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**P062: QUALITY IMPROVEMENT IN PVC INDUSTRY THROUGH SIX-SIGMA ANALYSIS OF MACHINE PROCESS PARAMETERS****¹Owolabi C.T., ^{*1}Abdulkareem S., ¹Ajiboye T.K., ²Akande K.A. and ³Ahmed I.I.**¹Department of Mechanical, P.M.B 1515, University of Ilorin, Ilorin, Nigeria,²Department of Biomedical Engineering, P.M.B 1515, University of Ilorin, Ilorin, Nigeria³Department of Materials and Metallurgical Engineering, P.M.B 1515, University of Ilorin, Ilorin, Nigeria** Correspondence Author: sulkarm@yahoo.com, Phone: 0805 821 9222****Abstract***

Six-Sigma is an organized and systematic method for strategic process improvement that relies on statistical and scientific methods. In the present work Six Sigma methodology was adopted to reduce defect rates and achieve significant quality up-grade in a PVC pipe manufacturing industry. Taguchi method of experimental design was applied for optimization of the process, quality and performance output of manufacturing process. The cause and effect diagram was implemented to identify the root cause of defects resulting in poor product quality. From the analysis, the major root causes of defects were the process parameters- the vacuum pressure, temperature and take-off speed. Applying Taguchi method of experimental design for process parameter optimization, the process resulted in more superior quality. An estimated cost loss improvement of 37% was achieved and Part Per Million defects reduced from 67,487 to 20,503.

Keywords: Defects; Design of experiment; Process parameter; Six Sigma; Taguchi method; product quality.

1.0 Introduction

Conformance to quality is related to the degree at which product's specific features match the product specification. Quality improvement is best viewed as the reduction of variability in processes and products. Quality is a universal value and has become a global issue. In order to survive and be able to provide customers with good products, manufacturing organisations are required to ensure that their processes are continuously monitored and product quality improved (Judi et al, 2011). System engineering focuses on the fundamentality of a system with the aim of system optimization. Although quality engineering is not a solution for all problems in the industry, the practice of early and accurate evaluation is an effective means of avoiding product recalls and to ensure conformity of products to specific requirement (Takeshita and Hosokawa, 2007). The use of inspection to assure conformity to specific requirements dates back to the middle Ages. For instance, Craft Guilds established standards to differentiate their goods and safeguard the reputation of their trade. Skilled craftsmen carried out inspection and remedies are made right at the workbench. And through the early years of low-volume manufacturing, informal inspection of products and arbitrary review of worker output sufficed. However, as organizations and production yields became larger during the Industrial Revolution, the need for quality engineering became more evident. Since customer's need and expectation cannot be divorced from product's quality, there is need for organization to explore various techniques to maximize their product's quality.

The Taguchi technique is a powerful approach for solving product quality problems in various aspects of engineering fields. Taguchi method also known as Robust design has become increasing and been utilized widely in enhancing engineering productivity (Mehat, and Kamaruddin, 2012). Similarly, Six Sigma methodology focuses on reducing variation, measuring defects and improving the quality of products, process



and services. Six sigma methodology was originally developed by Motorola in 1980s and it targeted a difficult goal of 3.54 parts per million defects (Pyzdek, 2003).

2.0 Methodology

2.1 Taguchi Methodology

The standard procedures as proposed by Taguchi for optimisation (Dhole, et al, 2012) adopted in this work are as follow:

1. The quality characteristic to be optimized is first determined. The next step is to identify the noise factors that can have a negative impact on system performance and quality.
2. Control parameters thought to have significant effects on the quality characteristic are identified similarly their alternative levels is also identified.
3. Experiment matrix is designed and data analysis procedure is also defined. Matrix experiment is conducted and result of experiment recorded.
4. Analysis of data collected from the result of experiment conducted.
5. The final step is an experimental confirmation run using the predicted optimum levels for the control parameters being studied.

2.2 DMAIC Methodology

DMAIC methodology is a data-driven quality strategy used to improve processes. The details of the methodology are given below:

2.2.1 Define phase

Critical-to-quality (CTQ) in the company understudy are pipe roundness, bent and thickness. Establishing CTQs is vital for a company to meet customer needs and keep up with the competition.

2.2.2 Measure Phase

Twenty samples of 20mm pipes of length 3352mm were collected randomly for fifteen days. The thickness variations of the 300 pipe samples were measured, and analysed using MINITAB 16 software

2.2.2.1 Process Capability

Using the collected data, process capability analysis was carried out to know the capability of the processes.

Process Capability is a measure of the ability of the process to meet specifications. Figure 1 shows the process capability analysis for this study.

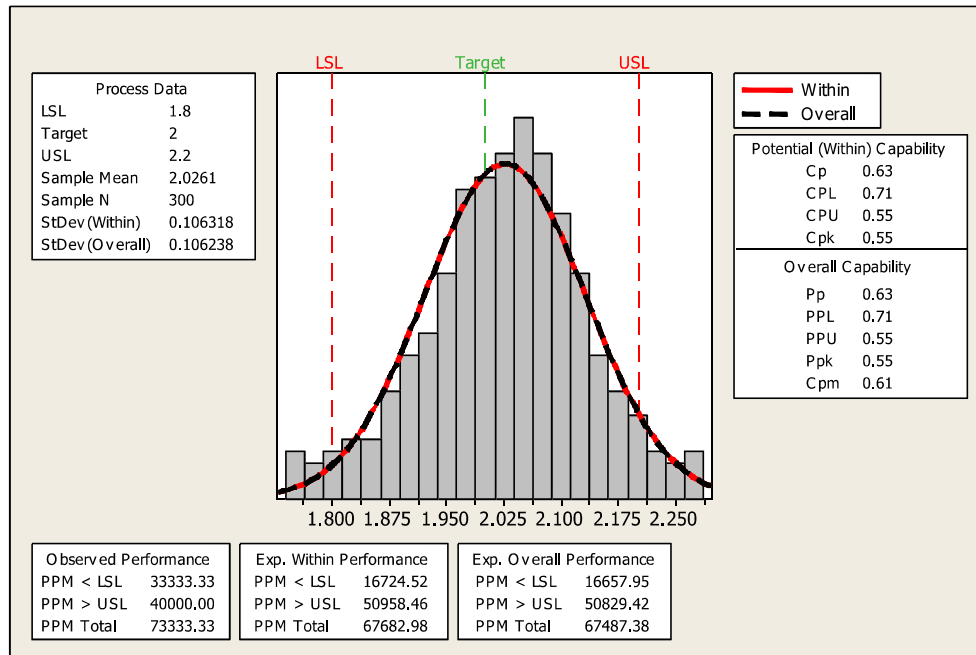


Figure 1: Capability analysis of pipe samples

2.2.2.2 Part Per Million (PPM)

Part Per Million (PPM) are a standardized quality measurement that determines defect levels. From the capability analysis, PPM for this process is 67,487

2.2.2.3 Defects in Extrusion Process

Data of product defects was collected from the factory. The total defects occurring on the four major products of the company within a period of six month were recorded and was analysed. The detailed analysis of major extrusion defects of pipe products was carried out using Pareto chart as a tool. Table 1 shows the Quality defects and frequency of the company products.

Table 1: Quality defects and frequency

S/N	Type of quality defects	Frequency of defects
1	Uneven Wall thickness	21700
2	Centring problem	15444
3	Diameter variation	13939
4	Scratch on surface	11880
5	Bend in pipe	6811
6	Holes in pipe	3326
7	Others	3880



2.2.2.4 Pareto chart

The purpose of the Pareto is to distinguish the "vital few from the trivial many." from the defects in figure 2, uneven wall thickness has the highest defect frequency of 27.8% and it is been given attention in this study considering its level of impact on customer satisfaction and cost of production.

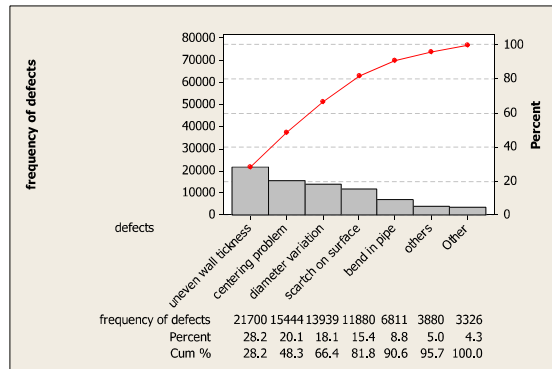


Figure 2: Pareto chart

2.2.3 Analyse Phase

In this phase, definition of the main causes of the variation was carried out using fishbone diagram as shown in figure 3. It was used to identify the potential causes for performance problem. Fishbone diagrams provide a structure for a group's discussion around the potential causes of the problem. Process parameter settings were identified as the main cause of variation in the process, hence there is need to determine the best parameter setting for optimum performance. Design of Experiment (DOE) was conducted to determine the optimum parameter setting.

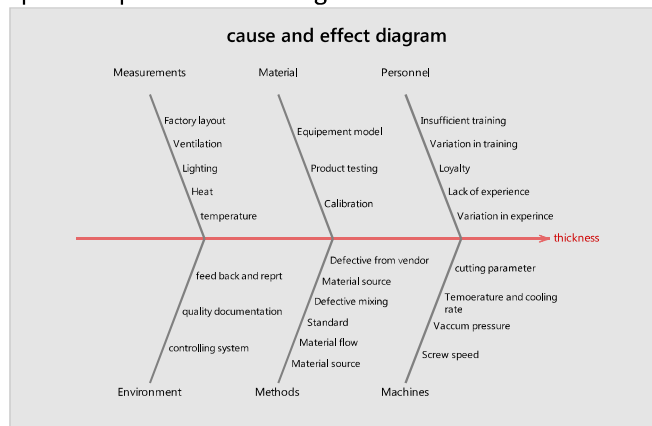


Figure 3: Cause and effect diagram

2.2.4 Improve phase

Three parameters were selected for optimisation namely: temperature, screw speed and vacuum pressure. It was decided to experiment all these parameters at three levels.

2.2.4.1 Selection of Orthogonal Arrays and Assignment of Factors.

It was assumed that no interactions exist, therefore degree of freedom for the factors under investigation, D , for a number of factors F , and number of level for each factor l , according to (Gijoa, et al, 2011) is given as:

$$D = F(l - 1) \quad (1)$$



Eleven parameters and three levels were considered (see Table 3), hence the minimum number of experiment required in the present work is 22 according to equation 1.

In order to select the particular orthogonal array for an experiment, the following inequality must be satisfied:

$$D_o \geq D$$

Where, D_o is the total degree of freedom available in an Orthogonal Array (OA), it is equal to the number of trial N minus one (Gijoa, et al, 20116)

$$D_o = N - 1 \quad (2)$$

From the array selector shown in table 2 (7), L27 Orthogonal Array was selected considering eleven (11) number of parameters with three (3) levels. Hence, D_o is 26 according to equation 2. Since $D_o \geq D$, L27 OA is valid for use in this study.

Table 2: The array selector

		Number of parameters								
		2	3	4	5	6	7	8	9	10
Number of level	2	L4	L4	L8	L8	L8	L8	L12	L12	L12
	3	L9	L9	L9	L18	L18	L18	L18	L27	L27
	4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32
	5	L25	L25	L25	L25	L25	L50	L50	L50	L50

Table 3: Process parameters used in conducting the experiment and their levels

S/N	Designation	process parameter	level 1	level 2	level 3
1	A	Vacuum pres. (Mpa)	20	25	30
2	B	Take-off sp. (rpm)	0.2	1.4	2
3	C	Temperature 1 (°C)	185	188	190
4	D	Temperature 2 (°C)	180	182	185
5	E	Temperature 3 (°C)	175	177	180
6	F	Temperature 4 (°C)	165	168	170
7	G	Temperature 5 (°C)	165	167	170
8	H	Temperature 6 (°C)	170	173	175
9	I	Temperature 7 (°C)	175	180	185
10	J	Temperature 8 (°C)	185	188	190
11	K	Temperature 9 (°C)	190	195	200

3.0 Loss Function

Taguchi loss function is a way to show how each non-perfect part produced, results in a loss for the company.

In this case, the quality loss due to variation of produced pipe thickness from the nominal thickness can be calculated as follows:

Given that y is the quality characteristic of a product, m is the target value for y and k is a constant called *quality loss coefficient*. According to quadratic loss function the quality loss, $L(y)$ is given by:

$$L(y) = k(y - m)^2 \quad (3)$$

And the average quality loss for a product of the company is calculated using a formula;

$$L = k[s^2 + (\mu - m)^2] \quad (4)$$

Where; S the mean square deviation of y around its own mean, μ is the average value of y for the set of parts and L = failure cost of the product.

Failure of selected product can be calculated using equation 5 (Mekonnen, 2013):

$$L(y) = p_c - (m \times r_p \times r_c) \quad (5)$$



Where

$L(y)$ = Failure Cost,

P_c = Production Cost (Naira/pc),

m = Mass of Product (Kg/pc),

r'_p = Recyclable Percentage, and

r_c = Cost of Raw Material (Naira/Kg)

4.0 Percentage Improvement (PI)

In order to establish the extent of cost benefit of variation reduction. The percentage improvement is calculated

$$PI = \frac{L_B - L_A}{L_B} \times 100\% \quad (6)$$

5.0 RESULTS AND DISCUSSIONS

5.1 Experiment Results

Using L27 orthogonal array, the experiment was conducted. Thickness was measured and recorded for each trial conditions. Figure 4 shows the response values, response mean ($\bar{y}$), variance (S^2) and Signal to Noise (S/N) ratio.

Table 4: The response values

	resp. value1 (y_1)	resp. value 2 (y_2)	resp. value 3 (y_3)	resp. value 4 (y_4)	resp. value 5 (y_5)	resp. mean ($\bar{y}$)	Var. (S^2)	S/N ratio
1	2.020	1.980	2.010	1.900	2.120	2.006	0.006	28.067
2	2.140	2.120	2.080	2.010	2.000	2.070	0.004	30.299
3	2.190	2.160	2.110	1.990	2.070	2.104	0.006	28.551
4	1.860	1.970	2.040	1.970	1.990	1.966	0.004	29.507
5	1.960	1.890	1.930	2.010	2.030	1.964	0.003	30.704
6	1.950	1.970	2.040	1.810	1.790	1.912	0.012	24.978
7	2.010	1.990	1.770	1.940	1.990	1.940	0.010	25.888
8	2.090	2.120	2.170	2.090	2.000	2.094	0.004	30.588
9	2.020	2.050	2.110	2.010	2.070	2.052	0.002	34.148
10	1.990	2.090	2.120	2.050	2.100	2.070	0.003	32.087
11	2.250	2.120	2.120	2.430	2.030	2.190	0.024	22.980
12	2.170	2.000	2.240	2.040	2.060	2.102	0.010	26.488
13	1.880	2.080	2.090	1.870	1.980	1.980	0.011	25.500
14	2.360	2.250	2.140	2.350	1.990	2.218	0.024	23.086
15	2.260	2.360	2.210	2.270	2.190	2.258	0.004	30.670
16	1.910	1.820	1.950	1.890	1.770	1.868	0.005	28.251
17	2.100	2.000	2.010	2.040	2.090	2.048	0.002	33.067
18	2.250	2.120	2.120	2.430	2.030	2.190	0.024	22.980
19	2.100	2.060	2.070	2.070	2.140	2.088	0.001	36.101
20	1.970	1.880	1.780	1.980	1.810	1.884	0.008	26.348
21	2.120	2.020	1.910	1.870	1.790	1.942	0.017	23.538



The ratio	22	1.980	1.910	2.010	2.040	2.000	1.988	0.002	32.221	S/N
	23	2.290	2.080	2.250	2.320	2.300	2.248	0.009	27.272	
	24	2.030	1.910	2.120	1.910	1.930	1.980	0.009	26.588	
	25	2.180	2.150	2.210	2.110	1.950	2.120	0.010	26.356	
	26	2.020	2.160	2.040	2.180	2.140	2.108	0.005	29.218	
	27	1.980	1.870	1.900	2.020	1.990	1.952	0.004	29.714	

selected for this study is nominal the better quality characteristics. This is because in this work variability around a target is to be reduced. S/N ratio helps to identify the optimum conditions of operation that would result in reduced variability produced in the process. There are three categories of quality characteristics in the measurement of S/N ratio; namely: the lower-the-better, the higher-the-better, and the nominal-the-better characteristics.

S/N ratios for nominal the better:

$$S/N = 10 \log \left(\frac{\bar{y}^2}{s^2} \right) \quad (7)$$

Using equation 7, the S/N ratios (nominal the better) for the 27 experimental runs were computed. The following steps were taken for calculating the mean, variance and S/N ratio for experiment run 1.

$$\bar{y} = \frac{\sum y_n}{n} \quad (8)$$

and

$$s^2 = \frac{\sum (y - \bar{y})^2}{n - 1} \quad (9)$$

Where:

$\bar{y}$ = is the response mean

y_n = multiple values of response observations in the experiments.

n = size of observations

s^2 = variance

5.2 Analysis of Experimental Results

A valid relationship between the process parameters and their corresponding response variables is established to identify the critical parameters having a significant contribution in influencing the response functions. Taguchi's experimental design principle was applied to identify the optimal parameter settings for the said process. The average response means and S/N ratio of the pipe thickness were determined for each trial condition as given in Table 4. The average values of the response mean and S/N ratio for each parameter at different levels were calculated and given in Table 5 and 6 respectively.

After all of the S/N ratios were computed for each run of the experiment, graphical approach was used to analyse the data. In the graphical approach, the SN ratios were plotted for each factor against each of its levels. Finally, confirmation tests were run at the "optimal" product settings to verify that the predicted performance was actually realized.

Table 5: Response table for means



Level	Vac pres. (A) (MPa)	Take-off sp. (B) (rpm)	Temp.1 (C) (°C)	Temp.2 (D) (°C)	Temp.3 (E) (°C)
1	2.012	2.051	2.056	2.091	2.003
2	2.103	2.057	2.043	1.985	2.092
3	2.034	2.041	2.051	2.074	2.055
Delta*	0.091	0.016	0.013	0.106	0.089
Rank	2	10	11	1	4

Table 5: Response table for means (continued)

Temp.4 (F) (°C)	Temp.5 (G) (°C)	Temp. 6 (H) (°C)	Temp. 7 (I) (°C)	Temp. 8 (J) (°C)	Temp. 9 (K) (°C)
2.078	2.027	2.063	2.003	2.076	2.088
1.991	2.097	2.03	2.086	2.05	2.025
2.08	2.025	2.056	2.06	2.023	2.037
0.089	0.072	0.032	0.083	0.053	0.063
3	6	9	5	8	7

* Δ = max.-min.

Table 6: Response table for signal to noise ratios nominal

Level	Vacuum.press. (A) - (MPa)	Take-off sd. (B) (rpm)	Temp. 1 (C) (°C)	Temp. 2 (D) (°C)	Temp. 3 (E) (°C)
1	29.19	28.27	28.59	27.94	29.33
2	27.23	27.84	28	28.39	28.17
3	28.6	28.91	28.43	28.7	27.52
Delta*	1.96	1.08	0.58	0.76	1.81
Rank	6	9	11	10	7

Table 6: Response table for signal to noise ratios nominal (continued)

Temp. 4 (F) (°C)	Temp. 5(G) (°C)	Temp. 6(H) (°C)	Temp. 7(I) (°C)	Temp. 8(J) (°C)	Temp. 9(K) (°C)
27.38	26.94	30.15	27.75	25.81	29.35
28.59	29.6	28.19	29.66	29.3	26.93
29.05	28.48	26.68	27.61	29.92	28.74
1.67	2.66	3.47	2.05	4.11	2.42
8	3	2	5	1	4

* Δ = max.-min.

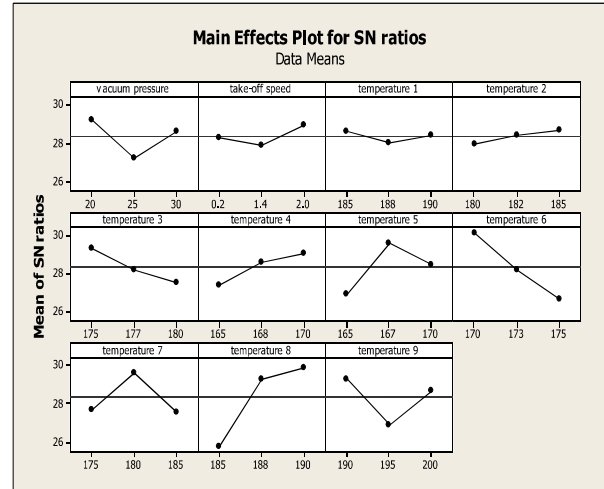
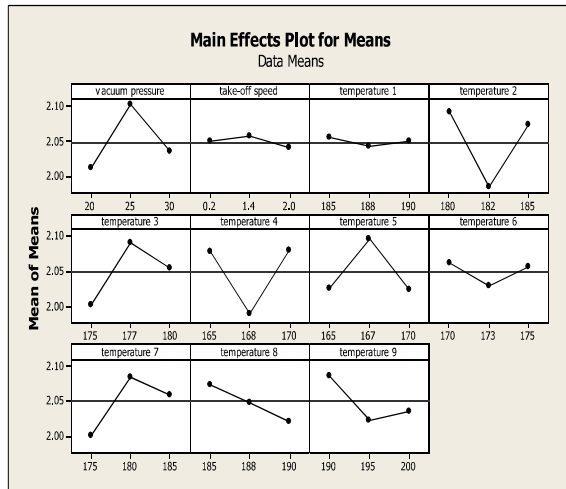


Figure 4: Response graph for Means

Figure

5: Response graph for SN ratios

Figure 4 and 5 illustrate the response graphs for mean and SN ratio respectively for pipe thickness in the company. The target pipe thickness required to be produced is 2.0 mm. considering the mean response graph for mean in Figure 4, The following parameters settings are required to produce pipe product with the value close to the target value of pipe thickness: vacuum pressure value 20 MPa, take of speed value 2.0 rpm, temperature 1 value 188 ($^{\circ}\text{C}$), temperature 2 value 182 ($^{\circ}\text{C}$), temperature 3 value 175 ($^{\circ}\text{C}$), temperature 4 value 168 ($^{\circ}\text{C}$), temperature 5 value 170 ($^{\circ}\text{C}$), temperature 6 value 173 ($^{\circ}\text{C}$), temperature 7 value 175 ($^{\circ}\text{C}$), temperature 8 value 190 ($^{\circ}\text{C}$) and temperature 9 value 195 ($^{\circ}\text{C}$). However, the optimum processing parameters settings are not selected by the mean response graph alone but it also consider setting their effect on SN ratio (Gadekar, et al, 2015). Similarly, considering the SN ratio graph on Figure 5, vacuum pressure value 20 (MPa), take-off speed value 2.0 (rpm), temperature 1 value 185 ($^{\circ}\text{C}$), temperature 2 value 185 ($^{\circ}\text{C}$), temperature 3 value 175 ($^{\circ}\text{C}$), temperature 4 value 170 ($^{\circ}\text{C}$), temperature 5 value 167 ($^{\circ}\text{C}$), temperature 6 value 170 ($^{\circ}\text{C}$), temperature 7 value 180 ($^{\circ}\text{C}$), temperature 8 value 190 ($^{\circ}\text{C}$) and temperature 9 value 190 ($^{\circ}\text{C}$). In other to select the optimum operational processing parameter, value of mean response which is closer to the target value and that has a large or not significantly reduced S/N ratio is considered for selection. In this study, the factors and their respective levels selected are shown in Table 7.

Table 7 Factor setting and level selected in the design of experiment

S/N	Operational parameter	Setting	Level
1	Vacuum pressure (Mpa)	20	1
2	Take-off speed (rpm)	2	3
3	Temperature 1 ($^{\circ}\text{C}$)	190	3
4	Temperature 2 ($^{\circ}\text{C}$)	182	2
5	Temperature 3 ($^{\circ}\text{C}$)	175	1
6	Temperature 4 ($^{\circ}\text{C}$)	168	2
7	Temperature 5 ($^{\circ}\text{C}$)	170	3
8	Temperature 6 ($^{\circ}\text{C}$)	173	2
9	Temperature 7 ($^{\circ}\text{C}$)	175	1
10	Temperature 8 ($^{\circ}\text{C}$)	190	3



11	Temperature 9 (°C)	200	3
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From equation 5, the failure cost of the selected product is calculated;

$$L(y) = 101.52 \text{ naira / pc} - (0.65 \text{ kg / p} \times 76\% \times 99.3 \text{ naira / kg})$$

$$= 52.47 \text{ naira / pc, applying Eq.3, the quality loss coefficient } k \text{ is:}$$

$$52 = k(2.4 - 2.0)^2$$

$$k = 325$$

Using equation 4, the average loss per piece on the product before improvement, L_B and after improvement, L_A was calculated to be 3.875 and 2.416 Naira/piece respectively. Similarly, from equation 6, percentage improvement PI is 37%.

Taguchi hypothesize that any variation from the exact specifications entails a cost or loss to the firm. Loss function concept is one way to illustrate how variation impacts on costs. From the loss function analysis, the analysis clearly shows losses due to variations impact on company cost. Loss incurred before the process improvement was calculated to be 3.87 ₦/pc and loss after the improvement was 2.42 ₦/pc. Based on the process improvement carried out, the percentage improvement and cost saved as a result was estimated to be 37%.

6.0 Control

The last phase is control phase and the purpose of this phase is to sustain the benefits of the new process implemented and to insure that over time the optimum setting determined does not get loss. For complete success of Six Sigma, the following were recommended:

1. proper documentation of the process
2. In-process inspection to make sure pipe is not defect.
3. On-the-job training of its technical staff on Taguchi DOE
4. The continuous monitoring of critical process parameters

7.0 Conclusions

DMAIC based Six Sigma approach has been implemented to optimize the processes parameters of a PVC pipe manufacturing industry. Six Sigma provided measurable indicators and adequate data for analytical analysis. Systematic application of Six Sigma DMAIC approach and methodology results in improved performance. The Taguchi method of experimental design was used to analyze the optimum setting of individual process parameters. From Taguchi analysis, the best process parameters setting (Table 6) for an improved process performance was achieved. On implementing the result of the experiment, an improvement of product quality was achieved; pipe thickness variation was improved from 2.0261 to 1.99382 and Part Per Million defect, PPM reduced from 67,487 to 20,503. Similarly cost saving of about 37% was achieved. Hence, it can be concluded that variation is not free; it consumes resources, money, and time. Reducing variation always reduces costs.

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