CASE 32

Optimization of Resistance Welding Conditions for Electronic Components

Abstract: In the manufacture of automobile switches using electronic components such as light-emitting diodes or resistors, a good electrical connection between the component and the terminal is essential. Soldering has long been used to make this connection, but resistance welding is becoming more and more popular, due to easy automation and the shorter time required for the process. Currently, evaluation of resistance welding relies on a strength test; therefore, evaluation cannot be made without destroying the delicate wire in the component. In this study, evaluation is made by the generic function for welding current–voltage characteristics rather than by strength.

1. Introduction

We often need to use resistance welding to join leads in electronic parts with electrodes such as a light-emitting diode. Resistance welding is a technology used to combine metal materials by heating and the application of pressure, with resistance heat generated by electric current supplied between the metal materials. Among some of the major evaluation methods of resistance welding conditions for electronic parts are strength tests such as tension and peeling tests, and cross-sectional observation tests. In general, because of the thin diameter of leads in electronic parts, if we perform a strength test on a fixed lead, it often breaks at the point of the lead whose strength is lower than that of a joint. In this case, while the strength at a joint can be regarded as sufficient, we cannot assess how well the joint is welded. Taking the objective of resistance welding into account, we know that conductivity needs to be secured between a lead and a jointed electrode. Since good conductivity implies a good joint, to satisfy our objective we should evaluate electrical conductivity by measuring electrical characteristics for resistance-welding electronic leads.

2. Evaluation Method

Since the objective function of a joint is to secure the conductivity between a lead and an electrode, we selected current and voltage characteristics as the generic functions of a joint. Setting a supplied current to a signal factor, M, and a voltage difference to an output, y, we proceeded with the analysis using a zero-point proportional equation. If the joint condition between a lead and an electrode is poor, we assume that the resistance of the joint increases and that the slope of the input and output relationship flattens.

On the other hand, if the entire joint is uniform in condition, we are supposed to measure the same current and voltage characteristic no matter which part of the joint we pick up. That is, a small fluctuation in sensitivity among different measurement positions at the joint indicates high uniformity of resistance welding. Thus, as noise factors, we selected four joints and measured the voltage drop to assess uniformity. In addition, to find welding conditions to satisfy current and voltage characteristics, even if the electrode becomes somewhat contaminated, we also chose electrode contamination as another noise factor. Figure 1 outlines the measure-

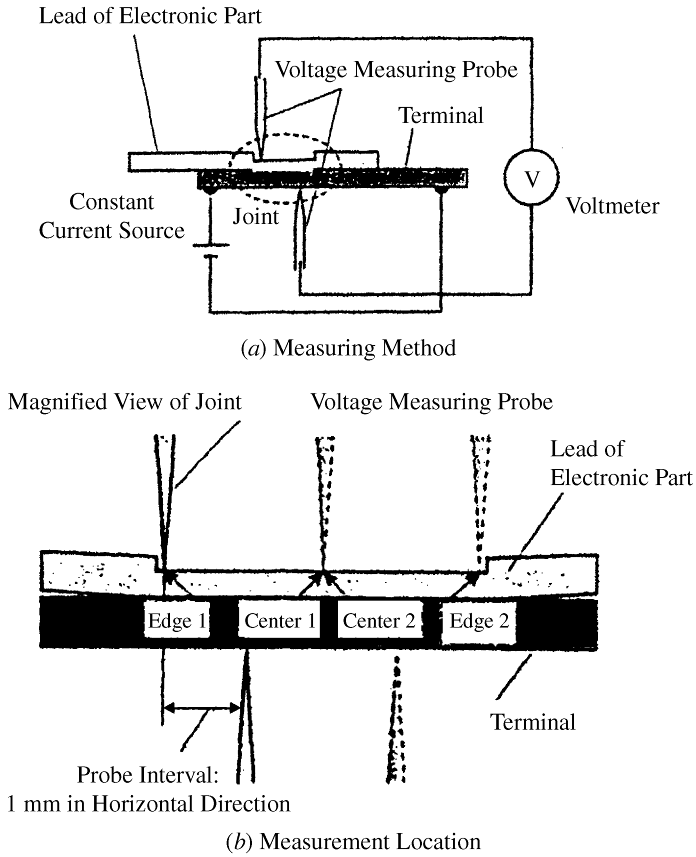


Figure 1
Measuring method of current and voltage characteristics

ment method and positions. Because of the tiny resistance at the joint, to measure voltage drop properly, we selected three levels of current, 5, 10, and 15 A, which is a wider range than that of a normal tolerable current in electronic parts. Additionally, we prepared a special measurement device to achieve the accuracy of locating the voltage measuring probe.

3. SN Ratio

Using test pieces for each welding condition laid out in an L_{18} orthogonal array, we measured the current and voltage characteristics. Table 1 gives one example of the experimental data. Based on this, we show the calculations for the SN ratio and sensitivity.

Total variation:

$$S_T = 0.020^2 + 0.029^2 + \cdots + 0.101^2 + 0.058^2$$
$$= 0.091721 \qquad (f = 24) \tag{1}$$

Linear equations:

$$L_{11} = (5)(0.020) + (10)(0.041) + (20)(0.093)$$
$$= 2.370$$
$$L_{12} = 3.045$$
$$\vdots$$
$$L_{24} = 1560 \tag{2}$$

Table 1
Example of voltage drop at welding joint (mV)

Noise Factor		Signal Factor			
Contamination of Electrode	Measurement Position	M_1 5 A	M_2 10 A	M_3 20 A	Linear Equation
I_1: contaminated	J_1: edge 1	0.020	0.041	0.093	L_{11}
	J_2: center 1	0.029	0.058	0.116	L_{12}
	J_3: center 2	0.024	0.050	0.105	L_{13}
	J_4: edge 2	0.018	0.037	0.070	L_{14}
I_2: not contaminated	J_1	0.020	0.040	0.086	L_{21}
	J_2	0.027	0.055	0.108	L_{22}
	J_3	0.024	0.049	0.101	L_{23}
	J_4	0.016	0.032	0.058	L_{24}

Effective divider:

$$r = 5^2 + 10^2 + 20^2 = 525 \qquad (3)$$

Variation of proportional term:

$$S_\beta = \frac{(2.370 + 3.045 + \cdots + 2.630 + 1.560)^2}{(8)(525)} = 0.088229 \qquad (f = 1) \qquad (4)$$

Variation of differences of proportional terms due to contamination of electrodes:

$$S_{I\times\beta} = \frac{(2.370 + \cdots + 1.860)^2 + \cdots + (2.220 + \cdots + 1.560)^2}{(4)(525)} - 0.088229 = 0.000130 \qquad (f = 1) \qquad (5)$$

Variation of differences of proportional terms due to measurement positions:

Table 2
Control factors and levels

Control Factor	Level 1	Level 2	Level 3
A: error column	1	2	—
B: electrode material	B_1	B_2	B_2'
C: electrode diameter	Small	Large	Large
D: upslope time	Short	Mid	Long
E: electricity supplying time	Short	Mid	Long
F: welding current	Small	Mid	Large
G: applied pressure	Small	Mid	Large
H: downslope time	Short	Mid	Long

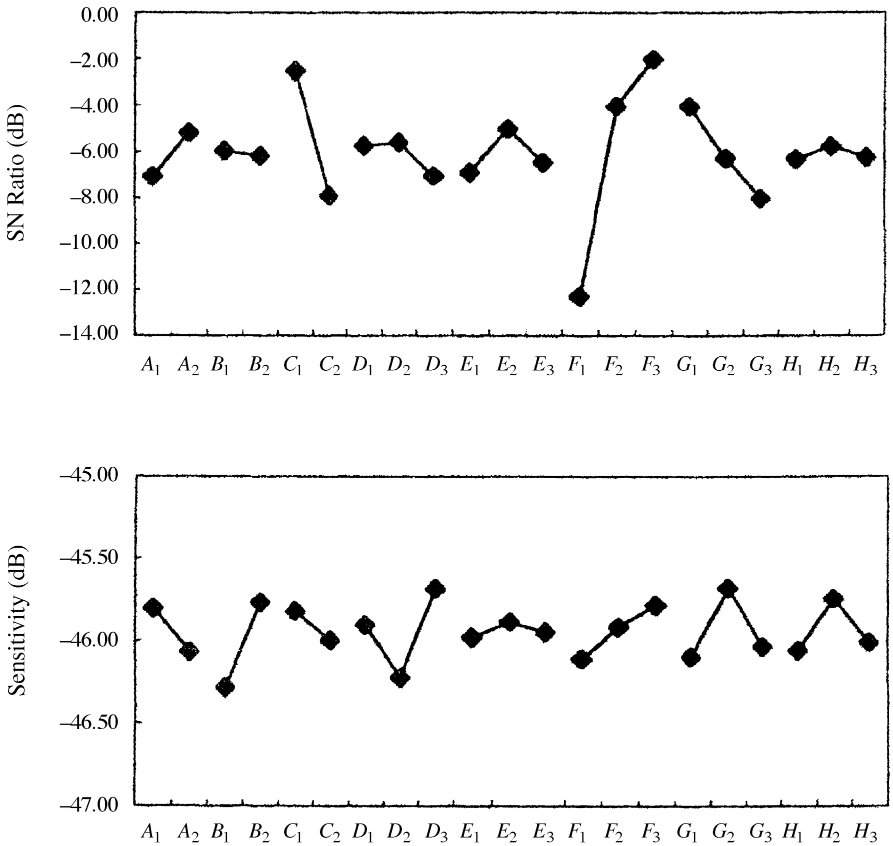
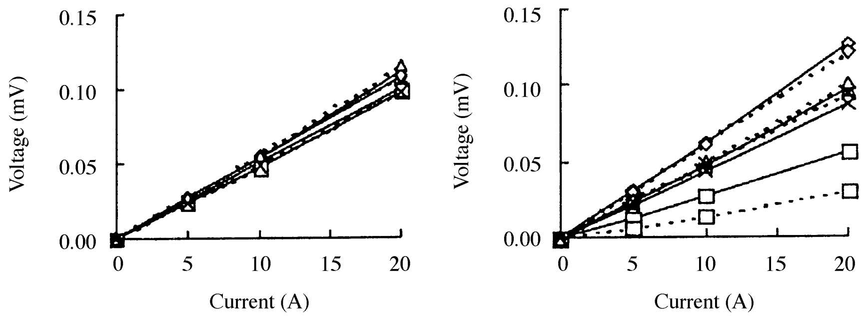


Figure 2
Response graphs

Table 3
Results of confirmatory experiment (dB)

	SN Ratio		Sensitivity	
Configuration	**Estimation**	**Confirmation**	**Estimation**	**Confirmation**
Worst	−16.02	−13.22	−46.27	−47.05
Optimal	3.68	1.95	−45.83	−45.68
Gain	19.70	15.17	0.44	1.37



(*a*) Optimal Condition (*b*) Worst Condition

Figure 3
Characteristics of current and voltage in confirmatory experiment

$$S_{J\times\beta} = \frac{(2.370 + 2.220)^2 + \cdots + (1.860 + 1.560)^2}{(2)(525)} - 0.088229$$

$$= 0.003275 \qquad (f = 3) \tag{6}$$

Error variation:

$$S_e = 0.091721 - 0.088229 - 0.000130 - 0.003275$$

$$= 0.000087 \qquad (f = 19) \tag{7}$$

Error variance:

$$V_e = \frac{0.000087}{19} = 0.000005 \tag{8}$$

Total error variance

$$V_N = \frac{S_{I\beta} + S_{J\beta} + S_e}{23} = 0.000152 \tag{9}$$

SN ratio:

$$\eta = 10 \log \frac{[1/(8)(525)](0.088229 - 0.000005)}{0.000152}$$

$$= -8.59 \text{ dB} \tag{10}$$

Sensitivity:

$$S = 10 \log \frac{1}{(8)(525)} (0.088229 - 0.000005)$$

$$= -46.78 \text{ dB} \tag{11}$$

4. Optimization and Result of Confirmatory Experiment

Table 2 shows the control factors and levels chosen for the experiment. *A* is an error column. Since control factor *B*, electrode material, and control factor *C*, electrode diameter, have two levels, their third levels are assigned as a dummy level. The levels of control factors *E*, electricity supply time, and *F*, welding current, are dealt with as sliding levels around *D*, the upslope time, such that the welding energy in each experiment becomes neither extremely high nor extremely low.

Figure 2 shows the response graphs obtained from the experiments based the orthogonal array. As the optimal configuration, we selected the combination of $B_1C_1D_2E_2F_3G_1H_2$ by chosing each level with a high SN ratio. To estimate the gain, we performed a confirmatory experiment based on factors *C*, *F*, and *G* with large effects. Table 3 summarizes estimations of the SN ratio and sensitivity and the experimental results. In addition, Figure 3 shows the characteristics of current and voltage in the confirmatory experiment.

According to the results in the confirmatory experiment, we can see that fairly good reproducibility was obtained in the gain in the SN ratio. The characteristics of current and voltage in the confirmatory experiment demonstrate that the viability in measurement position was obviously reduced under the optimal configuration compared to that under the worst configuration. As a result of observing the sections of the joints, we have confirmed that all of them have good joint conditions. Additionally, a normal strength test under the optimal configuration used as a double-check has revealed that rupture at the lead, which indicates sufficient strength at the joint, was observed. Although this evaluation method is not easy to implement in terms of measurement, it is regarded as applicable to other types of joints.

Reference

Takakichi Tochibora, 1999. Optimization of resistance welding conditions for electronic components. *Quality Engineering*, Vol. 7, No. 3, pp. 52–58.

This case study is contributed by Takakichi Tochibora.