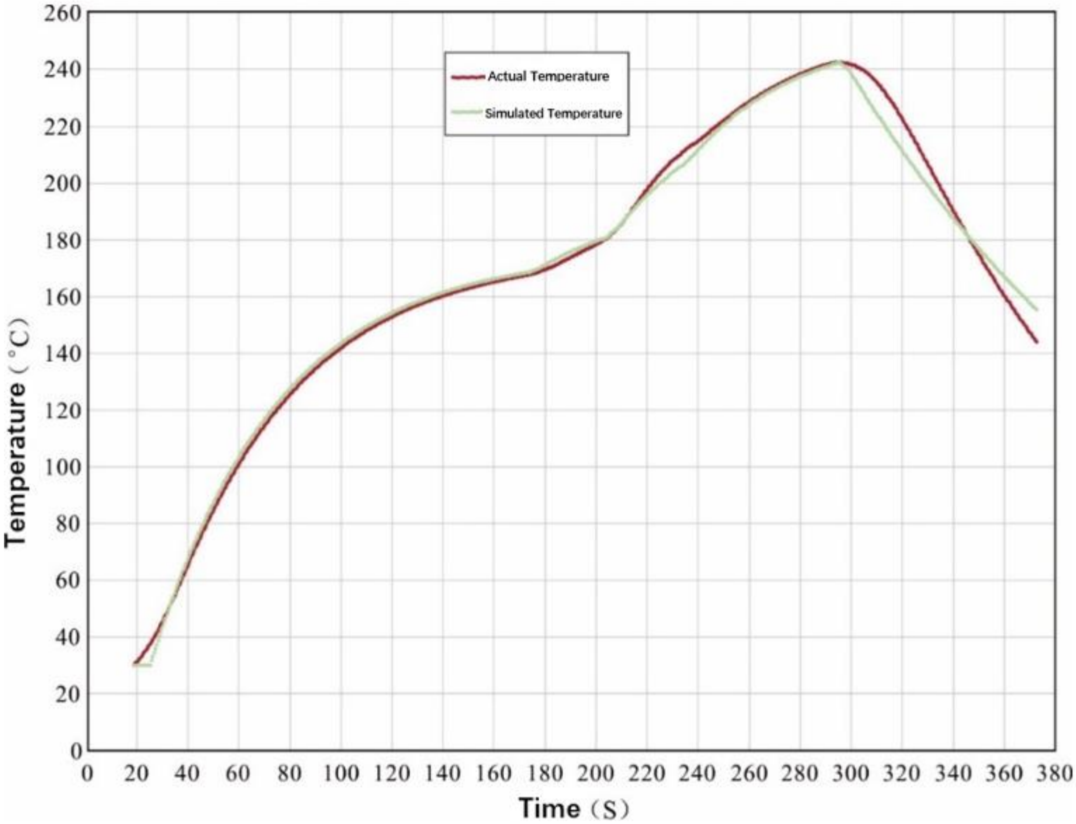
We carry on the cubic spline interpolation to make the data keep smooth and continuous. We draw the furnace temperature curve by using the data after interpolation.



Picture 2. The furnace temperature curve

3.3 Error analysis of particle swarm optimization model

When using particle swarm optimization to calculate thermal conductivity a and thermal conductivity k_0, we only use the optimal solution of the equation derived from theory. In order to intuitively see the quality of the model in the actual situation, we put the curve of the actual temperature and the simulated temperature in a graph for comparison.



Picture 3. Comparison of experimental temperature data and simulated temperature data

When the temperature is before 180, the distance between the two curves is very close, but after 180, the two curves appear a certain degree of separation, especially when the temperature reaches the peak temperature, the object begins to cool down, the two curves are almost linear, but the object cooling speed is faster in actual situation. The simulated temperature curve is very close to the actual temperature curve, which can be considered as a good model.

According to the change of the image, we guess that in the actual production, the physical and chemical properties of the object have changed irreversibly due to the increase of temperature, which leads to the deviation of the function of temperature change with time in the higher temperature environment and in the process of cooling down from the peak value.

3.4 Experiment 2: find out the maximum belt speed under limited conditions

When the temperature of each new temperature zone is determined, in order to study the maximum speed of conveyor belt in the reflow furnace, we establish the maximum conveyor speed model under the constraint conditions. For each new temperature zone which has been set and has different temperature, we first analyze the influence of the length and temperature of each new temperature zone on the conveyor belt speed from the qualitative point of view.

3.4.1. Time of PCB temperature between 150 ℃ and 190 ℃

When the other parameters of the reflow furnace are fixed, the longer the temperature of the circuit board is between 150 ℃ and 190 ℃, which means that the longer the time the circuit board experiences in the new temperature zone 1, that is, the slower the speed of the conveyor belt.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202101_7(1).0013

3.4.2. The time when the temperature of printed circuit board is greater than 217 ℃

When the other parameters of the reflow furnace are constant, the longer the temperature of printed circuit board is higher than 217 ℃, the longer the time the circuit board experiences in the reflow zone, and because the length of the reflow zone is a certain value, the speed of the conveyor belt is slower.

3.4.3. Peak temperature of printed circuit board

The higher the peak temperature of PCB is, the longer the heating time of PCB is, the slower the speed of conveyor belt is.

3.4.4. Effect of temperature slope on transmission speed

When the other parameters of the reflow furnace are constant, the greater the temperature rise slope, the greater the temperature difference, indicating that the speed of the conveyor belt is faster.

Through the above analysis, in order to obtain the maximum speed of the conveyor belt, we first list the constraints.

(a) When the temperature of the object rises from 150 ℃ to 190 ℃, it may experience several different temperature ranges. It is suggested that when the temperature rises from 150 ℃ to 190 ℃, the time t_i taken for the object to pass through different temperature regions is assumed to be $\sum_{i=1}^{n} t_i\ (n \leq 7), 60 \leq \sum_{i=1}^{n} t_i \leq 120$.

(b) According to the requirements of the peak temperature in the question, the constraint relationship of the peak temperature can be obtained as $240 \leq T_{Max} \leq 250$.

(c) Since the temperature is higher than 217 ℃ in the rising and falling stages, it is recorded as the time when the temperature is greater than 217 ℃, and the sum is the time used in the rising and falling stages $t_l = t_a + t_b (40 \leq t_l \leq 90)$.

Because in each simulation, we have to calculate whether the slope change of each segment meets the constraint conditions, and the time complexity is high, so we put the slope test after the maximum value.

After obtaining the constraints, we carry out Monte Carlo simulation. First, we reduce the maximum speed of the conveyor belt to an integer. Considering that the speed range V_c of the conveyor belt has been given, we first convert the real number range into the integer range to get the reduced set $W = \{65,66,67, \dots\dots 99,100\}$, and then replace each element of the set into the simulation. Note that the set composed of the speed values satisfying the constraint conditions is $W_B = \{w_{B1,}w_{B2}, \dots\dots, w_{Bj}\}$. At the same time, the maximum value of the element in the set is taken as the maximum value under the integer condition, and is recorded as V_0. Then we take $\delta = 1$ as the first search radius and record $D(V_0, \delta)$ as the first optimization region. In this region, Monte Carlo simulation is used to generate random numbers to obtain the optimal solution of the first simulation meeting the conditions; then we search for the radius $||Min(V_1 - V_0 + \delta, V_1 - V_0 - \delta)||$ to obtain the optimal solution of the second simulation meeting the conditions by taking the search origin as the search origin; after obtaining, we take the center as the radius $||Min(V_2 - V_1 + V_0 - \delta, V_2 - V_1 + V_0 + \delta)||$ advance Line search. Through repeated iterations, the maximum value of the conveyor belt satisfying the conditions can be obtained.

Through the search, we finally determined that the maximum transmission speed is $82.9cm/min$.

3.5 Analysis of maximum belt speed mode

When we analyze the slope of the maximum velocity function obtained, we find that at about 22, the temperature rise slope of the object suddenly rises from 0 to a value slightly greater than 3, and returns to normal at about 25. The change is shown in table 5-3.

We suspect that it is because the surface temperature of the object changes suddenly when the object just enters the small temperature zone 1 from the furnace front area, which causes the slope to rise. Moreover, the time when the temperature rise slope is greater than 3 only lasts about 3, and the

ISSN: 2414-1895 DOI: 10.6919/ICJE.202101_7(1).0013

constraint condition of rising slope $k \in [0,3]$ is still satisfied in other places, and the time consumed in the whole welding process can be ignored. Therefore, we consider that when the velocity is $82.9cm/min$, which, is an approximate solution of the maximum velocity.

Form 3 Relationship between temperature rise slope and time

time/s	Temperature rise slope
21	0
21.5	0
22	3.221674039
22.5	3.188619314
23	3.155903735
23.5	3.12352382
24	3.091476127
24.5	3.059757247
25	3.028363806
25.5	2.997292465

References

[1] Gao jingang, Optimization and control of reflow curve in SMT production line [D].Shanghai Jiaotong University.

[2] Wang jianhua, Lu hao, The latest development of welding prediction theory [C]. Proceedings of the 8th National Welding conference (3).

[3] Huang bingyuan, SMT Modeling and Simulation of reflow soldering temperature field [D]. Tianjin University, 2015.