# The Optimal Parameter Design of CD-R Substrate

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## Abstract

In recent years, high-speed recording CD-R has already become the mainstream of CD-R market. Therefore, to promote the efficiency of recording CD-R is of significant importance. This study uses Taguchi's parameter design to improve the yield rate for the process of CD-R substrate. We have found 13 three-level controllable factors from the fishbone diagram, repeated 10 times the experiment with the $L_{27}(3^{13})$ orthogonal array, and measured seven quality characteristics. We employ four general methods to find the optimal parameter conditions individually. Then, we perform the confirmation experiment and compare the results. Finally, we obtain the optimal parameter conditions. According to the analysis of benefits, the optimal parameter conditions can reduce the quality loss of CD-R substrate to about 21%. In the future, the results can be extended to other research of DVD-R substrate.

**Key Words**: Taguchi Methods, Multiple Quality Characteristics, CD-R, Substrate

## 1. Introduction

In recent years, high-speed recording CD-R has already become the mainstream of CD-R market. However, there are problems such as unstable quality, low-speed recording CD-R and bad CD-R. In order to overcome these drawbacks, the quality of CD-R is connected highly with the substrate of the preceding manufacturing process, so this research will take substrate as the main analysis. Before applying the Taguchi's approach, the company adopted the trial-and-error approach towards manufacturing; i.e. operators adjusted machine set-ups according to their experience and the on-site defect situation. Following this method proved difficult when it came to assessing the optimal conditions for the entire manufacturing process. Thus, it was not practical.

Among the publications or practical applications of Taguchi Methods, most papers emphasize the optimal process of a single quality characteristic. However, in the actual manufacturing process, the quality characteristics are related. Therefore, we consider the optimal process of multiple quality characteristics to enhance the quality of the product.

This study utilizes Taguchi's parameter design to improve the yield rate for the process of CD-R substrate. We find 13 three-level controllable factors from the fishbone diagram, repeat 10 times the experiment with the $L_{27}(3^{13})$ orthogonal array, and measure seven quality characteristics. We employ four methods to find the optimal parameters combinations individually. Then, we perform the confirmation experiment and compare the results.

Finally, we obtain the optimal parameter conditions. According to the analysis of benefits, the optimal parameter conditions can reduce the quality loss of CD-R substrate. This staudy aims to use the Taguchi method to improve the manufacturing process and decrease nonconformity. In the future, the results can be extended to other research of DVD-R substrate.

## 2. Literature Review

Taguchi's approach has already prevailed for more than 20 years with widespread applications in the industry. Derringer and Suich (1980) employed desirability function and multiple regression analysis to maximize the combined desirability of quality characteristics for the process of product. Khuri and Conlon (1981) used an achievement function to optimize multiple quality characteristics. Logothetis and Haigh (1988) presented a two-stage procedure for optimizing multiple quality characteristics. Pignatiello (1993) derived the expression of an expected loss function to minimize the function for multiple quality characteristics. The case study of Phadke (1988) employed the quality loss function to make the necessary trade-offs when different characteristics suggest different optimum levels for the very large scale integrated (VLSI) circuits. Elsayed and Chen (1993) provided a multiple characteristics model involving on the loss function. Ames et al. (1997) extended the quality loss function to total quality loss function for evaluating multiple quality characteristics of a product, where total quality loss is the sum of individual quality loss. Su and Tong (1997) presented an approach derived from the principal component analysis. Tong and Su (1997) used the Fuzzy theories to optimize the parameter design. Tong et al. (1997) presented an approach to standardizing the loss of individual quality characteristic by setting standardization values between 0 and 1. Vining (1998) employed a polynomial regression function to optimize multiple quality characteristics. Tsui (1999) extended Pignatiello's approach and created a new model. Antony (2001) used Taguchi's quality loss function for simultaneous optimization of multiple quality characteristics in manufacturing processes. Lin et al. (2002) employed Fuzzy logic and grey relational analysis to optimize the EDM process with multiple quality characteristics. Lu and Antony (2002) employed a fuzzy rule-based inference system to optimize multiple quality characteristics. Wu (2002) estimated second order loss functions of the individual quality characteristic, and adopted the linear programming model using percentage reduction of quality loss to maximize the total amount of quality loss reduction. Jhang and Chan (2003) applied quality loss by giving suitable weight of individual quality characteristic to improve the process yield rate for the air cleaner of vehicle. Wu (2004) presented an approach to optimizing the correlated multiple quality characteristics using principal component analysis and grey relational analysis of quality loss. This study will employ the above methods to improve the yield rate of manufacturing process for CD-R substrate.

## 3. Implementation and Result

### 3.1 Important cause analysis

After collecting data from the manufacturing process and discussion with specialists, the cause and effect diagram is depicted in Figure 1. After brain storming with engineers having actual practical experiences, we select 13 controllable factors, as follows.

A: Locks mold $\text{pressure}_1$
B: Lock mold $\text{pressure}_2$
C: Lock mold $\text{pressure}_1$ delay time
D: preserve $\text{pressure}_1$,
E: preserve $\text{pressure}_2$,
F: material tube $\text{temperature}_1$,
G: material tube $\text{temperature}_2$,
H: injection $\text{speed}_1$,
I: injection $\text{speed}_2$,
J: transform $\text{position}_0$,
K: transform $\text{position}_1$,
L: movable side mold temperature,
M: fix side mold temperature.

Table 1 lists the experimental factors and their levels.

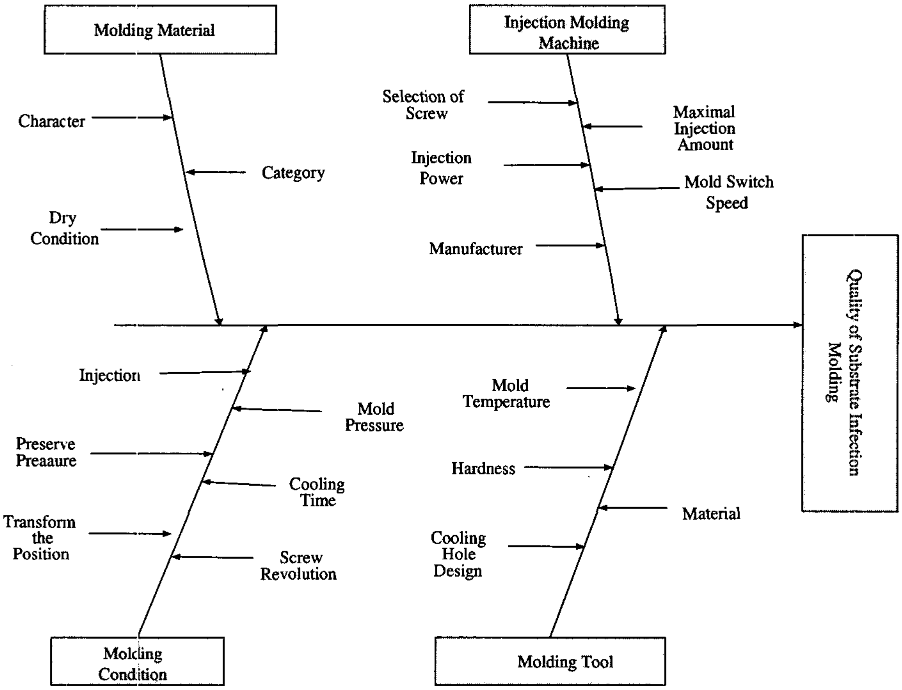

**Figure 1.** The cause effect diagram of injection molding for CD-R substrate

**Table 1.** The level of injection molding parameters

| factor / level | level 0 | level 1 | level 2 |
|---|---|---|---|
| A | 145 | 150 | 155 |
| B | 50 | 60 | 70 |
| C | 0.9 | 1.1 | 1.3 |
| D | 22 | 25 | 28 |
| E | 20 | 23 | 26 |
| F | 300 | 320 | 340 |
| G | 310 | 330 | 350 |
| H | 12 | 15 | 18 |
| I | 60 | 70 | 80 |
| J | 30.5 | 31.5 | 32.5 |
| K | 27 | 28 | 29 |
| L | 101 | 103 | 105 |
| M | 104 | 107 | 110 |

## 3.2 Orthogonal Array

This experiment selects 13 controllable factors to carry out the experiment, with other controllable factors regarded as fixed. The experiment adopts the $L_{27}$ $(3^{13})$ orthogonal array, and each controllable factor gives three levels. Because of the time and cost limit, each experiment is repeated 10 times, the order of production is the noise factor.

## 3.3 Quality Characteristics

There are seven quality characteristics, Depth, Retardation, Radial Deviation, Tangential Deviation, Axial Deflection, Axial Acceleration, and Thickness measured.

### 3.3.1 Depth

Depth denotes the orbital depth at which the molding data copy to the substrate, and the unit is $\mu$ m ($10^{-6}$ meters). When the depth of the substrate orbit is bigger, it indicates better quality of copy. Hence, the greater the Depth, the better the quality will be. So, Depth is larger-the-better.

### 3.3.2 Retardation

Retardation denotes the birefringence phenomenon with light running through the substrate to the product. Its measure standard is the aberrant distance which the light refracts, and the unit is nm ($10^{-9}$ meter). Retardation is presented by the curve, and in order to measure the discrimination of the quality characteristic, after discussion with engineers, we divide the quality characteristic curve of Retardation into three ranks, giving them different grades accordingly.

**Table 2.** The rank condition and grade of Retardation

| Rank | Condition | Grade |
|---|---|---|
| *None* | maximum Curve < 50 and minimum Curve > -50 | 2 |
| Some | maximum Curve > 50 or minimum Curve < -50 | 5 |
| Severe | maximum Curve > 100 or minimum Curve < -100 | 10 |

The rank of None indicates no drawback, the rank of Some indicates some drawbacks, and the rank of Severe indicates serious drawback. Therefore, the smaller the Retardation, the better the quality will be. So, Retardation is the smaller-the-better.

### 3.3.3 Radial Deviation

Radial Deviation denotes the horizontal warp produced by the substrate of the injection molding. It measures the warp angle of the substrate, and the unit is degree ( °). Retardation Deviation is presented by three refractive lines. In order to measure the discrimination of the quality characteristic, we divide the Radial Deviation curves into three ranks, giving them different grades accordingly. Therefore, the smaller the Radial Deviation, the better the quality will be. So, Radial Deviation is the smaller-the-better.

**Table 3.** The rank condition and grade of Radial Deviation

| Rank | Condition | Grade |
|---|---|---|
| *None* | -1 < minimum AVERAGE line < 0 and Range < 0.4 | 2 |
| Some | -1.5 < minimum AVERAGE line < -1 or Range > 0.4 | 5 |
| Severe | minimum AVERAGE line < -1.5 and Range > 0.4 | 10 |

### 3.3.4 Tangential Deviation

Tangential Deviation denotes the vertical warp produced by the injection molding substrate. It measures the warp angle of the substrate, and the unit is degree( °). Tangential Deviation is presented by two refractive lines. In order to measure the discrimination of the quality characteristic, we divide the Tangential Deviation curves into three ranks, giving them different grades accordingly. Therefore, the smaller the Tangential Deviation, the better the quality will be. So, Tangential Deviation is the smaller-the-better.

**Table 4.** The rank condition and grade of Tangential Deviation

| Rank | Condition | Grade |
|---|---|---|
| *None* | maximum MAX line < 0.2 and minimum MIN line >-0.2 | 2 |
| Some | maximum MAX line > 0.3 or minimum MIN line <-0.3 | 5 |
| Severe | maximum MAX line > 0.3 or minimum MIN line <-0.3 | 10 |

### 3.3.5 Axial Deflection

Axial Deflection denotes the axial obliquity produced by the injection molding substrate. It measures the distance of the substrate axial obliquity, and the unit is $\mu$ m($10^{-6}$ meter). Axial Deflection is presented by three curves, and in order to measure the quality characteristic, we divide the Axial Deviation curves into three ranks, giving them different grades accordingly. Therefore, the smaller the Axial Deviation, the better the quality will be. So, Axial Deviation is the smaller-the-better.

**Table 5.** The rank condition and grade of Axial Deflection

| Rank | Condition | Grade |
|---|---|---|
| *None* | minimum AVERAGE line > -100 and minimum MIN line > -200 | 2 |
| Some | -200 < minimum AVERAGE line < -100 or -300< minimum MIN line < -200 | 5 |
| Severe | minimum AVERAGE line < -200 or minimum MIN line < -300 | 10 |

### 3.3.6 Axial Acceleration

Axial Acceleration denotes the axial acceleration when the substrate revolves, the unit is $m/s^2$. Axial Acceleration is presented by two refractive lines, because it is better to approach 0 for Axial Acceleration refractive line, we divide the measuring refractive chart into three ranks, giving them different grades accordingly. Therefore, the smaller the Axial Acceleration, the better the quality will be. So, Axial Acceleration is the smaller-the-better.

**Table 6.** The rank condition and grade of Axial Acceleration

| Rank | Condition | Grade |
|---|---|---|
| *None* | minimum MAX line < 0.2 and minimum MIN line > -0.2 | 2 |
| Some | minimum MAX line > 0.2 or minimum MIN line < -0.2 | 5 |
| Severe | minimum MAX line > 0.3 or minimum MIN line < -0.3 | 10 |

### 3.3.7 Thickness

Thickness denotes thickness of the substrate. Because the accepted average thickness of inner and outer tracks for the substrate is 1.16mm ± 0.01mm, so the quality characteristic of the substrate thickness is nominal-the-best.

## 3.4 Experimental Results and Confirmation Experiment

This experiment uses the $L_{27}$ $(3^{13})$ orthogonal array and is repeated 10 times. The S/N ratio is shown in Table 7. The optimal parameter conditions for Phadke (1988), Tong et al. (1997), Tong and Su (1997) and Wu (2002), are then $A_0B_1C_0D_0E_0F_2G_1H_0I_0J_1K_0L_1M_1$, $A_0B_2C_1D_0E_0F_2G_1H_0I_1J_0K_0L_0M_1$, $A_1B_1C_1D_0E_0F_2G_1H_2I_1J_0K_0L_0M_1$ and $A_0B_1C_0D_0E_0F_2G_2H_2I_1J_0K_1L_1M_1$, respectively.

According to the above four optimal conditions, we perform confirmation experiment separately, each 10 times. The experiment results are shown in Table 8, where the reduction percentage of quality loss (RPQL) is

$$RPQL=\frac{L-L'}{L}\times 100\%=\left[1-\frac{K(10^{-\frac{\eta'}{10}})}{K(10^{-\frac{\eta}{10}})}\right]\times 100\%=(1-10^{-\frac{\eta'-\eta}{10}})\quad . \tag{1}$$

The optimal parameter conditions for this case are $A_0B_1C_0D_0E_0F_2G_2H_2I_1J_0K_1L_1M_1$.

**Table 7.** S/N ratio of 7 quality characteristics

| NO | A | B | C | D | E | F | G | H | I | J | K | L | M | *D* | *R* | *RD* | *TD* | *AD* | *AA* | *T* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 32.09523 | -17.4036 | -7.8533 | -9.13814 | -7.8533 | -14.6982 | 42.73979 |
| *2* | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 32.77168 | -18.893 | -19.6614 | -19.6614 | -19.6614 | -19.6614 | 42.88875 |
| *3* | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 32.8235 | -19.2942 | -7.8533 | -6.0206 | -6.0206 | -6.0206 | 43.60644 |
| *4* | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 32.08663 | -16.0206 | -13.1806 | -14.6982 | -16.7669 | -16.149 | 44.66251 |
| *5* | 0 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 0 | 2 | 0 | 0 | 1 | 32.60446 | -13.9794 | -12.7184 | -17.8104 | -15.1188 | -15.7864 | 46.5093 |
| *6* | 0 | 1 | 1 | 2 | 2 | 2 | 1 | 0 | 2 | 0 | 2 | 1 | 0 | 32.11368 | -6.0206 | -9.13814 | -10.9342 | -10.9342 | -9.13814 | 44.18639 |
| *7* | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 1 | 1 | 31.90766 | -20 | -10.1284 | -11.959 | -9.13814 | -18.451 | 42.47569 |
| *8* | 0 | 2 | 2 | 1 | 1 | 1 | 2 | 0 | 1 | 0 | 1 | 2 | 0 | 32.90446 | -6.0206 | -20 | -18.7737 | -20 | -18.893 | 45.98769 |
| *9* | 0 | 2 | 2 | 1 | 2 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 2 | 31.72718 | -13.9794 | -12.7184 | -14.0312 | -20 | -10.1284 | 44.01158 |
| *10* | *1* | *0* | *1* | *1* | *0* | *1* | *1* | *0* | *0* | *1* | *1* | *1* | *1* | 32.12539 | -13.9794 | *-10.9342* | -12.9885 | *-12.2011* | -17.8104 | 41.84351 |
| *11* | 1 | 0 | 1 | 1 | 1 | 2 | 0 | 1 | 2 | 2 | 0 | 2 | 0 | 32.8292 | -16.0206 | -20 | -19.2942 | -20 | -16.7669 | 43.17928 |
| *12* | 1 | 0 | 1 | 1 | 2 | 0 | 2 | 2 | 1 | 0 | 2 | 0 | 2 | 32.15248 | -11.6137 | -20 | -16.5706 | -20 | -14.9969 | 43.95578 |
| *13* | 1 | 1 | 2 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 32.35459 | -12.7184 | -11.6137 | -15.7864 | -16.0206 | -15.7864 | 45.17752 |
| *14* | 1 | 1 | 2 | 0 | 1 | 2 | 0 | 2 | 0 | 0 | 1 | 1 | 2 | 32.54108 | -12.7184 | -19.2942 | -10.9342 | -20 | -10.9342 | 44.58338 |
| *15* | 1 | 1 | 2 | 0 | 2 | 0 | 2 | 0 | 2 | 1 | 0 | 2 | 1 | 32.13727 | -6.0206 | -12.2011 | -16.149 | -7.8533 | -17.2346 | 43.78616 |
| *16* | 1 | 2 | 0 | 2 | 0 | 1 | 1 | 2 | 2 | 0 | 0 | 2 | 2 | 32.73563 | -6.0206 | -13.5984 | -18.893 | -18.451 | -16.5706 | 42.85003 |
| *17* | 1 | 2 | 0 | 2 | 1 | 2 | 0 | 0 | 1 | 1 | 2 | 0 | 1 | 32.45022 | -13.9794 | -7.8533 | -10.1284 | -16.7669 | -7.8533 | 45.01989 |
| *18* | 1 | 2 | 0 | 2 | 2 | 0 | 2 | 1 | 0 | 2 | 1 | 1 | 0 | 32.07789 | -6.0206 | -12.7184 | -9.13814 | -20 | -16.0206 | 41.23389 |
| *19* | 2 | 0 | 2 | 2 | 0 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 32.20037 | -20 | -13.1806 | -16.8753 | -18.893 | -15.7864 | 42.88875 |
| *20* | 2 | 0 | 2 | 2 | 1 | 0 | 1 | 1 | 2 | 0 | 1 | 0 | 1 | 32.10977 | -19.6614 | -10.9342 | -7.8533 | -19.6614 | -19.6614 | 44.58338 |
| *21* | 2 | 0 | 2 | 2 | 2 | 1 | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 32.03007 | -16.0206 | -17.9588 | -16.5706 | -13.4242 | -17.4036 | 46.96377 |
| *22* | 2 | 1 | 0 | 1 | 0 | 2 | 2 | 1 | 1 | 0 | 0 | 1 | 1 | 32.22168 | -6.0206 | -6.0206 | -10.1284 | -9.13814 | -6.0206 | 39.98119 |
| *23* | 2 | 1 | 0 | 1 | 1 | 0 | 1 | 2 | 0 | 1 | 2 | 2 | 0 | 32.22585 | -13.9794 | -19.6614 | -12.2011 | -20 | -15.1188 | 42.88875 |
| *24* | 2 | 1 | 0 | 1 | 2 | 1 | 0 | 0 | 2 | 2 | 1 | 0 | 2 | 32.00198 | -16.0206 | -19.6614 | -15.682 | -20 | -12.9885 | 42.79665 |
| *25* | 2 | 2 | 1 | 0 | 0 | 2 | 2 | 2 | 2 | 1 | 1 | 0 | 0 | 32.15953 | -7.8533 | -6.0206 | -6.0206 | -9.13814 | -10.9342 | 37.65016 |
| *26* | 2 | 2 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 2 | 0 | 1 | 2 | 31.9843 | -16.7669 | -20 | -14.9969 | -19.6614 | -14.5179 | 45.10544 |
| *27* | 2 | 2 | 1 | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 2 | 2 | 1 | 32.15326 | -19.0741 | -9.13814 | -12.5042 | -6.0206 | -14.3775 | 42.49593 |

Remark: D(Depth), R(Retardation), RD(Radial Deviation), TD(Tangential Deviation), AD(Axial eflection), T(Thickness)

**Table 8.** The results of confirmation experiment

| Condition | Present condition | Phadke (1988) | | | Tong et al. (1997) | | | Tong and Su (1997) | | | Wu (2002) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quality characteristic | $A_1B_1C_0D_1E_0F_0G_1H_0I_1J_0K_1L_0M_0$. | $A_0B_1C_0D_0E_0F_2G_1H_0I_0J_1K_0L_1M_1$ | | | $A_0B_1C_1D_0E_0F_2G_1H_0I_1J_1K_1L_0M_1$ | | | $A_1B_1C_1D_0E_0F_2G_1H_2I_1J_0K_1L_0M_1$ | | | $A_0B_1C_0D_0E_0F_2G_2H_2I_1J_0K_1L_1M_1$ | | |
| | | improve RPQL(db) | | | improve RPQL(db) | | | improve RPQL(db) | | | improve RPQL(db) | | |
| D | 32.14 | 32.10 | -0.04 | -0.81% | 32.10 | -0.04 | -0.97% | 32.41 | 0.27 | 6.11% | 32.68 | 0.55 | 11.79% |
| R | -3.27 | -11.80 | -8.52 | -611.7% | -12.00 | -8.72 | -644.73% | -7.17 | -3.90 | -145.36% | -6.89 | -3.61 | -129.67% |
| RD | -11.27 | -1.79 | 9.48 | 88.73% | -1.34 | 9.92 | 89.82% | -3.25 | 8.02 | 84.21% | -3.13 | 8.14 | 84.66% |
| TD | -6.04 | -7.20 | -1.15 | -30.35% | -9.26 | -3.22 | -109.7% | -8.31 | -2.27 | -68.54% | -4.44 | 1.61 | 30.94% |
| AD | -17.31 | -3.29 | 14.02 | 96.04% | -3.30 | 14.01 | 96.03% | -5.43 | 11.88 | 93.52% | -3.32 | 14.00 | 96.01% |
| AA | -11.45 | -5.89 | 5.56 | 72.17% | -5.39 | 6.06 | 75.25% | -4.86 | 6.59 | 78.06% | -4.58 | 6.87 | 79.45% |
| T | 38.20 | 37.36 | -0.842 | -21.39% | 39.585 | 1.385 | 27.31% | 38.84 | 0.64 | 13.78% | 36.52 | -1.68 | 47.10% |
| Average RPQL | | -58.19% | | | -66.71% | | | 8.83% | | | 18.01% | | |

## 3.5 Benefit Analysis

We compare the optimal parameter conditions with the present combination to carry out the benefit analysis.

The present parameter conditions are $A_1B_1C_0D_1E_0F_0G_1H_0I_1J_0K_1L_0M_0$, while the optimal parameter conditions are $A_0B_1C_0D_0E_0F_2G_2H_2I_1J_0K_1L_1M_1$. The increasing $\triangle\eta=\eta'$ of optimal parameter conditions $-\eta$ of present parameter conditions. The optimal parameter conditions are better than the present parameter conditions, because six quality characteristics have increased benefits, only Retardation is worse than that of the present parameter conditions.

$$\frac{L'}{L}=Average\left(\frac{1}{2}^{\frac{\Delta\eta(D)}{3}}+\frac{1}{2}^{\frac{\Delta\eta(R)}{3}}+\frac{1}{2}^{\frac{\Delta\eta(RD)}{3}}+\frac{1}{2}^{\frac{\Delta\eta(TD)}{3}}+\frac{1}{2}^{\frac{\Delta\eta(AD)}{3}}+\frac{1}{2}^{\frac{\Delta\eta(AA)}{3}}+\frac{1}{2}^{\frac{\Delta\eta(T)}{3}}\right)=0.78525 \qquad (2)$$

The quality loss of CD- R substrate reduces 21.475%

# 4. Conclusions

This study utilizes Taguchi's parameter design to enhance the yield rate for the process of CD-R substrate. We have found 13 three-level controllable factors from the cause-effect diagram, repeated 10 times the experiment with the $L_{27}(3^{13})$ orthogonal array, and measured seven quality characteristics. We employ four general methods to find the optimal parameter conditions individually. Then, we perform the confirmation experiment and compare the results. Therefore, the optimal parameter conditions are obtained. According to the benefit analysis, the optimal parameter conditions can reduce the quality loss percentage of CD-R substrate to about 21%. The company can extend the results horizontally to other CD-R and other product lines, such as CD-RW and DVD-R research and development.

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