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A Robust Design for Plastic Injection Molding Applying Taguchi Method and PCA

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ABSTRACT

Plastics injection molding technology is widely used in industrial products. However, the product quality is inconsistent and variance is significant in the conventional plastic injection molding process. This phenomena occurs due to the absence of a systematic method for maintaining stable processes. If this issue can be resolved, product quality can increase to higher levels and further reinforce industry competitiveness. This study uses a combination of the Taguchi method and principal component analysis (PCA) to improve the real product quality of cosmetic containers produced by conventional plastics injection molding processes through optimizing the parameters. This study determined that when all the values of the three quality characters were moved to the intervals of specification, the standard deviation reduced by approximately 6 % to 10 %. Additionally, PCA can be effectively applied to problems with multiple quality characteristics to establish an integral solution. Furthermore, the holding pressure can be considered as an adjustment factor to the process mean. Through analysis of variance, this study determined that the material melting temperature, holding pressure, and injection location significantly affected the size of the finished product.

***Key Words*:** plastics injection molding, quality, Taguchi techniques, PCA

田口方法與主成分分析法在塑膠射出成型穩健生產之應用

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摘　要

塑膠射出成型技術已經被廣泛應用於工業產品中，但由於射出成形製程常欠缺系統性之方法以維持品質之穩定，而發生產品品質之不一致性或變異的情形。若能解決此一問題，則產品品質水準必能有所提升，進而提高企業競爭力。本研究結合田口方法與主成分分析法（principal component analysis, PCA）來最佳化生產製程參數以改善化妝盒產品品質，研究結果顯示品質特性之平均值均移至規格界線內，標準差也減少約 6% 及 10%；同時 PCA 可以取得多品質特性之整體最佳解以有效解決多品質特性問題；又，射出成型之保壓壓力可為製程平均值之調整因

子；材料溫度、保壓壓力、射出位置對於完成品品質之尺寸大小有顯著之影響。

關鍵詞：塑膠射出成型，品質，田口方法，主成分分析法

I. INTRODUCTION

Plastic injection molding, a process widely applied to light and high demand products, has played a significant role in the development of modern industrial technology. With its widespread usage, plastic injection molding products have become an indispensable tool for modern living. The parameters of the injection-molding process, which includes temperature, pressure, and shooting position, are important control factors in the process of plastic injection molding. It determines the quality of injection products. Therefore, whether or not parameters of the injection-molding machine are correctly set will influence the quality stability of plastic injection molding products.

In the traditional production process, parameters are established by engineers who are backed by years of experience in conducting subjective trials. Thus, the quality of injection molding products varies according to the parameters assigned by different production engineers. Hence, assisting entrepreneurs in determining manufacturing process parameters and allowing them to stabilize product quality and sharpen their competitiveness are crucial.

This research aims to identify the combination of optimal parameter level of plastic injection manufacturing process using the Taguchi method. Most of the previous applications of the Taguchi method only emphasis on single-response problems, while the multi-response problems have received relatively little attention. However, several quality characteristics of a numerous cosmetic components are usually considered for product quality by consumers. In this paper, the combination of common design parameters for multiple quality characteristics was explored by using principal component analysis. A confirmation trial is performed to ensure the repeatability of product quality characteristics underlying the optimal parameter level combination.

II. INJECTION MOLDING PROCESS AND TAGUCHI METHOD

Defects in the injection molding process usually originate from several sources, including the preprocessing treatment of plastic resin prior to the injection molding process, selection of injection-molding machine, and setting of parameters [12]. Among the common quality problems are weld line, sink marks, flashing, bubbles and voids, silver streaks, flow marks, jetting, cracking, warping, burning, discoloration, size variance, and other product quality characteristics. Although the quality characterustics caused by different factors, all these problems affect each other. Ong et al. [6] molded micro-rods of varying lengths and diameters by using a specially designed tabletop injection molding machine and investigated whether complete filling of the micro-cavities was possible and whether small cavity openings could restrict melt flow into the cavities. The results showed that injection pressure was the most important parameter for microinjection molding.

Chen et al. [2] optimized the parameters of the injection molding manufacturing process for polycarbonate/poly butylene terephthalate (PC/PBT) automobile bumpers by Taguchi method. Their research purpose was to eliminate silver streaks on the surface of finished products. Experiment results identified four important factors influencing the presence of silver streaks: mould temperature, filling time, fill/ postfill switch over control, and injection rate. Yang [11] applied the design of experiments (DOE) method based on Taguchi's orthogonal arrays to analyze the tribological behaviors and mechanical properties of polycarbonate (PC) which were reinforced with 20% short glass fiber (SGF) and 6% polytetrafluoroethylene (PTFE). In this paper, the specimens were prepared under different injection molding conditions by varying the control factors of filling time, melt temperature, mold temperature and packing pressure with three levels for each factor. Ong and Koh [5] investigated plastic injection molding of micro parts having dimensions in the order of micron scale and found that the mold temperature is the most significant parameter affecting the partial filling of a cavity. Injection pressure and injection rate (volumetric flow rate) were of secondary importance. Walia et al. [10] applied a Utility theory and Taguchi quality loss function to optimize the centrifugal force assisted abrasive flow machining (CFAAFM) process parameters.

The conventional Taguchi method is an approach intended for achieving robustness of a single-response case. It cannot be used to optimize a multi-response issue. Su and Tong [9] proposed the conduct of the principal component analysis (PCA) to optimize multi-response problems in the Taguchi method. This proposed procedure yields a satisfactory result.

Antony [1] employed the principal component analysis to rectify multi-response problems. Similarly, Fung and Kang [3] optimized the injection-molding process to obtain the friction properties of fiber-reinforced PBT using the Taguchi method and the PCA. The most influential injection-molding parameters for single and multiple responses problems were observed.

In the present research, case study reveals that PCA is a powerful method for addressing the multi-response issue. This research integrates the Taguchi method and the PCA simultaneously reducing the variation among several plastic molding products and sizes, such as length, width, and height, in various directions and in improving the accuracy of size.

III. RESEARCH METHODS

1. Taguchi Method

The traditional quality control methods are designed to reduce variation during the manufacturing stage. The emphasis has been on tightly controlling manufacturing processes to conform to a set of specifications. Taguchi methods, also known as quality engineering methods, refer to quality improvement activities at the product and the process design stages in the product development cycle. By this method, variables that affected product quality are analyzed systematically to determine the optimum combination of process variables that reduces performance variation while keeping the process average close to its target. The Taguchi method is a widely accepted methodology in contemporary experimental design. Orthogonal array and signal-to-noise (S/N) ratio are the main tools for this method. Orthogonal array is a tool tapped for arranging the experiment, whereas the S/N ratio is used to represent a response or quality characteristic; the largest S/N ratio is desired.

There are usually three types of quality characteristics: larger-the-better (LTB), nominal-the-best (NTB), and smaller-the-better (STB). The corresponding S/N ratio can be obtained using the following [7, 8]:

A. LTB

$$SN_{LTB} = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}\right) \quad (1)$$

B. NTB

$$SN_{NTB} = 10 * \log_{10}\left(\frac{\bar{y}^2}{s^2}\right) \quad (2)$$

C. STB

$$SN_{STB} = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}{y_i}^2\right) \quad (3)$$

where s is the standard deviation, y_i is the measured property, $\bar{y} = \sum y_i/n$, and n is the number of samples in each test trial.

The Taguchi method, which combines experimental design techniques with quality loss considerations, is the conventional approach used to achieve robustness. It is appropriate only for a single-response case, and it cannot be applied to optimize a multi-response issue. In the present research, multi-response problem are studied. So the PCA was employed to optimize the multi-response production process.

2. PCA

The PCA is a multivariate statistical method that selects a small number of components to account for the variance of original multi-response. The technique was first proposed by Pearson in 1901 and was later developed by Hotelling [4]. The concept of PCA was carried out using the following steps: converting quality characteristic value into quality loss and standardizing it; transforming the value to a range between 0 and 1; analyzing the original characteristics and converting these into irrelevant “components”; and finally inducing the optimal parameter level combination of multi-quality characteristics. The procedure is described in detail as follows [1, 9]:

Step 1: Calculate quality loss for each response L_{ij} ◦ where L_{ij} pertains to quality loss for ith response at jth trial.

Step 2: Normalize quality loss for each response using the following formula:

$$N_{ij} = \frac{L_i^{\max} - L_{ij}}{L_i^{\max} - L_i^{\min}} \quad (4)$$

where N_{ij} is the normalized quality loss for ith response at jth trial and

$$L_i^{\max} = \max\{L_{i1}, L_{i2}, ..., L_{ij},\};$$

$$L_i^{\min} = \min\{L_{i1}, L_{i2}, ..., L_{ij},\}.$$

Step 3: Perform PCA based on the calculated data, N_{ij}.

Step 4: Determine the number of principal components, k, on the basis of eigenvalue is larger than 1.

Step 5: Calculate the multi-response performance index using the following formula, which can be used to determine the optimal conditions:

$$\omega_{kj} = \sum_{i=1}^{r} v_{ki} N_{ij} \quad (5)$$

where $v_{k1}, v_{k2}, ..., v_{kj}$ v_{ki} are the elements of the eigenvector corresponding to the kth largest eigevalue.

Step 6: Determine the optimal factor/level combination based on ω value. A larger ω value implies better product quality.

IV. EXPERIMENTAL DESIGN OF PLASTIC INJECTION MOLDING OF COSMETIC CONTAINERS

A real product of cosmetic container (shown as in Figure 1) of a conventional plastics injection molding from Company *M* was employed to demonstrate the working of proposed method. There are three dimensions of this product were considered as important quality characteristics. All of which were NTB, with the respective characteristic requirements of X=75.30, Y=75.35, and Z=68.98 mm

1. Experimental Design and Analysis

When the plastic injection molding mould was fixed, relevant literature was reviewed, and a discussion and screening were conducted with engineers and other professionals representing Company M. A total of 11 controllable factors and three levels for all 11 factors were selected (details provided in Table 1). Subsequently, the Taguchi parameter design was conducted, the setting of which indicated that L27(3^{13}) is an appropriate orthogonal array. This orthogonal array is presented in Table 2 [8].

Following a total of 27 Taguchi experiments, and eight runs for each experiment are conducted. all the three quality characteristics and the S/N ratio of each experimental run for NTB were obtained using Equation 2. The average S/N ratio values of each factor in different levels are summarized in Table 3.

Fig. 1. Cosmetic container

Table 1. Experimental factors and their levels

	Factors	Level 1	Level 2	Level 3
A	Material melting temperature	180°C	225°C	215°C
B	Injection pressure	63	70	77
C	Material reheat temperature	168°C	210°C	220°C
D	Mold temp.-male	36°C	40°C	44°C
E	Mold temp.-female	63°C	70°C	77°C
F	Injection position-1	18 mm	18.9 mm	19.8 mm
G	Injection position-2	15.3 mm	16.2 mm	17 mm
H	Injection speed-1	23 mm/sec	25 mm/sec	28 mm/sec
I	Injection speed-2	18 mm/sec	20 mm/sec	22 mm/sec
J	Holding pressure-1	36 kpa	40 kpa	44 kpa
K	Holding pressure-2	54 kpa	60 kpa	66 kpa

Table 2. Orthogonal array $L_{27}(3^{13})$ of the experimental runs

Trial	Control factors												
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	2	1	3
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Table 3. Average S/N values of each factor in different levels

Factors	Character X				Character Y				Character Z			
	1	2	3	Diff.	1	2	3	Diff.	1	2	3	Diff.
A	68.18	68.69	71.99	3.81	70.28	67.14	74.15	7.01	70.99	67.65	75.99	8.33
B	69.18	70.29	69.37	1.11	71.01	67.12	73.09	5.97	67.46	71.93	75.25	7.79
C	69.35	69.81	69.69	0.46	71.44	69.96	69.66	1.79	69.46	72.83	72.35	3.37
D	71.54	69.27	68.04	3.49	72.09	71.41	67.76	4.32	74.68	71.98	67.97	6.71
E	69.41	68.62	70.82	2.19	69.82	70.53	70.73	0.91	71.73	72.68	70.23	2.45
F	69.40	68.66	70.79	2.13	70.62	69.96	70.59	0.66	70.16	75.05	69.43	5.62
G	68.95	69.82	70.08	1.13	70.00	69.77	71.31	1.54	71.19	71.82	71.63	0.63
H	69.90	70.47	68.48	1.99	70.79	69.93	70.47	0.87	73.03	71.08	70.53	2.50
I	70.02	69.05	69.78	0.96	69.65	69.09	72.66	3.56	69.47	73.16	72.01	3.68
J	68.49	69.32	71.04	2.56	70.31	68.38	72.24	3.86	73.92	67.51	73.21	6.41
K	71.01	71.01	66.83	4.18	71.46	73.77	66.03	7.74	75.99	74.19	64.45	11.55

As illustrated in Table 3, the S/N ratios of 68.18, 68.69, and 71.99 were shown in three different levels of controllable factor A for character X. The biggest difference (maximum – minimum) of S/N rations among three levels was 3.81. The same meaning as above can be shown for other controllable factors in different levels.

Factors A, D, E, F, J, and K are highly dependent on the quality of character X. The factor/level combination $A_3D_1E_3F_3J_3K_1$ is recommended for the production process as a result. Similarly, the factor/level combination $A_3B_3D_1I_3J_3K_2$ is recommended to obtain the quality of character Y in the production process. Meanwhile, $A_3B_3D_1F_2J_1K_1$ is recommended for obtaining the quality of character Z.

Based on the above analysis, there are conflictions for optimal level combination F, J, and K among characteristics X, Y, and Z. Therefore, based on the above results, there are improvement potentials for the traditional Taguchi method, allowing for the simultaneous solving of the optimization of the three quality characteristics of the products.

2. PCA

The PCA and the Taguchi method were integrated in this study to manage multi-response problems. According to the PCA steps mentioned earlier, these three quality characteristics were transformed into quality loss and were normalized by Equation (4). The normalized results are listed in Table 4. Software package SPSS 13.0 was employed for the PCA to identify the eigenvalue of all the quality characteristics. The first principal component is chosen to represent the original three responses. These eigenvalues are presented in Table 5.

In previously published studies [1, 9], only the first principal component was selected to represent the original response because only one eigenvalue is greater than 1. In this study, one of the three eigenvalues is greater than 1. Thus, one principal component is a major concern. The eigenvector for the first largest eigenvalues is [0.8966, 0.9164, 0.6008]. Subsequently, ω value can be calculated using Equation (5), and it can be expressed as Equation (6). The calculation results of all other ω values are presented in Table 6.

Table 4. Principal components of three quality responses

Exp	X	Y	Z	Exp	X	Y	Z	Exp	X	Y	Z
1	1	0.8175	0.7301	10	0.9684	0.9823	0	19	0.9926	0.9718	0.9077
2	0.8958	0.9626	0.9902	11	0.9711	0.9969	0.9518	20	0	0	0.3786
3	0.6121	0.0259	0.5417	12	0.7016	0.7897	0.9201	21	0.8872	0.9877	1
4	0.9924	0.9801	0.9547	13	1	0.9541	0.8801	22	0.9977	0.8485	0.7238
5	0.9985	0.9608	0.8179	14	0.7723	0.0331	0.8065	23	0.7905	0.882	0.9466
6	0.9151	0.9229	0.9672	15	0.9872	0.9687	0.9488	24	0.6059	0.1329	0.7652
7	0.9986	0.9471	0.8495	16	0.9998	0.8936	0.5779	25	0.9643	0.996	0.998
8	0.7188	0.723	0.9269	17	0.8357	0.8719	0.9708	26	0.9572	1	0.9562
9	0.9855	0.9774	0.8515	18	0.7275	0.5349	0.8536	27	0.7085	0.7926	0.9359

Table 5. Eigenvalues for the principal components

Principal component Eigenvalue		Components extracted from First Component Eigenvalue	
First	2.00455	X	0.8966
Second	0.78227	Y	0.9164
Third	0.21378	Z	0.6008

$$\omega_{1j} = 0.8966 \cdot X_j + 0.9164 \cdot Y_j + 0.6008 \cdot Z_j \qquad (6)$$

The ω value determines the combination of optimal parameter level. The higher the ω value is, the better the quality will be. The S/N value of main effects for all factor levels were recalculated based on the results of the ω values, as illustrated in Table 7.

Based on Table 7, the combination $A_1B_3C_1D_3E_2F_1G_2H_1I_3J_3K_1$ stands for the best design parameters for the production process. Results of the analysis of variance (ANOVA) of ω values are presented in Table 8.

To compare the anticipated improvement among different recommended process combinations, four important factors (i.e., K, G, C, and H) with the highest contribution in the analysis of variance from Table 8 were identified as research subjects. The redetermination of the three levels of the four factors is illustrated in Table 9. To reduce the number of experiments, $L_9(3^4)$ orthogonal array was utilized to investigate the four factors with three levels for each factor. In the experiment, the unselected controllable factors were all assumed the optimal parameter level combination in the L27 experiment as the production conditions in order to verify the repeatability of the optimal parameter level combination.

After conducting the L9 Taguchi experiment, the expression of the traditional S/N ratio was applied. The responses obtained from these trials are presented in Table 10:

Table 7. S/N values for the first principal component

Factor	Level			Max-min.
	1	2	3	
A	2.06	1.97	1.87	0.1939
B	1.79	2.01	2.10	0.3089
C	2.18	1.86	1.85	0.3300
D	1.92	1.99	1.99	0.0728
E	1.97	2.12	1.80	0.3217
F	2.03	1.94	1.93	0.0955
G	1.74	2.22	1.95	0.4789
H	2.14	1.99	1.77	0.3701
I	1.96	1.92	2.02	0.1029
J	1.86	2.02	2.02	0.1680
K	2.24	2.16	1.50	0.7420

Table 8. Response ANOVA of ω values for the first principal component

Factor	*d.f.*	SS	Mean square	F value	SS′	Contribution (%)
B	2	1.4157	0.7078	3.2829	0.9845	4.80%
C	2	1.9079	0.9540	4.4243	1.4767	7.20%
E	2	1.3738	0.6869	3.1858	0.9426	4.60%
G	2	2.8441	1.4221	6.5953	2.4129	11.77%
H	2	1.8417	0.9208	4.2706	1.4104	6.88%
K	2	8.1047	4.0523	18.7939	7.6735	37.42%
Error	4	1.4642	-	-	-	-
(Pooled)	14	3.0187	0.2156		5.6061	27.34%
Total	26	20.5066			20.5066	100.00%

Note: SS’: Net sum square.

Table 9. Experimental factors and levels for injection molding

Factor	1	2	3
C	168 °C*	200 °C	210 °C
G	16.2 mm*	15.9 mm	16.5 mm
H	23 mm/sec*	30 mm/sec	40 mm/sec
K	54 kpa*	45 kpa	60 kpa

Note: *Optimal parameter level for PCA in L27 trials.

Table 6. ω value of the experimental run

Exp	X	Y	Z	ω	Exp	X	Y	Z	ω	Exp	X	Y	Z	ω
1	0.8966	0.7491	0.4386	2.0843	10	0.8683	0.9002	0	1.7684	19	0.8899	0.8906	0.5453	2.3258
2	0.8031	0.8821	0.5949	2.2801	11	0.8707	0.9135	0.5718	2.3561	20	0	0	0.2274	0.2274
3	0.5488	0.0237	0.3254	0.898	12	0.6291	0.7236	0.5528	1.9055	21	0.7954	0.9051	0.6008	2.3014
4	0.8898	0.8982	0.5735	2.3615	13	0.8966	0.8743	0.5287	2.2997	22	0.8946	0.7776	0.4348	2.107
5	0.8952	0.8805	0.4914	2.2671	14	0.6925	0.0303	0.4845	1.2073	23	0.7087	0.8082	0.5687	2.0857
6	0.8204	0.8457	0.5811	2.2172	15	0.8851	0.8877	0.57	2.3428	24	0.5432	0.1218	0.4597	1.1247
7	0.8953	0.8679	0.5103	2.2736	16	0.8964	0.8188	0.3472	2.0625	25	0.8646	0.9127	0.5996	2.3768
8	0.6444	0.6625	0.5568	1.8638	17	0.7493	0.799	0.5833	2.1315	26	0.8582	0.9164	0.5745	2.3491
9	0.8836	0.8957	0.5116	2.2908	18	0.6523	0.4902	0.5128	1.6553	27	0.6352	0.7264	0.5623	1.9239

Table 10. Average S/N values of each factor in different levels

Factors	Character X				Character Y				Character Z			
	1	2	3	Diff.	1	2	3	Diff.	1	2	3	Diff.
C	71.27	70.73	70.75	0.54	74.57	73.65	72.80	1.77	73.25	71.77	70.42	2.84
G	71.09	70.41	71.24	0.83	73.61	72.63	74.78	2.16	70.30	72.54	72.59	2.29
H	69.79	72.03	70.92	2.24	72.30	74.71	74.02	2.41	69.75	72.99	72.70	3.24
K	70.39	71.72	70.63	1.33	73.40	75.45	72.17	3.27	71.78	71.90	71.76	0.15

According to the above table of responses for the quality characteristics X, Y, and Z, the optimal parameter level combination applicable to all three characteristics is $C_1G_3H_2K_2$. In the setting of the L9 Taguchi experiment, all the four factors were set with level 1 at the optimal level obtained after the PCA of repeatability. Because the estimated value of S/N ratio of quality characteristic is 68.50, the data obtained in the L9 experiment can be used to verify whether high repeatability exists at the optimal level of PCA or not. Hence, the confidence interval of the S/N ratio of production with optimal conditions and the confidence level of 95% is as follows:

$$68.50 \pm \sqrt{F_{\alpha;1,d.f._{pooled}} \cdot MS_{pooled} \cdot \left[\frac{1}{n_{eff}} + \frac{1}{r}\right]}$$

$$= 68.50 \pm \sqrt{4.60 * 0.2156 * \cdot \left[\frac{1+12}{27} + \frac{1}{8}\right]}$$

$$= 67.72 \sim 69.28$$

The S/N ratio obtained in the L9 experiment was 68.59, which is within the 95% confidence interval. Note that: 68.59 is within the range of 67.72~69.28. This verifies the repeatability of the optimal parameter level combination of the L27 experiment. Similarly, the repeatability of quality characteristics Y and Z can also be obtained.

V. CONCLUSIONS

The approach presented in this paper takes advantage of both the Taguchi method and PCA, which forms a robust and practical methodology in deal with multiple response optimization problems. The paper also presents the case study to illustrate the potential of this powerful integrated approach for tackling multiple response optimization problems in a plastic injection process of cosmetic containers. A set of responses is transformed into a set of small numbers of uncorrelated components by PCA. The number of dimensions and the degree of complexity of the multi-response problems are reduced. Accordingly, optimal conditions in the parameter design stage can be easily identified based on these uncorrelated components. The case study of the plastic injection molding in a cosmetic container manufacturing process demonstrates the effectiveness of the proposed procedure. It is found that all the values of three quality characters have been moved to the intervals of specifications and the standard deviation have been reduced around 6% to 10%. It also has been observed that material melting temperature, holding pressure, and injection position are the three major factors that significantly influence the plastic injection molding in the cosmetic container manufacturing process.

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