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A Study of the Influence of L-Cut on Resistance of Chip Resistor Based on Finite Element Method

Wang Zhijuan
College of Information Engineering, Minzu University of China,
Minority Languages Branch, National Language Resource Monitoring & Research Center
No. 27, South Street of Zhongguancun, Haidian District, Beijing, China, 100081
E-mail: wangzhijuan2000@yeah.net

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Abstract: The resistance increase by transverse cutting is more quickly than by ordinate cutting when using laser trimming. Therefore, the precision and efficiency of laser trimming can be improved at low cost through reasonable design of the L-cut. In this paper, the finite element method is used to study the influence of L-cut on the resistance of chip resistor. Experiments proved that the qualitative and quantitative conclusions of the influence of L-cut on the resistance obtained by the finite element method are consistent with the experimental results. Thus, using the conclusions of the influence of L-cut on the resistance obtained by the finite element method can provide the control basis for improving the trimming precision and trimming efficiency.

Keywords: Laser trimming, Trimming precision, Resistance of chip resistor, L-cut, Finite element method.

1. Introduction

Laser trimming is the most precise method to adjust resistance of chip resistor [1]. The scanning path of laser on the resistive film is called cutting path, which is relative to the laser trimming precision. Due to the influence of control difficulty of the laser beams, the laser cutting path is generally straight line or combinations of straight lines. The common laser-cutting paths are shown in Fig. 1.

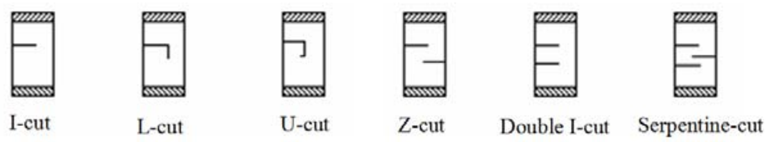


Fig. 1. The basic laser cutting paths.

As shown in Fig. 2, the laser-cutting path that is vertical to the current flow is called transverse cutting. It increases the resistance quickly. The laser-cutting path that is parallel to the current flow is called ordinate cutting. It increases the resistance slowly. L-cut can guarantee the trimming precision based on guaranteeing the trimming efficiency, and therefore is broadly applied in the laser trimming. Through mastering the influence of L-cut on the resistance of chip resistor, the precision and efficiency of laser trimming can be improved at a low cost through reasonable design of L-cut.

At present, there are only independent studies on the influence of the transverse cutting length and the ordinate cutting length on the resistance of chip resistor [2-9]. There is no the study on the influence of L-cut on the resistance of chip resistor. A method based on the finite element is introduced to study the relationship of L-cut and resistance in this paper. Then the relationship between L-cut and resistance of chip resistor is studied applying this method. Finally, the experimental data are applied to prove the qualitative and quantitative conclusions gotten by the finite element method.

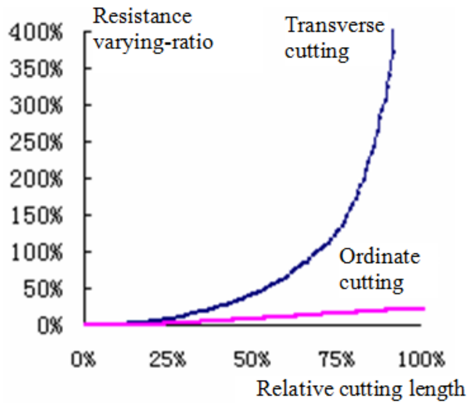


Fig. 2. The influence of transverse and ordinate cutting length on the resistance of chip resistor.

2. Introduction of Research Method based on Finite Element Method [10]

Formula (1) is the calculation formula of the resistance of chip resistor. Rt is the resistance. U is the voltage applied on two electrode of the resistor. E is the electric field intensity. l is any line section within the region of the resistor. $\rho_s = \rho/h$, h is the thickness of resistive film and ρ is the resistivity.

$$R_t = \rho_s \frac{U}{\int_l E \bullet dl} \tag{1}$$

The method to solve the resistance of chip resistor trimmed by L-cut is introduced in following paragraphs.

Firstly, the finite element analysis software ANSYS with the electric field analysis and calculation module is applied to divide the chip resistor trimmed by L-cut path into lots of small resistors. The finite element node diagram of chip resistor is shown in Fig. 3.

Secondly, the electric field intensity of every small resistor under certain voltage action is solved. As shown in Fig. 4, the electric field intensity of each finite element can be calculated using ANSYS. The arrow color shows the size of electric field intensity of each finite element and the arrow points to the direction of the electric field intensity of each finite element.

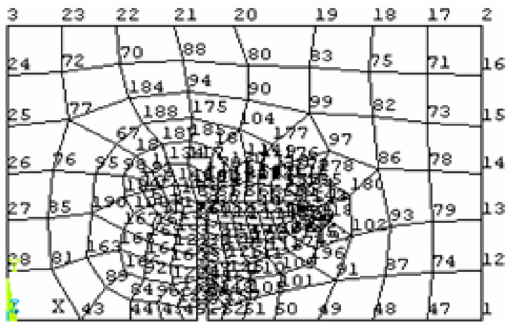
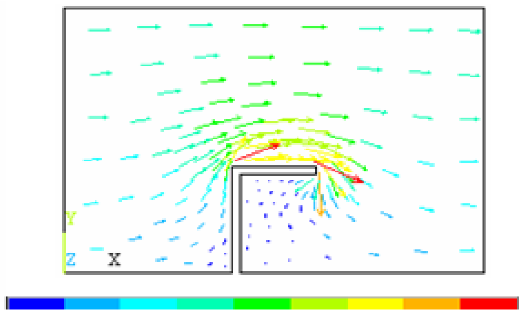


Fig. 3. Finite element node diagram of chip resistor.



Electric field intensity changes from small to large

Fig. 4. Electric field intensity diagram of chip resistor.

Thirdly, solve the line integral of electric field intensity of all small resistors on a certain line. Using formula (1), the resistance of resistor trimmed by the L-cut can be calculated. Fig. 5 is the solution diagram of the resistance through ANSYS.

Finally, the relationship between different L-cut and corresponding resistance can be analyzed through the data analysis software Excel and Origin. And the qualitative and quantitative relationships between L-cut and the resistance of chip resistor can be obtained.

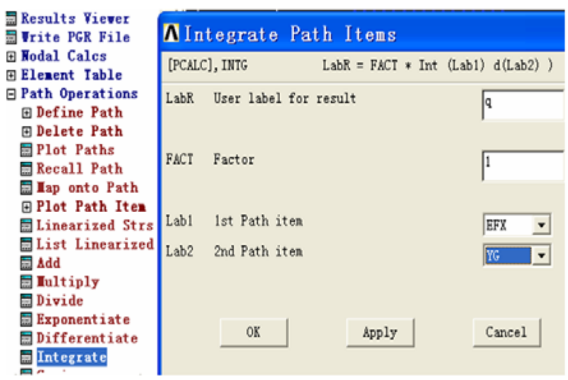


Fig. 5. The Path Operations of the ANSYS.

3. Influence of L-cut on the Resistance based on Finite Element Method

The chip resistor trimmed by L-cut is shown in Fig. 6. L_1 and W_1 respectively represent the length and the width of the chip resistor. L_2 is the distance from the left electrode to the begin position of L-cut. W_2 is the transverse cutting length. L_3 is the ordinate cutting length and C is the diameter of laser beam.

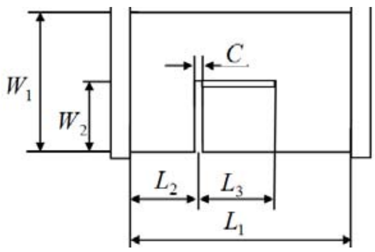


Fig.6. Chip resistor trimmed by L-cut.

R_k is the varying ratio of resistance, it can be expressed in formula (1). R_{t0} is the initial resistance of before laser cutting, $R_{t0} = \rho_s L_1/W_1$. R_t is final resistance of the resistor trimmed by laser. $L_{initial}$ is the relative begin position. L_{kx} is the relative transverse cutting length. L_{ky} is the relative ordinate cutting length.

$$R_k = \frac{R_t - R_{t0}}{R_{t0}} \times 100\% \tag{2}$$

$$L_{initial} = L_2/L_1 \tag{3}$$

$$L_{kx} = W_2/W_1 \tag{4}$$

$$L_{ky} = L_3/L_1 \tag{5}$$

The influence of L-cut on the resistance is very complicated. So, R_{kx} and R_{ky} are used to study the influence of L-cut on the resistance. As shown in Formula (6) and (7), R_{kx} is the varying ratio of resistance caused by transverse cutting and R_{ky} is varying ratio of resistance caused by ordinate cutting. R_{tx} is the resistance when the transverse cutting is over.

$$R_{kx} = \frac{R_{tx} - R_{t0}}{R_{t0}} \times 100\% \tag{6}$$

$$R_{ky} = \frac{R_t - R_{tx}}{R_{tx}} \times 100\% \tag{7}$$

So the relationship between R_k and R_{kx} , R_{ky} is shown in Formula (8).

$$R_k = R_{kx} + R_{ky} + R_{kx}R_{ky} \tag{8}$$

3.1. The Influence of $L_{initial}$ and L_{kx} on R_{kx}

Fig. 7 is the relationship diagram of R_{kx} and L_{kx} , $L_{initial}$ of 0603 1K resistor when $L_{initial}$ is respectively 0.125, 0.25, 0.5, 0.75 and 0.875.The influence of $L_{initial}$ and L_{kx} on R_{kx} will be introduced in following.

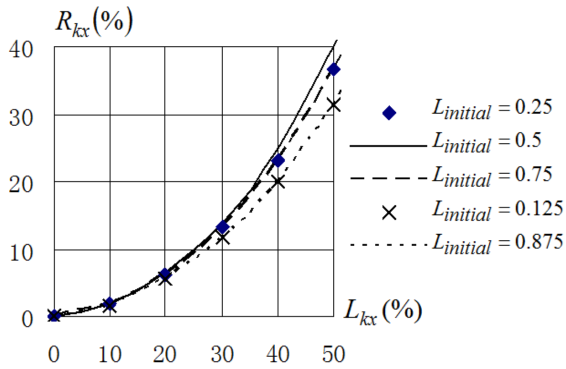


Fig. 7. The relationship between R_{kx} and $L_{initial}$, L_{ky}

3.1.1. The Influence of L_{kx} on R_{kx}

When $L_{kx} \leq 0.5$, the relationship between R_{kx} and L_{kx} is an approximate quadratic function. And their relationship can be expressed with Formula (9). C_1 is a constant related to the resistor type and $L_{initial}$. $C_1 > 0$.

$$R_{kx} = C_1 L_{kx}^2 \,(L_{kx} \leq 0.5) \tag{9}$$

3.1.2. The Influence of $L_{initial}$ on R_{kx}

The begin position of L-cut influences the increase speed of the resistance.

(1) When $L_{initial} = 0.5$, R_{kx} increases at the quickest speed with the increase of L_{kx} .

(2) When the begin positions of L-cut are symmetric, the two R_{kx} increase at the same speed with the same increase of L_{kx} .

(3) The closer the begin position of L-cut is to two electrodes, the slower the increase speed of R_{kx} is with the same increase of L_{kx} .

3.2. The Influence of $L_{initial}$, L_{kx} and L_{ky} on R_{ky}

3.2.1. The Influence of L_{ky} on R_{ky}

For the influence on the edge effect of the resistor, the influence of ordinate cutting length L_{ky} on R_{ky} is divided into the linear section and nonlinear section. Fig. 8 shows the relationship diagram of R_{ky} and L_{ky} of the 0603 1K resistor gotten by finite element method when $L_{initial} = 0.5$ and $L_{kx} = 0.5$.

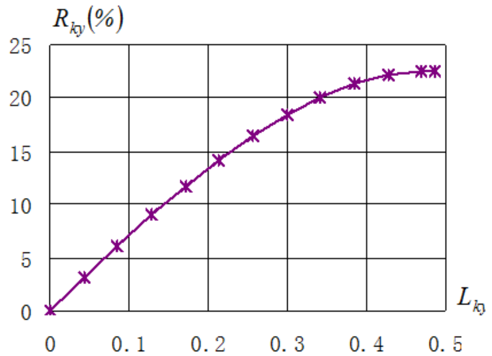


Fig. 8. Relationship diagram of R_{ky} and L_{ky}.

When $L_{ky} \le a_i$, R_{ky} and L_{ky} have a linear relationship, and the linear relationship can be expressed in Formula (10). C_3 is a constant related to $L_{initial}$ and L_{kx}. $C_3 > 0$.

$$R_{ky} = C_3 L_{ky} \; (L_{ky} \le a_i) \tag{10}$$

When $L_{ky} > a_i$, R_{ky} and L_{ky} have a nonlinear relationship and a_i is a constant related to the resistor type and cutting path.

3.2.2. The Influence of L_{kx} on R_{ky}

Fig. 9 shows the relationship diagram between L_{kx} and R_{ky} - L_{ky} of 0603 1K resistor when $L_{initial} = 0.5$.

The larger L_{kx} is, the quicker the increase speed of R_{ky} with the increase of L_{ky} is. Meanwhile, for same ordinate cutting length, with the increase of L_{kx}, the increase of R_{ky} is same with the increase of L_{kx}. So the influence of L_{kx} on R_{ky} is a linear relationship which can be expressed in Formula (11). C_4 is a constant that relates to the resistor type, $L_{initial}$ and L_{ky}. $C_4 > 0$.

$$R_{ky} = C_4 L_{kx} \; (L_{kx} > 0) \tag{11}$$

The relationship between R_{ky} and L_{kx}, L_{ky} is shown in Formula (12). C_2 is a constant related to the resistor type and $L_{initial}$. $C_2 > 0$.

$$R_{ky} = C_2 L_{kx} L_{ky} \; (L_{kx} > 0, \; L_{ky} \le a_i) \tag{12}$$

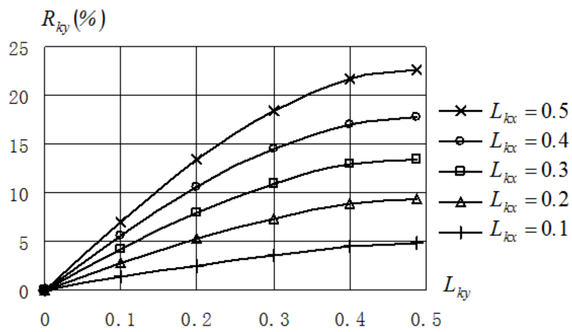


Fig. 9. Relationship diagram of L_{kx} and R_{ky} - L_{ky}.

3.2.3. The Influence of $L_{initial}$ on R_{ky}

Fig. 10 shows the relationship diagram of R_{ky} and L_{ky} of 0603 1K resistor gotten by the finite element method when $L_{kx} = 0.2$ and $L_{initial} = 0.25, 0.5, 0.75$. The closer the begin position of L-cut is to two electrodes, the quicker the increase speed of R_{ky} is with the same increase of L_{ky}.

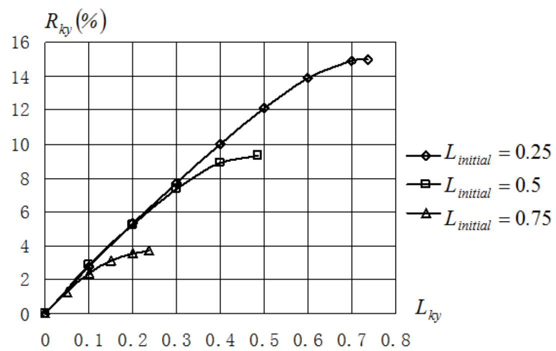


Fig. 10. Influence diagram of $L_{initial}$ on R_{ky}.

3.3. The Influence of L-cut on R_k

3.3.1. The Influence of L_{kx} and L_{ky} on R_k

According to the analysis in 3.2, 3.3, the relationship between R_k and L_{kx}, L_{ky} is shown in

Formula (13) within certain L_{kx} and L_{ky} ($0 < L_{kx} \le 0.5,\ L_{ky} \le a_i$).

$$R_k = C_1 L_{kx}^2 + C_2 L_{kx} L_{ky} + C_1 C_2 L_{kx}^3 L_{ky} \qquad (13)$$

C_1, C_2 are two constants related to the resistor type and $L_{initial}$. a_i is the relative ordinate cutting length when the relation between R_{ky} and L_{ky} is liner. a_i is a constant related to the resistor type and $L_{initial}$.

From formula (13), when $L_{kx} \le 0.5,\ L_{ky} \le a_i$, the relationship between R_k and L_{kx} is cubic function, the relationship between R_k and L_{ky} is liner.

3.3.2. The Influence of $L_{initial}$ on R_k

Fig. 11 shows the relationship diagram of R_k and L_{ky} of 0603 1K resistor gotten by the finite element method when $L_{kx} = 0.5$ and $L_{initial} = 0.3,\ 0.5,\ 0.7$.

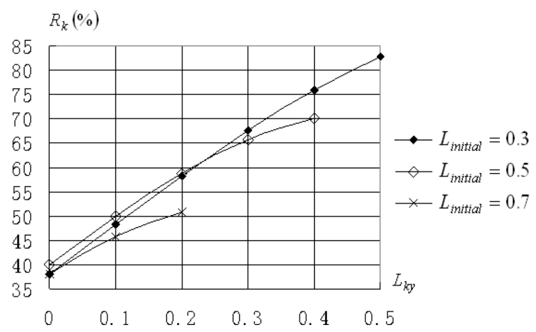


Fig. 11. The relationship diagram of R_k and L_{ky} .

According to Fig. 11, the influence of $L_{initial}$ on R_k can be expressed in two cases.

(1) When $L_{ky} \le b_i$, the influence of $L_{initial}$ on R_{kx} is prevailing. That is, when $L_{initial} = 0.5$, R_{kx} increases at the quickest speed with the increase of L_{ky} .

(2) When $L_{ky} > b_i$, the influence of $L_{initial}$ on R_{ky} is prevailing. That is, the closer the begin position of L-cut is to left electrodes, the quicker the increase speed of R_k is with the same increase of L_{ky} . b_i is a constant related to the resistor type and L_{kx} of L-cut.

4. Experiments

The experimental data are gotten by using Laser Trimming System that is made by Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences. Let Laser Trimming System trim the resistor at certain step and measure the resistance using resistance measuring system. R_{ke} is the varying ratio of resistance gotten by experiment. 0603 type 1K resistors are used in experiment.

The influence of L-cut on the resistance is very complicated. So, we take two steps to study the influence of L-cut on the resistance based on experiments.

4.1. The Influence of $L_{initial}$ and L_{kx} on R_{ke} when $L_{ky} = 0$

Fig. 12 is the influence diagram of $L_{initial}$ and L_{kx} on R_{ke} when $L_{ky} = 0$. The following conclusions can be reduced.

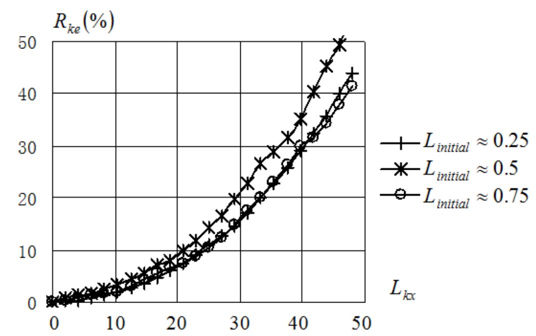


Fig. 12. Influence diagram of $L_{initial}$ and L_{kx} on R_{ke} .

When $L_{initial} = 0.5$, R_{ke} increases at the quickest speed with the increase of L_{kx} . When the begin positions of L-cut is symmetric, the two R_{ke} increase at the same speed with the same increase of L_{kx} . The closer the begin position is to two electrodes, the slower the increase speed of R_{ke} is with the same increase of L_{kx} . These conclusions are consistent with the conclusions gotten by finite element method.

When $L_{initial} \approx 0.5$ and $L_{kx} \le 0.5$, the relationship between R_{ke} and L_{kx} gotten by experiment data can be expressed with Formula (14). And Formula (15) is the relationship between R_k and L_{kx} gotten by finite element method .They are almost same.

$$R_{ke} \approx 1.66 L_{kx}^2 \qquad (14)$$

$$R_k \approx 1.62 L_{kx}^2 \qquad (15)$$

4.2. The Influence of L_{ky} on R_{ke}

Fig. 13 is the relationship diagram of R_{ke} and L_{ky} when $L_{initial} \approx 0.3$ and $L_{kx} \approx 21\%$ .The relationship of R_{ke} and L_{ky} is nearly liner when $L_{ky} < 40\%$, their relationship is nonlinear when $L_{ky} > 40\%$. These conclusions are consistent with the conclusions gotten by finite element method in 3.2 and 3.3.

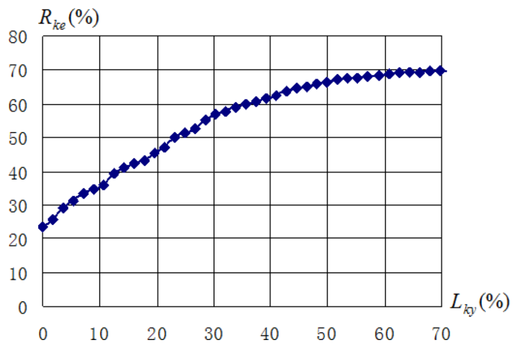


Fig. 13. The relationship diagram of R_{ke} and L_{ky}

4.3. The Influence of L_{kx} on R_{ke} when $L_{ky} \neq 0$

Fig. 14 is the relationship of R_{ke} and L_{kx} when $L_{initial} \approx 0.3$, $L_{kx} \approx 0.21, 0.42, 0.63$ and $L_{ky} \leq 0.2$. The relationships of R_{ke} and L_{kx} are consistent with the conclusions gotten by finite element method.

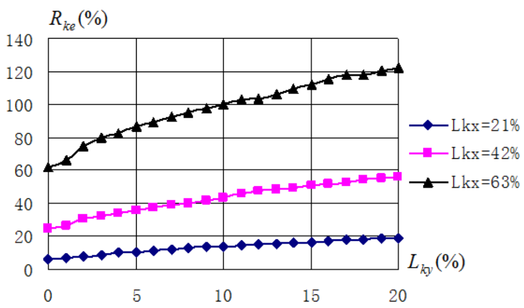


Fig. 14. The relationship diagram of R_{ke} and L_{kx}

5. Conclusions

The influences of L-cut on resistance of chip resistor are following:

(1) As shown in formula (13), the relationship of R_k and L_{ky} is liner. The relationship of R_k and L_{ky} is nonlinear.

(2) The influences of $L_{initial}$ on R_k can be expressed in two cases. The closer $L_{initial}$ is to 0.5, the quicker the increase speed of R_k with the increase of L_{kx} is when $L_{ky} \leq b_i$. The smaller $L_{initial}$ is, the quicker the increase speed of R_k with the increase of L_{kx} is when $L_{ky} > b_i$. b_i is a constant related to the resistor type and $L_{initial}$.

Experiments proved that the qualitative conclusions of the influence of L-cut on the resistance obtained through the finite element method are consistent with the experimental results. So the L- cut can be designed reasonably according to the relationship of L-cut and resistance of chip resistor. And the precision and efficiency of laser trimming can be improved at a low cost.

6. Acknowledgment

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