A Method of Squeegee pressure Optimization for Mass Production Thick Film Heaters Using SPC and Neural Network

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Abstract: The Mass production of ceramic heater has encountered with the estimation for the proper parameters of the printing conditions. This paper presents a method to estimate the squeegee pressure. It uses resistance distribution from the trial run with approximate squeegee pressure which comes form statistical process control (SPC). Then, the resistance distribution and its total resistance are input to the backpropagation neural networks that can recognize resistance's distribution patterns. The value of output network derived from the input value can identify to the appropriate squeegee pressure. The experimental results are demonstrated to ensure the efficiency and the reliability of this method with the accuracy 96.75 percent. Indeed, embedded on this method will aid us to reduce the loss from the normal mass production.

1. Introduction

Thick film heaters have more influence in our daily use such as in thick film microelectronic, modern domestic appliances, copy machine and so on. The thick film heaters manufacturing process depend on large lot production. The missing of heater's resistance target and the unbalance of setting the squeegee pressure both are frequently occur and difficult to control. Thus, this cause is one major production cost and decreases the productivity. The objective of screen-printing process is to deposit paste (ink) of predictable dimension on a ceramic substrate. The heater's resistance is defined from sheet resistivity of resistance paste as the figure1. However, the thickness of resistance and another properties would be screened on the substrate so sensitive to squeegee pressure.

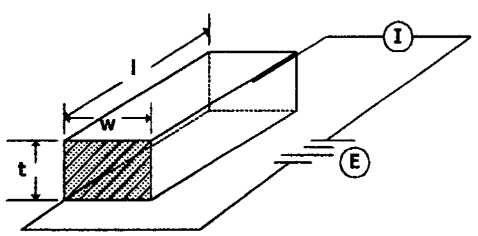

Figure 1. Sheet resistivity

The relation between paste deposited dimension and sheet resistivity as the equation 1.

$$R = \frac{\rho l}{tw} \qquad (1)$$

where R = resistance
ρ = resistivity
l = length of sample
t = thickness of sample
w = width of sample

$$\frac{\rho}{t} \equiv \rho_s \equiv \text{Sheet resistivity}$$

Nowadays, the setting of squeegee pressure is defined by manual operation. Therefore, the resistance extremely depends on operator's skill and experience. There have been many times appeared the missing resistance target wrong decision.

This paper presents a method to identify the squeegee pressure by using SPC to evaluate and analyze the resistance's distribution of the thick film heater. Since, the starts of trial run to obtain the trial squeegee pressures that are the input of backpropagation neural networks, then the input data are classified and recognized. Thus, the output of network would be the optimization squeegee pressure.

2. Basic concept

The screen-printing process is illustrated by following diagram.

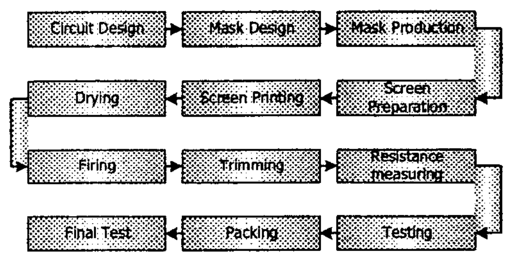

Figure 2. Screen-printing process

According to the significant of the squeegee pressure would affect on either dimension of resistance paste that deposited or resistances of heater as show in figure 3 and 4 in serially. The squeegee pressure should be decided on the printing process with the precise squeegee pressure since the resistance will increase when we increased the squeegee pressure.

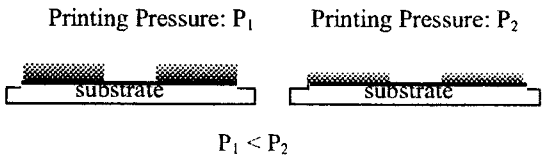

Figure 3. Squeegee pressure and paste dimension.

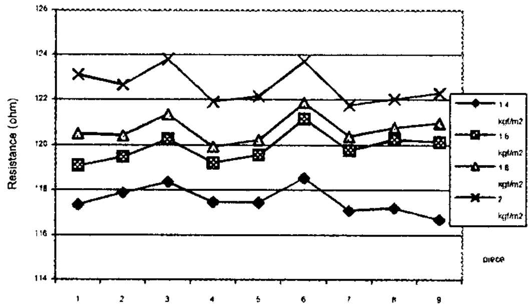

Figure 4. Resistance & Squeegee pressure

3. System configuration

The system is show on the figure5. We use SPC technique to monitor, control, evaluate, and analyze a process. The statistical software analyzes the data. Then, take this analyzed data to setup the trial screen-printing process. The heaters after the screen-printing process are measured the heater resistance's distribution. The result of measuring is the uniform resistance in each equal periods of thick film pattern involves the total resistance value from measuring the resistance between the ends of film resistance pattern. The experiment heater model is heater 200 Volt, maximum resistance is 90Ω and minimum resistance is 78Ω. The resistance's distribution of heater patterns, total resistance of each pattern and squeegee pressure are inputted to the three layers of the backpropagation neural networks. The network are composed of 1 input layer (12 nodes), 1 hidden layer (30 nodes) and 1 output layer (12 node). The network analyze result will be classify based on the 4 ranges of the resistance distribution characteristic and 3 ranges of the total resistance value. After network was trained the optimized squeegee pressure and printing conditions will define for the run of large lot production.

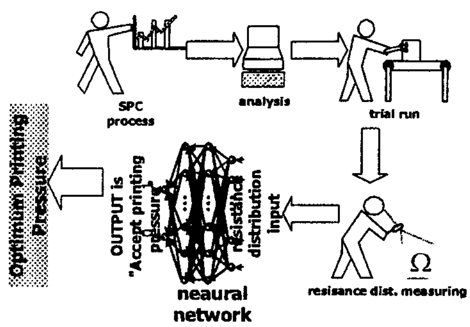

Figure 5. System Configuration

4. The heater's resistance distribution measuring.

According to the figure 6, which is the printing process. The resistance is left on the substrate. Afterward the firing process we measured the heater's resistance distribution as the figure7. The out from processing unit would show the uniformity, variance and the total resistance of heater.

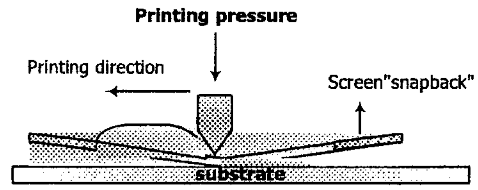

Figure 6. Printing resistance paste process

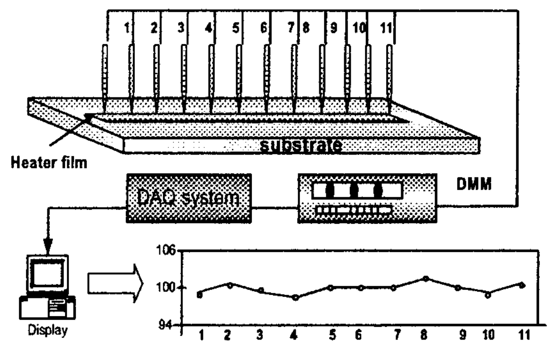

Figure 7. The resistance distribution measuring unit.

5. The backpropagation neural networks

The Sigmoid function are used to connected and feed forward with the nonlinearly in each node

The modification of weight is performed as follows.

$$f(net) = 0 = \frac{1}{1 + e^{-(\sum WX + bias)}} \quad (2)$$

$$f'(net) = 0' = f(net)(1 - f(net)) \quad (3)$$

Where, 0 is the output of nonlinear transfer function, W is weight, and X is input to the unit. W and bias are randomly selected in start state and modified during training. The modification of weight is performed as follows.

$$\Delta W_{ji}(t) = -\eta \frac{\partial E}{\partial W_{ji}(t)} + \alpha \Delta W_{ji}(t-1) \quad (4)$$

Where, $\Delta W_{ji}(t)$ is the weight change at training index t between layer j and layer i, η is learning rate coefficient,α is momentum coefficient. E is a error term, the derivative of the output layer weight connecting previous layer node I to output node j is:

$$\frac{\partial E}{\partial W_{ji}} = -o_i f'(net_j)(d_j - o_j) = -o_i \delta_j \quad (5)$$

Where, o_i is output of previous layer node I, net_j is the weighted sum coming into output layer node j, o_j is that node's obtained activation, and d_j is desired or target output for that node.

$$\delta_j = f'(net_j)(d_j - o_j) \quad (6)$$

$$\delta_j = f'(net_j)\sum(\delta_k W_{kj}) \quad (7)$$

(6) is used for weight change between output layer and hidden layer and (7) is used for weight change between hidden layer and input layer where, W_{kj} is the weight connecting node j in this hidden layer to node k in the next layer, δ_k is the deltas for the layer following this hidden layer, δ_j is the deltas being computed for this hidden layer. The sample of data for training network as the following

102 102 102 102 100 102 102 102 102 102 94.00 1 0 0 0 0 0 0 0 0 0 0 0 1

98 98 98 98 100 98 98 98 98 98 94.25 1 0 0 0 0 0 0 0 0 0 0 0 1

100 100 100 100 100 100 100 100 100 100 94.50 1 0 0 0 0 0 0 0 0 0 0 0 1

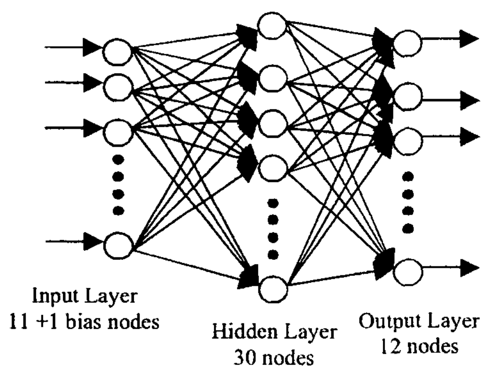

Figure 4 Three layers of neural network learning

6. The result of experiment and discussion

The designed system was tested by the production of the ceramic heater 200-volt type: resistance specification 78Ω – 90Ω. The ceramic heater 2,400 pieces were measured the resistance distribution and the total resistance to be the input of designed network. The pattern of these distributions used to recognize and learning by the training process before. Hence, the squeegee pressure and printing condition in this run process would be specified the quality of setting process. If output of designed system is the unsatisfied condition. Operator should correct the setting process again before run the mass production. The output from the neural network and the judgement result describe as the table 1. Refer to the test result, the designed system have the accuracy 96.75%. Distinguishing between the figure5, which is the histogram of resistance distribution in running the normal operation and the figure2 that is the designed network result.

Table 1 Output from the neural network and the judgement result.

Data pattern (R_{DIST},R_{TOTAL})	The result of experiment		
	i/p Q'ty	Correct	Error
Pattern 1 (2%,3%)	539	513	26
Pattern 2 (2%,5%)	383	376	7
Pattern 3 (2%,>5%)	37	37	0
Pattern 4 (4%,3%)	437	421	16
Pattern 5 (4%,5%)	670	658	12
Pattern 6 (4%,>5%)	263	246	17
Pattern 7 (6%,3%)	43	43	0
Pattern 8 (6%,5%)	28	28	0
Pattern 9 (6%,>5%)	0	0	0
Pattern 10 (>6%,3%)	0	0	0
Pattern 11(>6%,5%)	0	0	0
Pattern 12(>6%,>5%)	0	0	0
Total	2400	2322	78

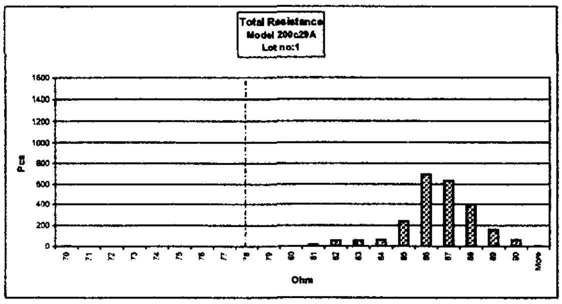

Figure 5 Distribution of the total resistance from the normal operation.

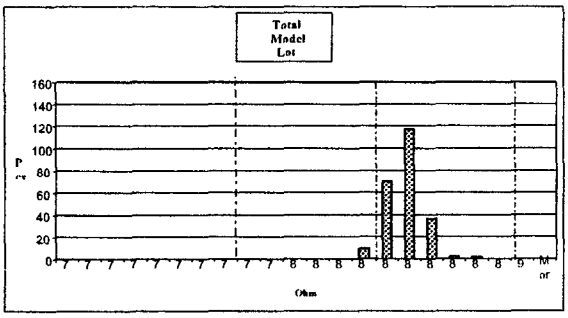

Figure 6 Distribution of the total resistance under control with the designed network.

7. Conclusion

Using SPC and backpropagation neural networks for the thick film heater manufacturing process would increase the confidential and reliability of process.

The squeegee pressure and printing condition in the test run process would be specified the quality of setting process before use these parameters in running the mass production. If output of designed system is the unsatisfied condition. Operator should correct the setting process again before run the mass production. The designed system has the accuracy 96.75% possible to improve the productivity and prevent the decision error by operator. However, the accuracy of this method still depends on same condition with control variables. We can improve the system accuracy by increasing the learning sample of the network.

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