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

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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.

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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.](image)

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.

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

Formula (1) is the calculation formula of the resistance of chip resistor. $R_t$ 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. $\rho = \rho \cdot h$, $h$ is the thickness of resistive film and $\rho$ is the resistivity.

$$R_t = \rho \cdot \frac{U}{\int_{l} E \cdot dl}$$ (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.

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.
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.](image)

\( R_k \) is the varying ratio of resistance, it can be expressed in formula (1). \( R_0 \) is the initial resistance of before laser cutting, \( R_0 = \rho_s L_1 / W_1 \). \( R_1 \) is final resistance of the resistor trimmed by laser. \( L_{initial} \) is the relative begin position. \( L_{ky} \) is the relative transverse cutting length. \( L_{ky} \) is the relative ordinate cutting length.

\[
R_k = \frac{R_1 - R_0}{R_0} \times 100\% \quad (2)
\]

\[
L_{initial} = \frac{L_2}{L_1} \quad (3)
\]

\[
L_{kx} = \frac{W_2}{W_1} \quad (4)
\]

\[
L_{ky} = \frac{L_3}{L_1} \quad (5)
\]

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. \( R_{kx} \) is the resistance when the transverse cutting is over.

\[
R_{kx} = \frac{R_0 - R_{kx}}{R_0} \times 100\% \quad (6)
\]

\[
R_{ky} = \frac{R_0 - R_{ky}}{R_{kx}} \times 100\% \quad (7)
\]

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

\[
R_k = R_{kx} + R_{ky} + R_{kx}R_{ky} \quad (8)
\]

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 \( L_{kx} \), \( L_{initial} \).](image)

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 \( L_{initial} \).

\[
R_{kx} = C_1L_{kx}^2 \quad (L_{kx} \leq 0.5) \quad (9)
\]

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 \( L_{\text{initial}}, L_{kx} \) 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 \( L_{\text{initial}} = 0.5 \) and \( L_{kx} = 0.5 \).

\[
R_{ky} = C_3 L_{ky} \quad (L_{ky} \leq a_i) \quad (10)
\]

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

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 \( L_{\text{initial}} = 0.5 \).

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, \( L_{\text{initial}} \) and \( L_{ky} \).\( C_4 > 0 \).

\[
R_{ky} = C_4 L_{kx} \quad (L_{ky} > 0) \quad (11)
\]

The relationship between \( R_{ky} \) and \( L_{kx} \), \( L_{ky} \) is shown in Formula (12). \( C_4 \) is a constant related to the resistor type and \( L_{\text{initial}} \). \( C_4 > 0 \).

\[
R_{ky} = C_2 L_{kx} L_{ky} \quad (L_{kx} > 0, \quad L_{ky} \leq a_i) \quad (12)
\]

3.2.3. The Influence of \( L_{\text{initial}} \) 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 \( L_{\text{initial}} = 0.25, 0.5, 0.75 \).

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 \( L_{ky} \).

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 $L_{ky}$ ($0 < L_{kx} \leq 0.5$, $L_{ky} \leq a_i$).

$$R_k = C_1L_{kx}^{-2} + C_2L_{kx}L_{ky} + C_3C_3L_{kx}^{-1}L_{ky}$$

(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 $L_{kx} \leq 0.5$, $L_{ky} \leq a_i$, 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 $L_{ky}$.](image)

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

1. When $L_{ky} \leq b_1$, 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 $L_{ky} > b_1$, 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 $L_{ky}$. $b_1$ 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 $R_{ke}$.](image)

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 $L_{initial} = 0.5$ and $L_{kx} \leq 0.5$, 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.

$$R_{ke} \approx 1.66L_{kx}^{-2}$$

(14)

$$R_k \approx 1.62L_{kx}^{-2}$$

(15)

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

Fig. 13 is the relationship diagram of $R_{ke}$ and $L_{ky}$ when $L_{initial} = 0.3$ and $L_{kx} \approx 21\%$. The relationship
of $R_k$ 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 $L_{ke}$ on $R_{ke}$ When $L_{ky} \neq 0$

Fig. 14 is the relationship of $R_{ke}$ and $L_{ke}$ 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 $L_{ke}$ are consistent with the conclusions gotten by finite element method.

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

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 $L_{kx}$ 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.

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