Application of Response Surface Method for Optimal Transfer Conditions of MLCC Alignment System

Su Seong Park
Jae Min Kim
Won Jee Chung
Mechanical Design & Manufacturing Engineering, Changwon National University
Changwon, 641-773, South Korea
Tel: +82-55-267-1138, 53-3 Fax: +82-55-263-5221
Email: unesco777@hanmail.net

And

O Chul Shin
Solomon Mechanics Inc.
Changwon, Kyongnam 641-847, **South Korea**

ABSTRACT

This paper presents the Application of Response Surface Method for Optimal Transfer Conditions of MLCC Alignment System. his paper is composed of two parts: (1) Testing performance verification of MLCC alignment system, compared with manual operation; (2) Applying response surface method to figuring out the optimal transfer conditions of MLCC transfer system. As a result testing performance verification of MLCC alignment system, the average alignment rates are 95% for 3216 chip, 88.5% for 2012 chip and 90.8% for 3818 chip. The MLCC alignment system can be accepted for practical use because average manual alignment is just 80%. In other words, the developed MLCC alignment system has been upgraded to a great extent, compared to manual alignment. Based on the successfully developed MLCC alignment system, the optimal transfer conditions have been explored by using RSM. The simulations using ADAMS® has been performed according to the cube model of CCD. By using MiniTAB®, we have established the model of response surface based on the simulation results. The optimal conditions resulted from the response optimization tool of MiniTAB® has been verified by being assigned to the prototype of MLCC alignment system.

Keywords: Multi-Layer Ceramic Capacitor (MLCC), Alignment system, Response Surface Method (RSM), MiniTAB®, ADAMS®

1. Introduction

Nowadays cellular phones, digital cameras and MP3's have been daily necessaries so that they become more compact and even lighter with powerful functions as days elapse. To cope with these demands, the electronic parts such as capacitors are much smaller. For this purpose, a new type of capacitor, called as Multi-Layer Ceramic Capacitor (abbreviated as MLCC), is shown up. The MLCC can allow an electronic product to be ultra-light. Accordingly, the demand of MLCC is consistently increasing. In turn, this pushes up the automation for producing MLCC's efficiently. This is why we are getting into research for MLCC production automation system with Solomon Mechanics Inc. However, the inter-process automation, *i.e.*, automation between two neighboring processes, is lower than the automation of each process.

In this paper, the MLCC alignment system which aims at the inter-process automation between the first and the second firing processes will be dealt with. In specific, without the MLCC alignment system, manual process would intervene for the inter-process between above two processes. Figure 1 shows the MLCC alignment system developed by Solomon Mechanics Inc.

This paper is composed of two parts: (1) Testing performance verification of MLCC alignment system, compared with manual operation; (2) Applying response surface method to figuring out the optimal transfer conditions of MLCC transfer system.

2. Testing performance verification of MLCC alignment system

2.1 MLCC alignment system

Fig. 1 MLCC Alignment System

The MLCC alignment system from the 1st firing process to the 2nd firing process can be outlined as follows: i) the feeding part of the 1st fired chips, ii) weight measuring part of chips, iii) conveyor unit for transferring chips from the feeding part to weight measuring part, iv) aligning part of chips, and v) transferring part of chips.

In order to verify the performance of MLCC alignment system, we have conducted some experiments by using various testing chips. The model numbers of MLCC are 3216, 2012 and 3818, whose size, area and weight are listed in Table 1. In Table 2, the alignment reference is shown for testing chips. In specific, 'GOOD' decision of alignment will be made when 90% quantity or 90% weight can be obtained. Especially the initial operating conditions for the MLCC alignment system is shown in Table 3. Here *Vel1* denotes the forward velocity of a feeder (of MLCC alignment system), while *Vel2* denotes the return velocity of a feeder. In the meanwhile, *Length* indicates the transfer distance of a feeder.[1]

The principle of MLCC alignment system can be briefly explained as follows. The chips of MLCC are dropped freely under gravitation from a chute as shown in Fig. 2. Then *Vel1* would make chips move forward by not exceeding a static friction between each chip and feeder floor, whereas *Vel2* would make chips move back by exceeding the static friction. Consequently this kind of iterating motion can result in the vibration which can further induce alignment. It can be noted that the rugged terrains in Fig. 2 will play an important role in alignment, by incorporating the vibrating floor of feeder.

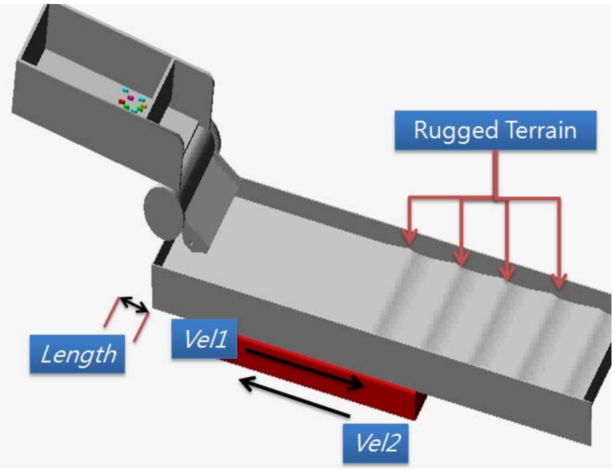


Fig. 2 Schematic of MLCC Alignment System

Table 1 Testing chips of MLCC

Items		Conditions		
MLCC	Model	3216	2012	3818
	Size(LWH)	3.2*1.6*1.2	2.0*1.2*1.2	3.8*1.8*1.8
	Area(cm^3/EA)	0.0512	0.024	0.069
	Weight(g/EA)	0.034	0.016	0.045
Cycle time		8 s		

Table 2 Alignment Reference for Testing chips

Alignment / MLCC	Quantity(EA)		Weight(g)	
	100%	90%	100%	90%
3216	4,688	4,219	159.38	143.44
2012	10,000	9,000	160.00	144.00
3818	3,428	3,089	154.46	139.02

Table 3 Initial factors

	Vel1(m/s)	*Vel2* (m/s)	*Length* (mm)
Initial factors	0.015	0.043	4.000

2.2 Result of testing performance verification

For each chip, 10 experiments have been made as shown in Table 3. The average alignment quantities and rates are 4,453/95% for 3216 chip, 8,853/88.5% for 2012 chip and 3,119/90.8% for 3818 chip. Even though 2012 chip has reached 88.5% in alignment rate below than 90% of GOOD alignment, the MLCC alignment system can be accepted for practical use because average manual alignment is just 80%. In other words, the developed MLCC alignment system has been upgraded to a great extent, compared to manual alignment.

Table 4 Results of Testing Experiments

Class / Test	3216		2012		3818	
	Quantity	Alignment Rate	Quantity	Alignment Rate	Quantity	Alignment Rate
1	4,439	94.7	8,829	88.3	3,098	90.3
2	4,491	95.8	8,843	88.4	3,122	91.0
3	4,439	94.7	8,858	88.6	3,106	90.5
4	4,467	95.3	8,877	88.8	3,127	91.1
5	4,456	95.1	8,863	88.6	3,132	91.3
6	4,490	95.8	8,918	89.2	3,137	91.4
7	4,424	94.4	8,745	87.5	3,116	90.8
8	4,482	95.6	8,860	88.6	3,102	90.4
9	4,433	94.6	8,878	88.8	3,161	92.1
10	4,409	94.1	8,856	88.6	3,083	89.8
Average	4,453	95.0	8,853	88.5	3,119	90.8

3. RSM and Optimum conditions

3.1 RSM

Based on the successfully developed MLCC alignment system, the optimal transfer conditions will be explored by using Response Surface Method [2] (abbreviated as RSM). In specific, RSM is used for finding the optimal values of 3 design factors (or variables) *Vel1*, *Vel2* and *Length* for chip feeding motion of the developed MLCC alignment system. By using ADAMS®[3], we have simulated 30 chips of 3216 chip.

Each chip has been constrained by the contact condition which can realize colliding effects between each other. For each simulation, the elapse time of transferring chips is set as 8 s, the same as the practical operation of the developed MLCC alignment system. The simulation resolution is set as 900 steps. The flowchart of RSM is summarized in Fig. 3.

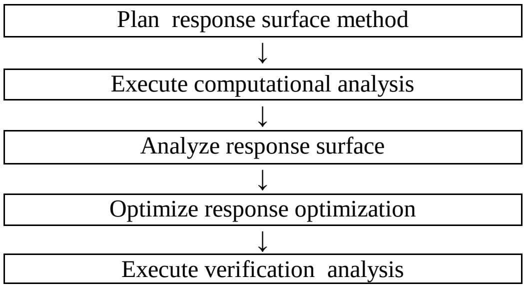


Fig. 3 Flowchart for response surface method

The response surface method with the Central Composite Design (abbreviated as CCD) method [4] is used to approximate a response variable (*i.e.*, transfer credit in this paper). In the CCD method, each design variable can be selected by using MiniTAB® [5], only considering the lower and upper bounds. In addition, total 20 ADAMS® simulations ($2^3+2*3+6=20$) are performed with 3 design variables as shown in Table 7

The CCD has added axial and center points the 2^k factorial design in order to estimate the change of design variables according to the level changes of response variables which would be resulted from less simulations or experiments. The CCD is composed of cube model and axial model. In this paper, the cube model of CCD is used as shown in Table 5. Figure 4 shows one of the simulation results using ADAMS® according to the design of experiment shown in Table 7. Table 6 shows the range (especially lower and upper bounds) of design variables for CCD. Here α for CCD is usually chosen to maintain rotatability in indicating the distance between the center

Table 5 Cube Model of CCD

Cube points	8
Center points in cube	6
Axial point	6
Center points in axial	1
α	1.68

Table 6 Range of Design Variables

Design variable	Lower	Upper
Vel1(m/s)	0.005	0.020
Vel2 (m/s)	0.030	0.060
Length (mm)	3.000	6.000

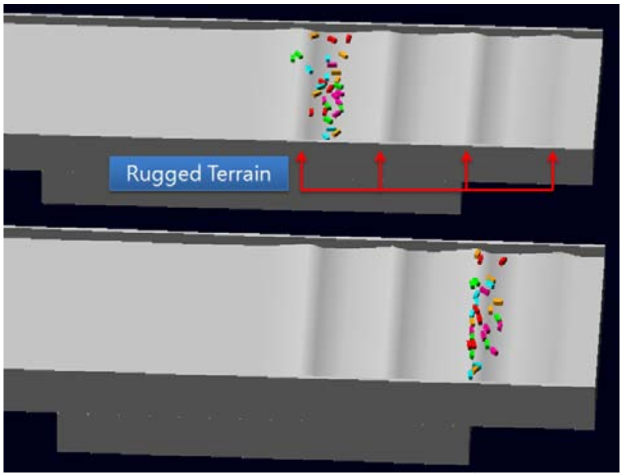


Fig. 4 Simulation of ADAMS®

3.2 Result of RSM

In Table 7, *Transfer Credit* indicates the performance index for each set of design variables (or operating conditions), *i.e.*, *Vel1*, *Vel2* and *Length*. In the simulation of ADAMS®, each chip can get 4 *Transfer Credits* when it can pass over 4 specified (rugged) terrains (which are needed for alignment of chips) as shown in Fig. 4. Actually when each chip should pass over the first terrain, it can have 1 *Transfer Credit*. It follows that the full *Transfer Credit* is 120 when 30 chips can pass over 4 terrains in 8 seconds.

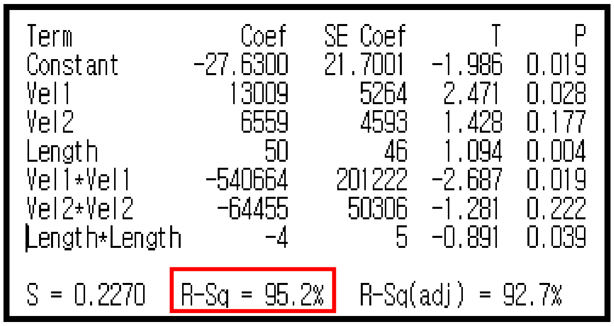
Table 7 Simulation Result

No.	*Vel1*	*Vel2*	*Length*	*Transfer Credit*
1	0.0050000	0.0600000	6.00000	28
2	0.0251134	0.0450000	4.50000	0
3	0.0050000	0.0600000	3.00000	0
4	0.0125000	0.0197731	4.50000	0
5	0.0125000	0.0450000	4.50000	0
6	0.0125000	0.0450000	4.50000	0
7	0.0050000	0.0300000	3.00000	21
8	0.0200000	0.0300000	6.00000	0
9	0.0125000	0.0450000	4.50000	120
10	0.0200000	0.0600000	6.00000	0
11	0.0125000	0.0450000	4.50000	95
12	0.0125000	0.0450000	7.02269	115
13	0.0001134	0.0450000	4.50000	0
14	0.0200000	0.0300000	3.00000	0
15	0.0125000	0.0702269	4.50000	90
16	0.0125000	0.0450000	4.50000	105
17	0.0125000	0.0450000	4.50000	105
18	0.0125000	0.0450000	4.50000	0
19	0.0125000	0.0450000	1.97731	3
20	0.0200000	0.0600000	3.00000	0

It can be noticed that *Transfer Credit* can have 0. This can be explained as follows. In simulation, only 30 chips are simulated rather than actual number of some thousands chips. In practice, a lot of chips can result in the interaction (between each other) which could push chips over 4 rugged terrains. Thus the interaction effect of only 30 chips can be much lower than that of some thousands chips. This can make *Transfer Credit* 0. In addition, the reason why only 30 chips are selected as a simulation model is that its simulation time in ADAMS® is about one and half hour for each simulation. The total simulation time amounts to 30 hours for 20 cases.

By using MiniTAB®, we have established the model of response surface based on the simulation results according to CCD. Especially a quadratic polynomial model has been estimated by using model fitting. For both the construction of response surface and the estimation of regression equation, a full quadratic form of estimation model has been established by considering response surface forms for all the design variables. Then by using residual analysis, lack-of-fit, and the coefficient of determination, decision on the compatibility of selected regression model has been made. When the selected model cannot be compatible, the response surface model can be reduced by pooling the terms which are not significant at the table of variance analysis. Through this process, a final regression model can be re-established.

Figure 5 shows the final model of response surface regression. In specific, for any model of response surface, the value of P for each term has been checked. Then from the largest P value, once one term can be made pooling so that a model can be fitted. After fitting, R-sq and lack-of-fit can be confirmed in Fig. 5 and Table 8, respectively. As a result, it follows that *Vel1*Vel2*, *Vel2*Length* and *Vel2*Length* are not significant, which in turn are ruled out by pooling as shown in Fig. 5.[6]



```
Term               Coef   SE Coef       T       P
Constant       -27.6300   21.7001  -1.986   0.019
Vel1              13009      5264   2.471   0.028
Vel2               6559      4593   1.428   0.177
Length               50        46   1.094   0.004
Vel1*Vel1       -540664    201222  -2.687   0.019
Vel2*Vel2        -64455     50306  -1.281   0.222
Length*Length        -4         5  -0.891   0.039

S = 0.2270    R-Sq = 95.2%    R-Sq(adj) = 92.7%
```

Fig. 5 Final Model of Response Surface Regression

In order to evaluate the compatibility of surface regression model, both residual analysis and analysis of variance (i.e., ANOVA) are used. Figure 6 shows normal probability plot of the residuals. In this figure, the final model of surface regression is in good accordance with normal distribution.

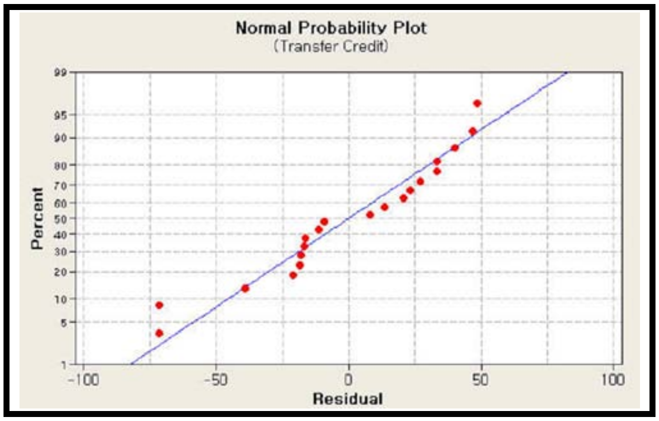


Fig. 6 Normal probability plot of the residuals for *Transfer Credit*

Table 8 shows ANOVA table for *Transfer Credit*. It can be noticed that the final model of surface regression is turned out to be compatible since lack-of-fit of 0.114 is greater than 0.05 (95%). Besides, the coefficient of determination (*i.e*., R-sq) of 95.2% denotes that the final model of regression surface is valid.

Table 8 ANOVA Table for *Transfer Credit*

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	10	29.1757	29.1757	2.91751	38.03	0.000
Linear	4	25.0150	4.2156	1.05390	13.74	0.000
Square	2	1.7278	1.7278	0.86391	11.26	0.001
Interaction	4	2.4329	2.4329	0.60822	7.93	0.001
Residual Error	19	1.4577	1.4577	0.07672		
Lack of fit	14	1.3038	1.3038	0.09313	3.03	0.114
Pure Error	5	0.1539	0.1539	0.03078		
Total	29	30.6334				

Based on the results of analyses, *Transfer Credit*, *T*, (which denotes the performance of chip transfer according to *Vel1*, *Vel2*, and *Length* in ADAMS simulations) can be obtained in a form of quadratic polynomial as follows:

$$T = -27.63 + 13009V_1 + 6559V_2 + 50L \\ -540664V_1^2 - 64455V_2^2 - 4L^2 \quad (1)$$

where T, V_1, V_2, and L denote *Transfer Credit*, *Vel1*, *Vel2*, *Length*, respectively.

3.3 Optimum conditions

In order to figure out the optimal transfer conditions of *Vel1*, *Vel2*, and *Length*, the tool of response optimization in MiniTAB® has been used based on equation (1). As mentioned before, this optimization seeks for 'Larger-the-better characteristics' since the response variable, i.e., *Transfer Credit*, would be better if it could be close to the full credit of 120. Under the constraint of 110 ≤ *Transfer Credit* ≤ 120, the optimal transfer conditions satisfying 'Larger-the-better characteristics', are *Vel1* = 0.019, *Vel2* = 0.0505, *Length* = 5.5454 as shown in Fig. 7.

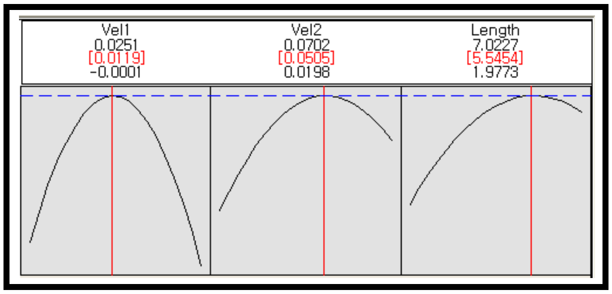


Fig. 7 Optimal Conditions resulted from MiniTAB®

4. Application to Prototype of MLCC System

The optimal conditions, *Vel1* = 0.019, *Vel2* = 0.0505, *Length* = 5.5454, resulted from the response optimization tool of MiniTAB® has been verified by being assigned to the prototype of MLCC alignment system shown in Fig. 1. Especially the operation result of MLCC alignment system using the initial conditions (*Vel1* = 0.015, *Vel2* = 0.043, *Length* = 4.000) is compared with that of MLCC alignment system using the optimal conditions as shown in Fig. 8. It can be noticed that the alignment rate using the optimal conditions has been increased by 1.5%, compared to the case of operation using the initial conditions for 3216 chip (see Table 9).

Table 9 Comparison of Operations using Initial and Optimal Conditions

Class	3216(Initial conditions)		3216(optimal conditions)	
Test	Quantity	Alignment Rate	Quantity	Alignment Rate
1	4,439	94.7	4523	96.5
2	4,491	95.8	4541	96.9
3	4,439	94.7	4518	96.4
4	4,467	95.3	4501	96.0
5	4,456	95.1	4549	97.0
6	4,490	95.8	4532	96.7
7	4,424	94.4	4514	96.3
8	4,482	95.6	4528	96.6
9	4,433	94.6	4532	96.7
10	4,409	94.1	4517	96.4
Average	4,453	95.0	4525.5	96.5

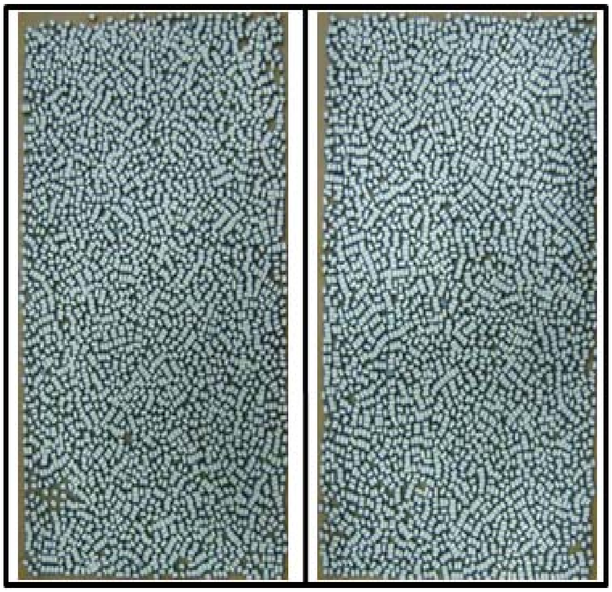


Fig. 8 Results of Operations for Prototype of MLCC System using Initial and Optimal Conditions

5. Conclusion

In conclusion, based on the successfully developed MLCC alignment system, the optimal transfer conditions have been explored by using RSM. The RSM with CCD method has been used to approximate a response variable, *i.e.*, *Transfer Credit*. The simulations using ADAMS® has been performed according to the cube model of CCD. By using MiniTAB®, we have established the model of response surface based on the simulation results. In order to evaluate the compatibility of surface regression model, both residual analysis and analysis of variance have been used to show that the final model of surface regression is in good accordance with normal distribution. Based on the results of analyses, the performance of chip transfer has been obtained in a form of quadratic polynomial, given by equation (1). The optimal conditions resulted from the response optimization tool of MiniTAB® has been verified by being assigned to the prototype of MLCC alignment system. It was shown that the alignment rate using the optimal conditions has been increased by 1.5%, compared to the case of operation using the initial conditions.

Acknowledgement

This work was partially supported (in part) by the Solomon Mechanics Inc.

References

[1] O. C. Shin, S. H. Jung, S. R. Jung, W. J. Jung, J. M. Kim,

[2] Song, C. G., Jo, B. G., “MSC.ADAMS For multibody dynamics analysis ", 2007

[3] W.C. Kim, J. J. Kim, B. W. Park, S. H. Park, T. S. Park, M. S. Song, S. Y. Lee, Y. J. Lee, J. W. Jeon, S. S. Cho, “Introduction to Statistics” pp.309-356, 2005

[4] Myers, R. H, and Montgomery, D. C. Response surface Methodology John wiley & Sons Inc. New York, 1995.

[5] S. B. Lee, “Minitab User Handbook”, 2002

[6] Jung, D.W. Chung, W.J. Kim, H.C. Bang, Y.M. Yoon, Y.M. “Six Sigma Robust Design of Fork Park for LCD Transfer System” WMSCI, 2006.