Robust Part Quality by Controlling the Injection Moulding Process with 2^4 Fraction Factorial Design: A Case Study

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Abstract **- The author wants to use a case study to investigate the injection moulding machine parameters which will affect the horizontal length dimension of a plastic component used in digital camera. Currently the injection moulding machine process setting caused variations in the diameter exceeding the specification limit. Therefore the experiment is needed to identify the process factors that could be set to maintain the horizontal length dimension closest to the target value and smallest possible variation. The experimental model is used to investigate four factors to identify the factors having large effect by using the Full Factorial Design of Experiment (DOE). The experiment has emphasized the use of these designs in identifying the subset of factors that are active and provide some information about the interaction.**

Index Terms**: Moulding, Factors, Responses, Interaction, DOE, Specification, Target Value, ANOVA.**

I. INTRODUCTION

In the injection moulding industry, the setting of machine parameters has crucial effects on the quality of products. Inappropriate machine parameter settings can cause production and quality problems [1]. In the actual operations, the machine parameter settings are often adjusted by a trial-and-error approach [2]. The moulding machine operators adjust one factor at a time (OFAT) until optimal conditions are obtained. However, this method is difficult to achieve due to the large number of factors being involved and the constraint of limited time.In this case the injection moulders can use Design of Experiments (DOE) approach to overcome the problem [3]. This study focuses on application of the full factorial DOE approach on obtaining the appropriate machine parameters setting to maintain the dimension of the horizontal length as close to the target value as possible.

Injection moulding is the most commonly used manufacturing process for the fabrication of plastic parts. A wide variety of products which vary in size and application are manufactured using injection moulding. The injection moulding process requires the use of an injection moulding machine, raw plastic material and a mould. The plastic is melted in the injection moulding machine and then injected into the mould, where it cools and solidifies into the final part. In this process, hot molten polymer is forced into a cold empty cavity of a desired shape and is then allowed to solidify under a high holding pressure. The entire injection moulding cycle can be divided into three stages: filling, post-filling and mould-opening [4]. During moulding process, the plastic material undergoes temperature and pressure increases, significant shear deformation, followed by rapid drop of temperature and pressure in the mould cavity, leading to solidification and other properties that determine the characteristics of the moulded part. Injection moulding processes are affected by numerous machine parameters. Because it is not possible to identify the effects of all parameters, it is necessary to select the parameters that have major effects on the output. Some of the potential parameters for an injection moulding process might be: injection pressure, barrel temperature, injection time, and pack pressure, holding pressure, mould temperature, injection speed and etc [5]. In moulding industry, the machine set-up operator or technician will choose the inputs of machine process parameters and the outputs will be the customer requirements. In Design of Experiments (DOE), the inputs are frequently referred to as factors and the outputs as responses. Selecting the correct factors and responses requires knowledge of what need to be improved as well as strong knowledge of the technology of injection moulding [6].

II. CASE STUDY

The case study was carried out at a plastic injection moulding department in a Camera Assembly Factory. One of the components in the Camera Assembly was the Back Cover which will be the main focus in this study. High reject rate of Back Cover due to dimension of the horizontal length (customer's specification is 77.30 ± 0.10 mm) was the main concern of the company. The target value for the horizontal length is 77.30 mm with specification limits 77.30 ± 0.10 mm. In other word, it is desirable that the actual horizontal length be as close to 77.30 mm as possible and within the limit [77.20, 77.40]. The machine process setting in use currently caused variation to exceed the specification of 0.10 mm. Thus the experiments needed to find the process factors that could be set to maintain the dimension of the horizontal length as close to the target value (77.30 mm) with variation as small as possible.

III. METHODOLGY

A study team was formed to solve the problem and the members were selected from the Production Engineering staff ranking from Technician, Supervisor and Quality Engineer. A brainstorming session was held to list out the possible causes of that problem. The causes were due to, for example, Mould, Machine, Method and Material that need to be identified. Based on the above four major categories, the team decided to work on machine parameter setting first to maintain the dimension of the horizontal length as close to the target value (77.30 mm) as possible. Finally, from the machine perspective, the team decided that the machine process parameter setting could be the key to overcoming that problem. Based on the advice of the company's process engineer, moulding supervisor, machine history, and maintenance report, the team decided to select the Barrel Temperature, Screw Rotation Speed, Cooling Time and Holding Pressure as input parameters (factors) and the horizontal length as output (response) and labeled as A, B, C and D respectively .

The appropriate working range was selected based on initial and pilot experiment data. The four experimental factors are to be investigated at the two levels as given in Table 1. The objective of this experiment is to obtain the machine process setting, i.e., combinations of factors levels for A, B, C and D, under which the horizontal length is closest to the target value 77.30 mm with variation as small as possible. A full two level factorial experimental design was carried out to study on how the above four factors will influence the response (horizontal length). Total of 16 experimental runs were required. At each combination of machine setting, the team leader will record the dimension of the horizontal length. The length was measured by using digital micrometer. An experimental design matrix was constructed (Table 2), so that, when the experiment was conducted, the response values could be recorded in the matrix. The actual experiment was conducted in the moulding department with some help from the staff of the company, taking one working day to be completed.

Table 1: Factors and Levels of the Experiments.

Factor	Units	Low Level (-)	High Level (+)
A. Barrel Temperature	Deg C	190	220
B. Screw Rotation Speed	Second	55	75
C. Cooling Time	Second	7	12
D. Hold Pressure	Psi	1200	1500

Table 2: Experimental Design Matrix with Horizontal Length

Std	Run	Block	Factor 1 : (A) Barrel Temperature (Deg C)	Factor 2: (B) Screw Rotation Speed (Sec)	Factor 3: (C) Cooling Time (Sec)	Factor 4: (D) Hold Pressure (Psi)	Response 1: Horizontal Length (mm)
3	1	Block 1	190.00	75.00	7.00	1200.00	77.16
8	2	Block 1	220.00	75.00	12.00	1200.00	77.22
16	3	Block 1	220.00	75.00	12.00	1500.00	77.40
4	4	Block 1	220.00	75.00	7.00	1200.00	77.24
10	5	Block 1	220.00	55.00	7.00	1500.00	77.47
5	6	Block 1	190.00	55.00	12.00	1200.00	77.26
11	7	Block 1	190.00	75.00	7.00	1500.00	77.12
15	8	Block 1	190.00	75.00	12.00	1500.00	77.28
7	9	Block 1	190.00	75.00	12.00	1200.00	77.34
2	10	Block 1	220.00	55.00	7.00	1200.00	77.30
12	11	Block 1	220.00	75.00	7.00	1500.00	77.50
9	12	Block 1	190.00	55.00	7.00	1500.00	77.10
1	13	Block 1	190.00	55.00	7.00	1200.00	77.14
6	14	Block 1	220.00	55.00	12.00	1200.00	77.18
14	15	Block 1	220.00	55.00	12.00	1500.00	77.37
13	16	Block 1	190.00	55.00	12.00	1500.00	77.33

IV. ANALYSE OF RESULT AND DISCUSSION

Upon completion of the runs, the results were fed to the Design Expert software and the results were analyzed. As mentioned earlier, the design chosen was a full, 2^4 fraction factorial design. The analysis includes ANOVA, model adequacy checking, interaction plots and cube plot. These analyses are discussed in details below.

Figure 1 below shows the half-normal plot, which shows the effects of various factors. Based on this graph, where the response variable is the horizontal length, the factors that lie along the line are negligible and five factors seem to be significant. The three main factors from this analysis are A, C and D and two-factor interactions are AC and AD.

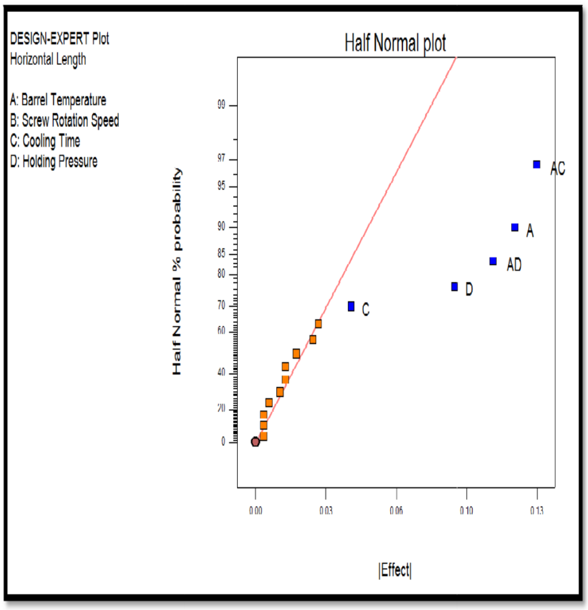

Figure 1: Half-Normal Plot of Horizontal Length

Analysis of Variances (ANOVA) – Figure 2 shows the results of ANOVA. Based on the response variable, hole diameter, it shows that the factors that we chose (A, C, and D) are significant and their interactions (AC and AD) are also significant because the values of “Prob > F” less than 0.05.

Response: Horizontal Length

ANOVA for Selected Factorial Model

Analysis of variance table [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	0.21	5	0.042	43.00	< 0.0001	significant
A	0.056	1	0.056	57.48	< 0.0001	
C	7.656E-003	1	7.656E-003	7.80	0.0190	
D	0.033	1	0.033	33.94	0.0002	
AC	0.066	1	0.066	67.57	< 0.0001	
AD	0.047	1	0.047	48.21	< 0.0001	
Residual	9.812E-003	10	9.812E-004			
Cor Total	0.22	15				

Figure 2: ANOVA Results for Horizontal Length

Normality Assumption - Figure 3 presents a normal probability plot of the residuals for horizontal length. It shows that the residuals are normally distributed because all the points fall in a line on the graph. In this case, the deviations from linear relationship are very minor.

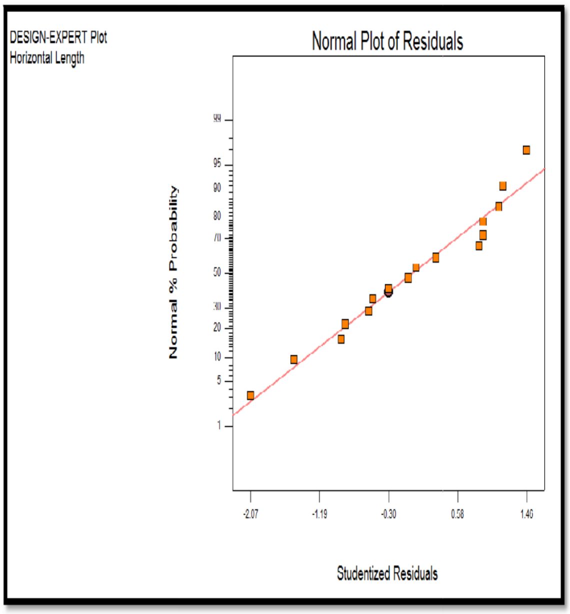

Figure 3: Normal Plot of Residuals for Horizontal Length

Residual Analysis - Figure 4 shows that the residuals are normally distributed and the equality of variance does not seem to be violated. There is no definite increase in residuals with predicted level, which supports the statistical assumption of constant variance.

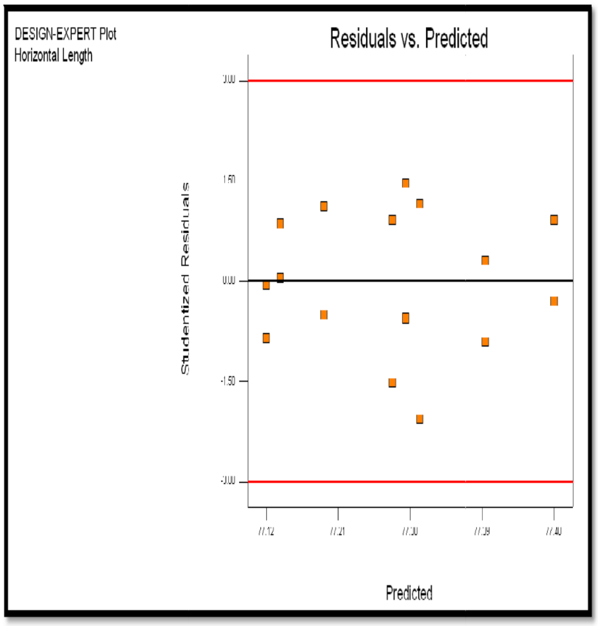

Figure 4: Residual vs. Predicted Plot for Horizontal Length

Interaction Graph Factors AC - Figure 5 shows the interaction effect of factors A and C. The other factors do not have any significant effect on the responses. In this case it is very clear that the horizontal length can be maintained close to target value 77.30 mm by increasing the Cooling Time (C+) and the Barrel Temperature (A) does not have much effect on horizontal length.

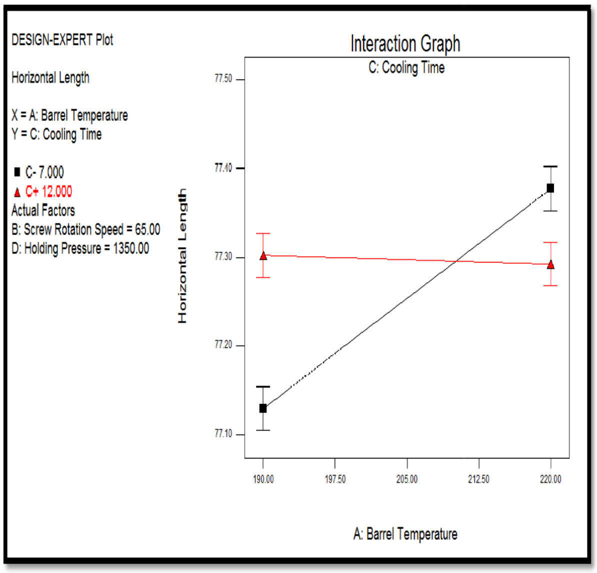

Figure 5: Interaction Graph Factors AC

Interaction Graph of Factors AD - Figure 6 shows the interaction effect of factors A and D. The other factors do not have significant effect on the responses. In this case it is very clear that the horizontal length can be maintained close to target value 77.30 mm by reducing the Holding Pressure (D-) and the Barrel Temperature (A) does not have much effect on horizontal length.

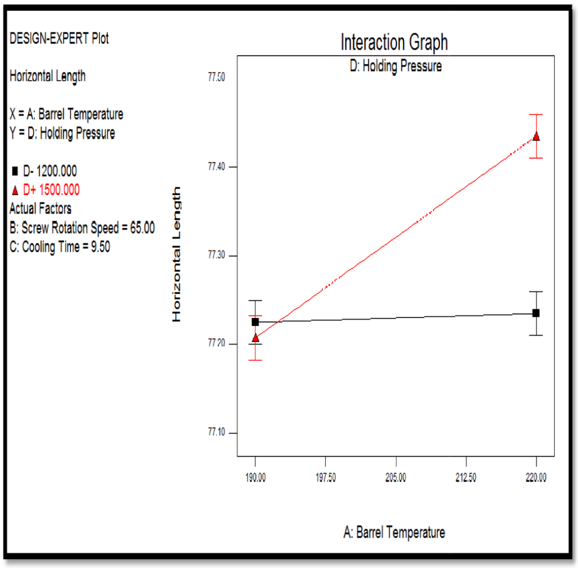

Figure 6: Interaction Graph of Factors AD

Figure 7, the cube plot shows how three factors (A, C and D) combined to affect the response. The horizontal length close to target value 77.30 mm at the A- , D- and C+ settings (upper front left corner).

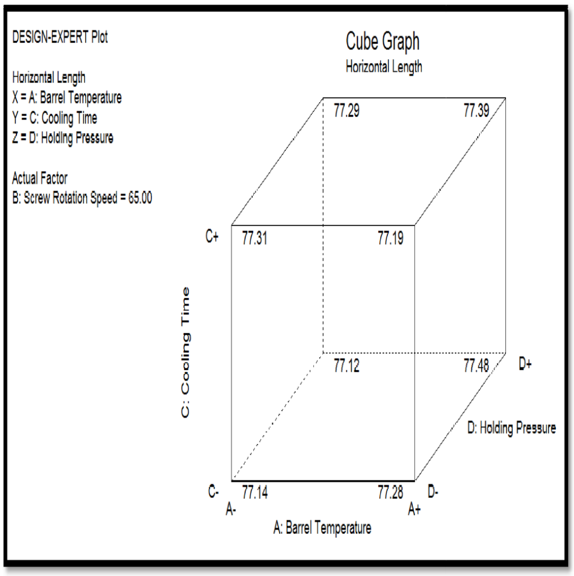

Figure 7: Cube plot of the combine Factors (A, C and D)

V. CONCLUSIONS

The full factorial of DOE approach has been applied to the injection moulding process to maintain the horizontal length as close to the target value (77.30 mm) with variation as small as possible. Four controllable factors chosen for the experiment are barrel temperature, screw rotation speed, cooling time and holding pressure (labeled as A, B, C and D). The significant factors have been identified and they were cooling time and hold pressure only other two factors do not have effect on the response. Finally it was decided by the team that the horizontal length was closest to target value 77.30 mm when the machine parameter setting were as follows; Barrel Temperature is 190 Deg C, Cooling Time is 12 sec and Holding Pressure is 1200 psi.

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