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Modellingand analysis of temperature change of reflow furnace

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ABSTRACT : In this paper, based on the principle of zero dimensional unsteady thermal conductivity, the temperature thermodynamic model of the welding zone is established with the temperature difference between the circuit board and the small temperature zone as the initial condition. On this basis, the optimal temperature at the end of the key low temperature zone is obtained, and the corresponding furnace temperature curve is drawn by using MATLAB.

Key word : Furnace temperature curve, unsteady heat conduction, temperature thermodynamic model

I. INTRODUCTION

As we all know, the reflow oven should keep the corresponding temperature in each part, which is also the main factor affecting the quality of electronic products such as integrated circuits. There are many forms of IC production process, one of which is to put the circuit board with electronic components into the reflow oven, and use the high temperature of the reflow oven to make the components automatically welded on the circuit board. At this time, the quality of the product is affected by the temperature of the reflow furnace. With the change of time, the heat absorbed by IC in reflow furnace is different, and the temperature also changes. Therefore, the mechanism analysis of the process can accurately control the temperature of the reflow furnace, so as to optimize the quality of the product. In this paper, on the basis of previous studies, the law of temperature change in the welding area will be explored. The corresponding mathematical model will be established. For the fixed speed of conveyor belt passing through the furnace and the set temperature of each temperature zone, the change of the central temperature of the welding zone is given, and the central temperature of the welding zone in the important low temperature zone is calculated.

II. PROBLEM ANALYSIS

First of all, considering the temperature effect of the gap between the two areas in front of and behind the furnace and the small temperature areas with different temperatures, its temperature is related to the temperature of the adjacent temperature areas, and it can not generate heat by itself. Here, the influence of the temperature in front of and behind the furnace and between different low temperature zones on the temperature of electronic components is not considered. Secondly, assume that the volume of electronic components is, the surface area is, and the temperature of the circuit board entering the furnace heating area is. When entering the first low temperature zone, if the temperature of the first low temperature zone is, there must be. Suppose the surface heat transfer coefficient between the circuit board and the air in the reflow oven, and other physical parameters (such as density and mass) of the circuit board remain constant. The temperature of the circuit board in the reflow oven changes with the change of the conveyor belt transmission time. Therefore, the unsteady heat conduction equation is used to discretize the equation by using the approximate derivative of forward difference to solve the temperature change relationship with time in the center of PCB welding area. In order to establish the furnace temperature change model conveniently, the following assumptions are made: (1) assuming that there is no heat transfer inside the circuit board; (2) assuming that the surface of the circuit board is heated evenly; (3) assuming that the time of the circuit board moving in the reflow furnace does not affect the thermal conductivity of the circuit board in the low temperature zone; (4) assuming that the circuit board is not affected by the heating radiation in the front of the furnace, the temperature does not change; (5) assuming that the temperature of the circuit board does not change. It is assumed that the small gap between each temperature region has no effect on the temperature change of the circuit board.

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III. DERIVATION OF UNSTEADY HEAT CONDUCTION EQUATION

Unsteady heat conduction refers to the heat conduction process in which the temperature of an object changes with time. When the actual electronic components are welded through the reflow oven, the circuit board attached with the electronic components enters the reflow oven with the conveyor belt. The circuit board passes through the low temperature zone with different temperatures in the reflow oven at a constant speed. The heat emitted from the low temperature zone makes the solder paste on the circuit board melt, so as to realize the welding work. In this welding process, the temperature of the circuit board changes with time, and the temperature in the reflow furnace also changes, that is, unsteady heat conduction. The temperature change of the circuit board in the reflow oven can be divided into two stages: the stage when the circuit board just enters the reflow oven and the stage when the temperature reaches equilibrium after a period of time.

$$\rho c\frac{\partial t}{\partial \tau}=\frac{\partial}{\partial x}(\lambda\frac{\partial t}{\partial x})+\frac{\partial}{\partial y}(\lambda\frac{\partial t}{\partial y})+\frac{\partial}{\partial z}(\lambda\frac{\partial t}{\partial z})+\phi \quad (1)$$

$$\rho c_p\frac{\partial t}{\partial \tau}=\lambda div(gradt)+\phi \quad (2)$$

where ρ is the density of the circuit board, c is the specific heat capacity, t is the temperature, ϕ is a generalized heat source, $div(gradt)$ is a stable Laplacian operator $\nabla^2 t$.

Introduction of thermal diffusivity

$$b=\frac{\lambda}{\rho c_p} \quad (3)$$

So we can get

$$\frac{\partial t}{\partial \tau}=b\nabla^2 t+\frac{\phi}{\rho c_p} \quad (4)$$

The general form of initial condition

$$t(x,y,z,0)=f(x,y,z) \quad (5)$$

The initial temperature is a fixed value

$$t(x,y,z,0)=t_0 \quad (6)$$

Unsteady heat conduction of the third boundary condition in a constant temperature medium

$$-\lambda(\frac{\partial t}{\partial n})_w=h(t_w-t_f) \quad (7)$$

where h is the heat transfer coefficient between the circuit board and the air in the reflow oven.

Under the third kind of boundary conditions, the influence of B_i number on the temperature distribution in a flat plate is adopted. According to the difference of the relative value between the thermal resistance $\frac{\delta}{\lambda}$ of the flat plate and the thermal resistance $\frac{1}{h}$ of the convective heat transfer, the change of the temperature field in the flat plate will appear in three cases: ① when B_i number tends to infinity, that is, the thermal resistance of the thermal conduction is far greater than that of the convective heat transfer; ② when B_i number tends to infinity, the thermal resistance of the convective heat transfer is far greater than that of the When a number tends to zero, the thermal resistance of convective heat transfer is much larger than that of heat conduction; ③ when B_i number is finite, the thermal resistance of heat conduction is close to that of convective heat transfer. Here, because the thickness of the welding area is relatively small, we only consider the case where B_i number tends to 0.

IV. THE ESTABLISHMENT OF THE MODEL

As the circuit board passes through five different temperature zones in the reflow oven at a constant speed with the conveyor belt, the temperature of the circuit board changes with the movement of the conveyor belt. Based on the zero dimensional unsteady heat conduction principle, the unsteady heat conduction equation of circuit board moving in small temperature region is obtained

$$\rho c\frac{\partial t}{\partial \tau}=\frac{\partial}{\partial x}(\lambda\frac{\partial t}{\partial x})+\frac{\partial}{\partial y}(\lambda\frac{\partial t}{\partial y})+\frac{\partial}{\partial z}(\lambda\frac{\partial t}{\partial z})+\phi \quad (9)$$

Secondly, the heat exchange on the interface is converted into the volume heat source of the whole circuit board

$$-\phi V=Ah(t_1-t_0) \quad (10)$$

Equations (9) and (10) are combined to obtain the following equation

$$\rho cV\frac{dt}{d\tau}=-Ah(t_1-t_0) \quad (11)$$

Introduction of temperature difference $\theta=t_1-t_0$, we obtain

$$\rho cV\frac{dt}{d\tau}=-Ah\theta \quad (12)$$

$$\theta(0)=t_1-t_0$$

The heat conduction differential equation is separated into variables :

$$\frac{d\theta}{\theta}=-\frac{Ah}{\rho cV}d\tau \quad (13)$$

therefore

$$\int_{\theta_0}^{\theta}\frac{d\theta}{\theta}=-\int_0^{\tau}\frac{Ah}{\rho cV}d\tau \quad (14)$$

$$\ln\frac{\theta}{\theta_0}=-\frac{Ah}{\rho cV}\tau \ (15)$$

$$\frac{\theta}{\theta_0}=\frac{t_1-t}{t_1-t_0}=e^{-\frac{Ah}{\rho cV}\tau} \ (16)$$

Because the units of volume V and area A are different, V/A has dimensions. In order to eliminate the influence of this dimension, we let

$$l_c=\frac{V}{A} \quad (17)$$

We have

$$\frac{Ah}{\rho cV}\tau=\frac{hl_c}{\lambda}\frac{\lambda}{\rho c}\frac{\tau}{l_c^2}=B_iF_0 \quad (18)$$

where B_i is the Biot number of characteristic length l_c, F_0 is called Fourier series, and it is also the characteristic length of l_c. It can be further simplified as (18)

$$\frac{\theta}{\theta_0}=e^{B_iF_0} \quad (19)$$

V. ANALYSIS AND SOLUTION OF THE MODEL

For the established differential equation, the forward difference is used to discretize the differential equation. According to the initial value $\theta(0)$, the temperature corresponding to the circuit board at different times can be calculated step by step. $h_n=\tau_{n+1}-\tau_n$ is called the step size from τ_n to τ_{n+1}, where the step size h is a constant.

Because $\theta(\tau,t)$ is continuous and satisfies the Lipschitz condition, there is a constant L such that

$$|\theta(\tau,t)-\theta(\tau,\bar{t})|\le L(t-\bar{t}) \quad (20)$$

According to the existence theory of ordinary differential equation, the solution of differential equation (19) must exist.

If $\frac{t(\tau_{n+1})-t(\tau_n)}{h}$ in (12) is replaced by forward difference $t'(\tau_n)$, we can obtain

$$\frac{t(\tau_{n+1})-t(\tau_n)}{h}\approx\theta(\tau_n,t(\tau_n)) \quad n=0,1,\cdots \quad (21)$$

i.e.

$$t(\tau_{n+1})\approx t(\tau_n)+h\theta(\tau_n,t(\tau_n)) \quad n=0,1,\cdots$$
(22)

If the approximate value t_n of $t(\tau_n)$ is substituted into the right end of the above formula, the result is the approximate value of $t(\tau_{n+1})$, denoted as t_{n+1}, then

$$t(\tau_{n+1})\approx\tau_n+h\theta(\tau_n,t_n) \quad n=0,1,\cdots \quad (23)$$

The solution of the differential equation is

$$\begin{cases} t(\tau_{n+1})\approx\tau_n+h\theta(\tau_n,t_n) \quad n=0,1,\cdots \\ \theta_0=t_1-t_0 \end{cases} \quad (24)$$

Using MATLAB software for simulation, the change of central temperature in welding area can be obtained as shown in the figure below

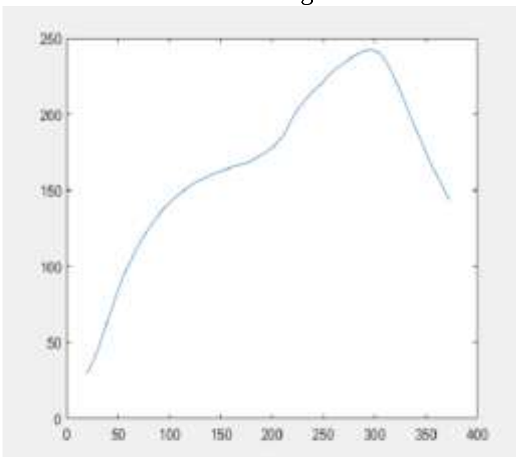

Figure1.Temperature curve of central furnace in welding area

According to the image, the temperature trend is roughly divided into first rising and then falling. Before 200s, the temperature in the center of the welding area increases rapidly with time. Between 200s and 250s, the temperature still rises, but the rising range is not as large as that of the previous 200s. Then the temperature drops and the circuit board reaches the cooling zone.

Next, according to the furnace passing speed of conveyor belt, the length of each low temperature zone and the gap distance between adjacent low temperature zones, the time of the circuit board passing through the center of welding area at the middle points of low temperature zone 3, 6, 7 and the end of low temperature zone 8 can be calculated. On this basis, according to the calculated temperature in the center of the welding area every 0.5 seconds, the length a of the small temperature zone, the gap length b between the temperature zones, and the conveyor belt speed v, the central temperature of the welding area at the midpoint of the small temperature zone 3, 6, 7 and the end of the small temperature zone 8 can be calculated.

The time passing through the center of the small temperature zone 3:

$$T_1 = \frac{2.5a + 2b}{v} \times 60 = \frac{2.5 \times 30.5 + 2 \times 5}{78} \times 60 \approx 73 \quad (25)$$

The time passing through the center of the small temperature zone 6:

$$T_2 = \frac{5.5a + 5b}{v} \times 60 = \frac{5.5 \times 30.5 + 5 \times 5}{78} \times 60 \approx 165 \quad (26)$$

The time passing through the center of the small temperature zone 7:

$$T_3 = \frac{6.5a + 6b}{v} \times 60 = \frac{6.5 \times 30.5 + 6 \times 5}{78} \times 60 \approx 175.5 \quad (27)$$

The time passing through the center of the small temperature zone 8:

$$T_4 = \frac{8a + 7b}{v} \times 60 = \frac{8 \times 30.5 + 7 \times 5}{78} \times 60 \approx 215 \quad (28)$$

Thus, the temperature of the middle point of low temperature zone 3, 6, 7 and the center of welding area at the end of low temperature zone 8 can be obtained as follows.

Table 1：The temperature of the middle point of the different temperature zone

Temperature zone	3	6	7	8
Central temperature of welding area（°C）	105.4777	174.2416	179.7186	213.3189

VI. CONCLUSION

The unsteady heat conduction differential model established in this paper can describe the temperature curve of the circuit board in the reflow furnace with time. The discretization method is used to deal with the differential equation, which greatly reduces the amount of calculation. The established model is in good agreement with the actual situation, and it is easy to analyze and solve the model. In addition, the unsteady heat conduction modeling method proposed in this paper can be directly applied to the temperature control field of internal combustion engine cylinder and plasma spraying.

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