Reducing Bending Defect Using Taguchi Optimization Method

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***Abstract*— This research aims to reduce the bending defect in injection molding machine. Taguchi optimization method is employed to determine the best parameter setting for the machine. The factors used in the experiments are cooling time, injection pressure, and injection speed. The findings revealed that the most significant factor that affects warping/bending is cooling time. The optimum parameters setting based on the analysis are cooling time at level 1 (20 sec), injection pressure at level 3 (55 bar), and injection speed at level 1 (12 mm/s). The confirmation experiment is also conducted by using the optimum parameter setting based on the analysis result. Finally, the Taguchi loss function shows that the production cost decreases from Rp. 348,326,- to Rp. 25,109,- for each product.**

Keywords*— *bending defect, Taguchi, parameter setting, production cost.

I. Introduction

Nowadays, most of plastics manufacturing company apply plastic formation process by using injection molding process. Injection molding is a hard process that needs many adjustments, i.e. design of mold, design of part, machine performance and parameter setting. According to [1], to produce more quantity and good quality of plastic product, parameter setting can be the first interactive corrective actions that can be fixed in order to achieve customer safisfaction. PT. ABC is one of the biggest company that runs polymer industry which manufactures its plastic product by applying injection molding method. To be able to compete with other competitors and to lead polymer industry, PT. ABC should have a good reputation. A company can get a good reputation through good service, good products with low defect rate and increasing customer satisfaction. Customer satisfaction can be seen from the amount of customer complaint that received by the company. The more the customer complaints, the worse performance of the company that will affect the customer satisfaction. Thus, quality a broad and pervasive philosophy that can significantly affect a firm's competitiveness [2].

Fourty eight out of 112 customers submitted complaints to PT ABC due to machine related problems during the period of January-July 2018. The customer complaints for Guide Cam Chain K97 (GCCK97) product must be replace with 7,593,298 pieces of product cause of various types of defect in the record. Based on the interview with operator and supervisors, the various types of defect commonly caused because there is no parameter standard when setting the machine parameter at the company. Therefore, the dominant problem of the machine caused by no standard for parameter settings of injection molding machine. One of the most common customer complaint during January – July 2018 is warping defect. Warping or bending is a part with defect product that has curved/bent and it is commonly caused by pressure distribution that not spread evenly on the product. There has been a product specification for GCCK97 contains the bending tolerance standard. When doing the observation of this research, there are several products that have variations of bending whether it is still in the bending tolerance but not close to the value target or it is out of the bending tolerance. The warping/bending product that is still in the bending tolerance but not close to the value target may be affect both sides of customer and company. If the bending is higher than the value target, the company will suffer losses because there will be an increasing production cost. If the bending is lower than the value target, the customer will suffer losses and not satisy with the company's performance.

Based on initial observation and interview with the operator, supervisor of line 1, QA inspector and troubleshooter of line 1, uncontrolled parameter settings make unstabilize variousity of product which caused decreased number of production and may increased customer complaint. Thus, there has to be an effective and efficient solutions in order to optimize the process parameter settings if the quality of plastic injection molding products need to be improved. [1] used` Taguchi method, RSM, and Hybrid GA-PSO to optimize plastic injection molding parameter. [3] used Design of Experiment and Taguchi Approach to minimize the defects percentage in injection molding process. Design of Experiment (DOE) is used as one of the most powerful approach for parameter estimation to drastically reduce number of experiments that has to be conducted and experimental cost. One of the common method used by many researchers is Design of Experiments based on Taguchi method to improve the process parameter settings. Taguchi method is known as a statistical approach to increase the quality of goods manufactured and to optimize the process parameters [4].

In order to reach the suitable combinations of parameter, Experimental design based on Taguchi method is a powerful and effective method to achieve its goal by helping engineers with limited number of experiments and understand how several parameters design affect the process output using limited budget and resource. This study aims to employ Taguchi optimization method to determine the best parameter setting for the injection molding machine to reduce the bending defect. Previous researches by [5]–[9] have shown that Taguchi method is one of the best method to determine the best parameter setting for the machine. Furthermore, [10] and [11] used Taguchi metho to improve the properties of materials.

II. Literature Review

A. Taguchi Method

Genichi Taguchi introduced Taguchi method to improve the quality of the product and process along with reduce the experiment costs and minimize the resources in order to conduct an experiment. The main goal of Taguchi method is to improve product or process robust against noise, which commonly known as Robust Design. Genichi Taguchi developed the Robust Design concept that can be implemented in manufacturing industry in order to develop high-quality product. There are several problems in manufacturing company that can be handled by robust design concept, such as [3]:

- How to economically eliminate the variousity of product using quality loss function as the measurement tool.
- How to make an optimum decision using organized experiment by considering the product specification based on customer request and the manufacturing process.

There are several factors that affect quality characteristic, such as noise factor, control factor, signal factor, and scale factor. The definition of each factor is described as follows:

- Noise factor Noise factor is a parameter that affect quality characteristic deviation of its target value. Noise factor is uncontrollable and hard to predict. Mostly, noise factor is expensive, difficult, and hard to control.
- Control factor Parameters is defined by the engineers. Control factor might have value from 1 or more defined as level. In the end of the experiment, the appropriate level with the control factor will be chosen. One of the aspect of robust design is determining optimal level condition for control factor.
- Signal factor Signal factor is factors that changed quality characteristic value that will be measured.
- Scale factor This factor is used to change the quality characteristic level average in order to achieve the required functional relationship between signal factor to quality characteristic. Scale factor can be known as adjustment factor.

Taguchi used orthogonal array to determine minimum number of experiment as lot of informations can be given based on all factors that influence the parameter. Orthogonal matrix is a balanced matrix from factor and level as of the influence of a factor or level is not combined with others. Orthogonal array elements are arranged based on rows and columns. Row is combination of factor level in the experiment. Column is factor in the experiment.

B. Signal to Noise (S/N) Ratio

Taguchi has developed Signal to Noise (S/N) Ratio concept in order to do the experiment with many factors involved. S/N ratio is commonly used to identify the factors that influenced the response. S/N ratio is part of robust design that depends on expected quality characteristic. Based on Taguchi method, there are three kinds of S/N ratios that commonly used to optimize static problem, such as Nominal the best, Smaller the Better, and Larger the Better. The analysis is using nominal the best characteristic. Nominal the best is a characteristic that is measured with specific target value. The value can be positive or negative value. The formula of S/N ratio is described in (1) and (2)

$$SN\ Ratio = 10\ x \log \frac{y^{-2}}{s^2} \quad (1)$$

$$s^2 = \frac{\sum_{i-1}^{n}(x_i - \mathrm{X})^2}{n-1} \quad (2)$$

C. Confidence Interval

Confidence interval is an estimated range of values which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data. In designing a quality of the product, confidence interval is divided into three types, such as:

- Confidence interval for factor level and the formula to determine confidence interval from each factor level is (3)

$$CI = \sqrt{F_{\alpha,v1,v2}\ x\ MSe\ x\ [\frac{1}{n}]} \quad (3)$$

- Confidence interval for factor level and the formula to determine confidence interval from each factor level is (4)

$$CI = \sqrt{F_{\alpha,v1,v2}\ x\ MSe\ x\ [\frac{1}{n_{eff}}]} \quad (4)$$

- Confidence interval for confirmation experiment result is measured by using (5):

$$CI = \sqrt{F_{\alpha,v1,v2}\ x\ MSe\ x\ [\frac{1}{n_{eff}} + \frac{1}{r}]} \quad (5)$$

D. Taguchi Loss Function

Taguchi defined quality as loss total that is given to the society since the product sent to the consumer. The loss is measured in cash. A product with bad structure and design will give loss to society since the beginning phase and continue to the improvement phase. Based on Taguchi, the performance of the product will be worse if the parameter value is deviate from the optimum value. Therefore, the loss function starts to be measured from the deviation of target value. The goal is to achieve the customer satisfaction by developing a product with a consistent value target. Thus, the most important aspect in Taguchi quality control is eliminate the variation near to the target value.

Taguchi defined the loss function as deviation as a quantity proportional to the deviation from the target quality characteristic. At zero deviation, the performance is on target and the loss is zero. Taguchi loss function is developed by Genichi Taguchi separated into three cases which are nominal the best, smaller the better, and larger the better. The analysis is using nominal the best characteristic. The case of nominal the best focuses on satifying the customer’s expectation or need.

III. Result and Discussion

This research is focused on the customer complaints for Guide Cam Chain K97 (GCCK97) bending problem. GCCK97 is launched in production starts in January, 2018. Thus, the production department is still lack about providing the guidelines parameter setting for GCCK97. When the product launched, the initial parameter setting is determined when the beginning trial before production begins. The production supervisor set the parameter setting according to their own experiences and sometimes they set the parameter setting near the initial parameter setting without considering to analyze and find the root cause of bending problem. To provide a proper parameter setting to solve bending problem in GCCK97, the actual condition of the product has to be analyzed first. The data used is the actual parameter setting, which are:

- injection pressure 48 bar
- injection speed 13mm/s
- cooling tme 25s.

Actual condition of these setting can be seen in Table I.

TABLE I. ACTUAL CONDITION

No of Experiment	Actual Bending Measurement
1	3.05
2	3.23
3	2.6
4	2.85
5	3.41
6	3.55
Means	3.12
Variance	0.13

A. Identification of Factors and Levels

Based on the interview with production supervisor and quality manager, there are several factors that affect the bending response of GCCK97. The interview method is conducted to find the root causes of the bending defect problem and then to determine the factors of machine parameters that are related to the causes of the problem. The root cause of GCCK97 bending/warping will be shown in the following Fig. 1.

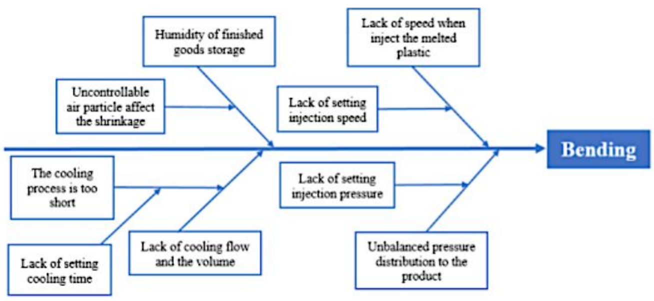

Fig. 1. Root cause analysis

Based on Fig. 1 can be seen that there are four factors that may affect bending of GCCK97, namely injection pressure, cooling time, injection speed, and humidity. Humidity is considered as noise factor. It seperated into three levels, which are morning, afternoon, and night. Based on the history data of machine JSW 5000i and interview to the machine operator and production supervisor is conducted in order to determine the required level of each factor. The level is determined based on the consideration with the production supervisor in preventing other defects occurred and based on production record data. Table II shows the control factors in the research.

TABLE II. CONTROL FACTORS AND LEVELS

Symbol	Control Factor	Level		
		1	2	3
A	Cooling time (sec)	20	25	30
B	Injection pressure (bar)	45	48	55
C	Injection speed (mm/sec)	12	13	15

B. Identification of Orthogonal Array

The rule in choosing the appropriate orthogonal array due to the experiment is the standard degree of freedom should be at least same or higher than the experiment's degree of freedom. In this experiment, the total degree of freedom is 7 which means closer to 8. Thus, the appropriate orthogonal array for the experiment is L_9 (3^4). The experiment order and the combination of control factors can be seen in Table III.

TABLE III. ORTHOGONAL ARRAY L_9 (3^4)

No	Inner Array			Outer Array		
	Control Factors			Output		
	Cooling time	Injection pressure	Injection speed	Y1	Y2	Y3
1	1	1	1			
2	1	2	2			
3	1	3	3			
4	2	1	2			
5	2	2	3			
6	2	3	1			
7	3	1	3			
8	3	2	1			
9	3	3	2			

C. Main Effect Analysis for Means

Main effect analysis aims to determine the effect of factor level to bending measurement means of GCCK97. The calculation of bending measurement average is done in each factor level of the experiment. The result can be seen in Table IV.

TABLE IV. ORTHOGONAL ARRAY L_9 (3^4)

No	Factor	Level 1	Level 2	Level 3	Delta	Rank
1	Cooling time	3.800	3.000	3.633	0.800	1
2	Injection pressure	3.367	3.467	3.600	0.233	2
3	Injection speed	3.567	3.400	3.467	0.167	3

From the Table IV, it is seen that the most influential factor to means of bending measurement is cooling time with the highest rank and the highest number of delta, which is 0.800. Next, the second factor that affects the means of bending measurement significantly is injection pressure with delta as much as 0.233 and placed in second rank. Last, injection speed is in the third rank with delta as much as 0.167.

D. Analysis of Variance for Means (ANOVA)

The contribution of all factors may be quantitatively predicted by ANOVA in all response measurements. Mostly, researcher uses Two Way Anova in Taguchi method. Two Way Anova is a method for experimental data that has two factor or more factor with two level or more. Two Way Anova table consists of sum of square, degree of freedom, mean squares, F-ratio, and P-value. Fig. 2 depicts the result of ANOVA.

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	1.06889	1.06889	0.534444	481.00	0.002
B	2	0.08222	0.08222	0.041111	37.00	0.026
C	2	0.04222	0.04222	0.021111	19.00	0.050
Residual Error	2	0.00222	0.00222	0.001111		
Total	8	1.19556				

Fig. 2. ANOVA result

The control factors consist of A, B, and C. A represents the cooling time, B represents the injection pressure, and C represents the injection speed. As it is seen from table above, the most significant factor is factor A with the smallest P-value (0.002 ⩽ 0.1). Besides, factor B is counted significant as well to the bending measurement with the P-value less than 90% level of significance (0.026 ⩽ 0.1). Factor C has P-value less than 90% level of significance (0.050 ⩽ 0.1), which means factor B has significant effect to the bending measurement as well. Thus, the result of ANOVA of experiment result means has the same result with the Main Effect Analysis, which is cooling time has the most significant effect to bending tolerance means.

E. Determination of Optimum Factor Level for S/N Ratio

Determining the optimum factor level for all significant factors can be done using the calculation of Main Effect Analysis for S/N ratio of bending tolerance, as it is shown in the Main Effects Plot graph in Fig. 3. Main Effects Plot is used to determine the optimum setting easily based on each factor.

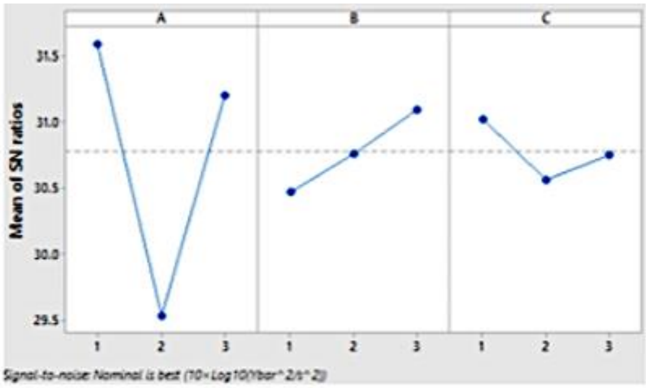

Fig. 3. Main effect plot for S/N ratio

The higher S/N ratio shows the smaller variation leads to the less sensitive of a process towards the noise factors. The type of S/N ratio used is nominal is best because there is target value in the middle of the variations of the response that needs to be achieved. The optimum level of each factor can be seen in Table V.

TABLE V. OPTIMUM LEVEL OF SETTING PARAMETER

Source	Control Factor	Optimum Level	Value
A	Cooling time	1	20
B	Injection pressure	3	55
C	Injection speed	1	12

F. Confirmation Experiment

Confirmation of experiment has a purpose to prove that the factor and level combination are able to achieve the goal of Taguchi method which are eliminate the deviation of target value and reduce the variation near target value. The result of confirmation experiment can be seen in Table VI.

G. Comparison Between The Prediction and Confirmation Experiment

The optimum condition from the prediction will be compared to confirmation experiment using the proposed parameter setting. If the response prediction is close to the confirmation experiment, the proposed parameter setting has achieved the requirements of Taguchi method. The result of comparison for means and S/N ratio can be seen in Fig. 4 and Fig. 5 respectively.

TABLE VI. CONFIRMATION EXPERIMENT RESULT

Experiment No.	Bending Result
1	3.99
2	3.98
3	4.02
4	3.97
5	3.79
6	4.12
Means	3.98
Standard Deviation	0.11
Variance	0.01
S/N Ratio	31.39

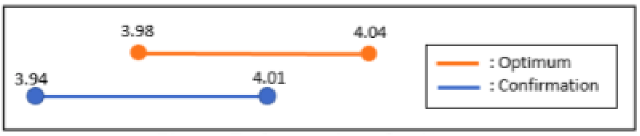

Fig. 4. Comparison for means

Fig. 5. Comparison for S/N ratio

From Fig. 4 and Fig. 5 can be concluded that the means and S/N ratio of confirmation experiment fits the optimum result.

H. Comparison Between The Actual and Confirmation Experiment

The comparison between actual condition and confirmation experiment has to be conducted as well in order and to analyze if there is an improvement from actual to proposed parameter setting. The comparison result can be seen in Table VII.

TABLE VII. COMPARISON BETWEEN THE ACTUAL AND CONFIRMATION

Bending Measurement	Actual	Confirmation
Min.	2.6	3.79
Max.	3.55	4.12
Means	3.11	3.98
Standard Deviation	0.35	0.11
Variance	0.12	0.01
S/N Ratio	18.87	31.39

Based on Table VII can be seen that the minimum of actual bending measurement is 2.6, where the confirmation experiment has 3.79 as the minimum of bending measurement. The maximum of actual bending measurement is 3.55, while the confirmation experiment has 4.12 as the maximum of bending measurement. Table above shows the result of means and standard deviation. There is an increasing for means before the optimization and after the optimization. As the target value is 3.8, the optimized means result is closer to the target value than the actual means result. Besides, the standard deviation from the actual condition to optimized condition is decreasing from 0.35 to 0.11.

Standard deviation is used to know the deviation between the sample data and the means. The higher standard deviation, the higher deviation between the sample data and the means. The lower standard deviation, the lower deviation between the sample data and the means. The variance of confirmation experiment is smaller than the initial condition, which means the Taguchi method is able to reduce the variability of bending measurement. The decreasing of variance is from 0.12 to 0.01. The S/N ratio of confirmation experiment is higher than the initial experiment, which means Taguchi method is able to minimize the deviation from the target value (3.8) and reduce the variability in the confirmation experiment. The increasing S/N ratio is from 18.87 to 31.39.

I. Taguchi Loss Prediction

Based on Taguchi, the performance of the product will be worse if the parameter value is deviate from the optimum value. Therefore, the loss function starts to be measured from the deviation of target value. The goal is to achieve the customer satisfaction by developing a product with a consistent value target. Thus, the most important aspect in Taguchi quality control is eliminate the variation near to the target value. The calculation of Taguchi Loss Function will be conducted for the initial experiment and the confirmation experiment. The bending tolerance of GCCK97 specification is 3.8. The calculation of Taguchi loss function shows that the loss in the actual condition costs is Rp 348,326,- for each product. In the other hand, the result of Taguchi loss function for the confirmation experiment costs is Rp 25,109,- for each product. Thus, the loss of production cost can be reduced from Rp 348,326,- to Rp 25,109,-. It is quite effective to use Taguchi loss function in order to analyze if there is a reduction in production cost, also if there is an increasing in the quality of the product. The following Fig. 6 shows the comparison of loss function between before and after experiment.

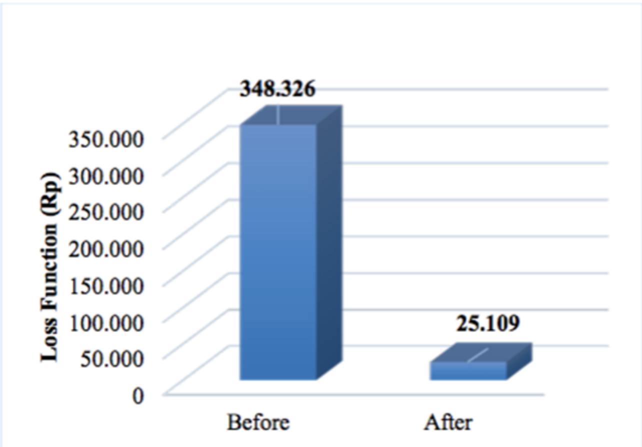

Fig. 6. Taguchi loss function before and after experiment

IV. Conclusion

This research shows the effectiveness of Taguchi optimization to reduce the bending defect in an injection molding machine. The findings revealed that the most significant factor that affect warping/bending is cooling time. Furthermore, the optimum parameter setting based on the factor are cooling time at level 1 (20 seconds), injection pressure at level 3 (55 bar), and injection speed at level 1 (12 mm/s). The confirmation result is able to produce GCCK97 bending measurement on average from 3.11 to 3.98, which is now closer to 3.8 as the bending tolerance in product specification. S/N ratio using the optimum parameter setting is increased from 18.87 dB to 31.39 dB. Thus, the proposed level combination and optimum factors using Taguchi method can minimize the deviation of GCCK97 bending measurement from the target value and reduce the variation of GCCK97 bending measurement. Finally, the Taguchi loss function is able to reduce the production cost from Rp. 348,326,- to Rp. 25,109,- each product.

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