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Method for Reducing Defect in Electroplating Process

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ABSTRACT

There are many startup companies established every day because the industry is changing rapidly. Each company requires a competitive edge in order to survive in this environment. To respond to these needs, many startup R&D companies need to implement concept such as Six Sigma and DMAIC. The Six Sigma approach has been increasingly implemented around the world especially in the manufacturing sector in order to improve productivity and reduce the defect. This paper discusses the defect reduction and productivity improvement in a startup innovation R&D company. The paper deals with an application of the DMAIC methodology in an industry which provides a milestone to define the problem, quantify the problem, reduce and eliminate sources of variation in manufacturing process, in order to optimize these operation variables using new solution from the Improve phase. The outcome of the research will be sustained because the approach such as new control plan and work description from the Control phase. From this research the implementation of DMAIC reduces the defect in manufacturing process from 24% to 0% leading to better utilization of resources and maintains consistent of product quality.

1. INTRODUCTION

1.1 Product

In 2014, the company did the R&D project to develop "cheap and efficient method to recover the precious metal from industry waste water". The result of the project was an electrowinning unit with a special cathode cell. Although the electrowinning method which uses electricity to extract metal from ion state is not a new method, in fact, it is pretty old and inefficient method, but the company found the solution to greatly enhance this method performance. This greatly improved electrowinning unit. The electrowinning unit has two important components (Figure 1), the unit and the special cell. The cell part was the result of R&D project and it was the most significant part to the performance of the electrowinning unit and it is a consumable part. In order for the electrowinning unit to operate the cell must perfectly fit with the unit slots. However the current manufacturing method was unable to achieved this.

When the product was about to launch the problem was found. About 24% of the cells were unable to fit with the units. Although the defect was found before the launch but this event severely affects the company. Firstly, the company lost about 75,000 Baht from this event. Secondly, the delivery date was delayed for at least 1 month and this affects the credit of the company. Finally, if the defect cell was able to pass the installing stage, it has high chance to breakdown during the operation which will cost the company about 200,000 Baht per unit. This was due to the company service policy. All the damage and problem that is done by the company product or solution will be fully responsible by the company.

1.2 Six Sigma

Six Sigma can be defined in many terms. Six Sigma is an approach in statistical analysis and measuring the defects per million opportunities between the mean and the nearest specification limit [1]. This can involve anything from a component, piece of material and service [2]. It was proven that improving quality actually

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reduced operating costs and increased customer satisfaction and also changed the mindset from improving quality will costs money to improving quality will increase profit [3].

In Six Sigma, the DMAIC method is used as one of the main procedures. The method breaks down specific project into phases; Define, Measure, Analyze, Design, and Control [2].

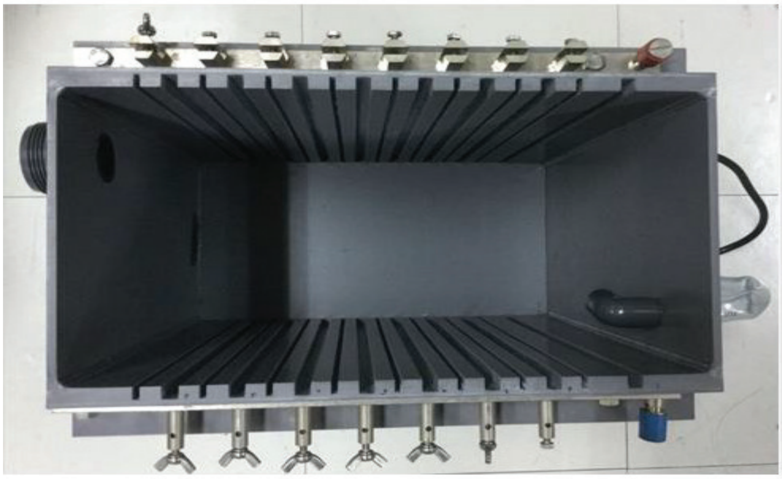

Figure 1 Electrowinning unit and cell slot

1.2.1 Define

The first step is called Define which starts with identifying the problem. For example, the problem can be associated with customer problem, product failure, financial concern, and process inefficiency. In order to achieve a suitable goal, understanding and defining the customer of the project is very important. Moreover, the scope of the project and resources needed have to be defined. The project resources include the personnel for the project and other costs seen up to this point. The team can evaluate the project' s potential critically with a well estimated costs and benefits [2].

1.2.2 Measure

After the problem is defined, next is the measure stage. The flow, feedback loops and hand-offs for the processes are mapped. From this information, models with quantitative understanding of the process can be obtained.

The actual process data are then used to ensure reliable process evaluation [4].

When the current performance level is determined, it will be compared to the best possible performance which the baseline can be the best historical performance. The benchmark is with a similar process or engineering maximum capacity calculations. From the known current performance and ideal performance, a more accurate potential benefits for the project can be predicted [2].

1.2.3 Analyze

From the first two steps of DMAIC, the business problem is defined, related processes identified and current performance evaluated. In the analyze step, the objective is to locate the difference that may arise from the goals set and the identified processes. The understanding of the relationship between the cause and effect of the problem is the most important for any improvements. The inputs that drive the output performance will be focused after the output performance of the processes' is known [2].

1.2.4 Improve

In this stage, the factors bringing the process towards the statistical solution are identified and validated. The solution will not be validated unless the desired change is observed from changing the factors. It is important to use appropriate statistical tools to evaluate the solution effects on the whole system' s performance as not all changes come without any shortcomings [5].

1.2.5 Control

The final step of DMAIC is the control stage. After the solutions are found and validated, an implementation and maintenance is required. The critical inputs are set under control and the process outputs monitored. Monitoring will ensure sustained improvements in new processes and operating procedures and that the process will not operate the old way [4].

2. THE DMAIC METHODOLOGY

2.1 Define phase

In this phase, the team will focus on identifying the problem of this project. The type and characteristic of the defects will be clarified. The official team and the responsibility will also be decided using project charter.

Project Charter

In this phase, the team was set up in order to set out the roles and responsibilities. The scope and the goals for the project are also presented. The charter consists of a business case file with possible benefit and background to the project. The project status table was revised as the project proceeds. The team realized that there was many type of information that will be needed in the further phase. In order to make sure that the project will flow smoothly, the team also define some of the data that will be needed for the project and how or who they need to contact for the data. The only data that cannot be access was the in depth information about the raw material which was classified as information of supplier. However from the past experience and confirmation from expertise, the existing data was enough to use in the project [6,7].

Critical to quality

In this section, the team identified the type of defect and tried to find out the relation of each type with the customers' need. The process is heavily related to brainstorming, gathering information and investigating the rejected cell.

Voice of the customer

There were three main clearly visible type of defect at that moment. The first defect was identified as deformed of product at the middle. The second one was the product which deformed at the rim. The last one was the thickness at the rim of both side was thicker than designed [8,9].

The conversion from VOC to CTQ was related to the three type of defect that was identified. The potential CTQ, each CTQ represent each defect, was listed below:

CTQ for defect type 1: The dimension at the middle of the cell

CTQ for defect type 2: The deformed spots at the edge of the cell

CTQ for defect type 3: The thickness at the rim of the cell

2.2 Measure phase

In this phase, the team will characterize further into the selected CTQ and also identify the potential X's which affect the Y's.

Data collection plan

In order to gather the data needed for further analysis, the data collection plan was developed There are many important steps that need to be addressed to ensure that the data collection process and measurement systems are stable and reliable. It was very important that the reasons for the measurement was clearly understood by everyone involved with the project and company so that the measurement procedure can be properly planned and ensure the good results of data collecting [10].

Measurement System Analysis

There was no MSA done directly for this project. The main reason for this was because there was the MSA, GAGE R&R ANOVA done for similar type of product recently. In the early state of developing this product, the MSA was done with the prototype product (Figure 2.1-2.2). The measurement that was used then, was the same one as the one that used in this project, furthermore, the company always calibrate tools and instruments.

The expertise also confirmed that the characteristic of cell in prototype phase and in this project is almost the same. There was only one different between them. While the current dimension of the product is 18x24 cm with thickness between 0.62-0.7 cm, the prototype was 10x10 cm with the same thickness. The skill of the operator should not have the noticeable effect with the data collecting because the measurement method and tool is very simple.

The data below shows the result of Gage R&R ANOVA Method. Total Gage R&R contribution in the %Study Var column (%Tolerance, %Process) was 26.58% which is still acceptable from the application. The Total Gage R&R could be reduced via using more accurate measurement tool to measure in term of three digit decimal. However the past experienced and research data proved that the current process did not required more advance tool. From the manufacturing, the process should increase the thickness only about 0.02 cm, but the defects one were at increased about 0.07 cm [11]. This shows that the current tool was suitable for the project in order to detect the defect cell.

Gage R&R

```
                                     %Contribution
Source                     VarComp   (of VarComp)
Total Gage R&R           0.0000442           7.29
  Repeatability          0.0000250           4.13
  Reproducibility        0.0000192           3.16
    Operators            0.0000001           0.02
    Operators*Parts      0.0000191           3.15
Part-To-Part             0.0005619          92.71
Total Variation          0.0006060         100.00


Process tolerance = 0.15


                                     Study Var  %Study Var  %Tolerance
Source                   StdDev (SD)  (6 * SD)       (%SV)  (SV/Toler)
Total Gage R&R             0.0066458  0.039875       27.00       26.58
  Repeatability            0.0050000  0.030000       20.31       20.00
  Reproducibility          0.0043780  0.026268       17.78       17.51
    Operators              0.0003043  0.001826        1.24        1.22
    Operators*Parts        0.0043674  0.026204       17.74       17.47
Part-To-Part               0.0237034  0.142220       96.29       94.81
Total Variation            0.0246174  0.147705      100.00       98.47
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Figure 2.1 Gage R&R for thickness (Part 1)

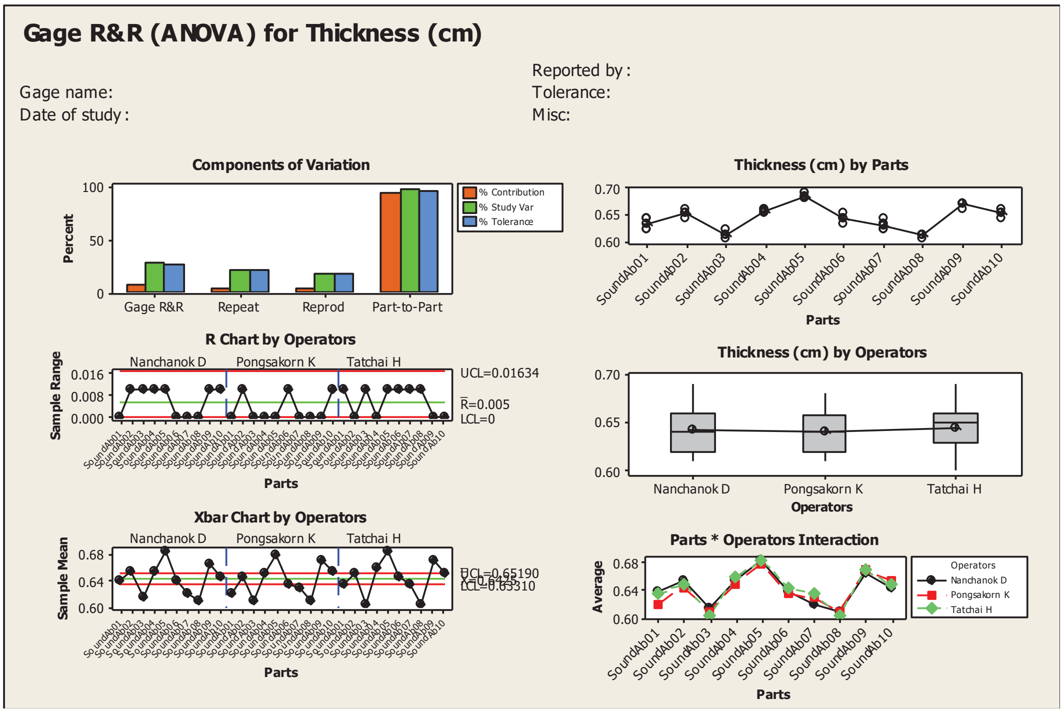

Figure 2.2 Gage R&R for thickness (Part 2)

Baseline performance

The DPMP baseline was determined from the number of defect from the last three batches (Figure 3). The average thickness was calculated and recorded into the measurement sheet. The current defect rate is 25.33% which is very high and affect the profit of the company in many ways (Figure 4). The data were short-term which is not accurate, but for practical reasons, there was no data that could be further collected. The data will at least give some basic information and habit of the product and process.

2.3 Analyze phase

In this phase, the team will focus on identifying the root cause of the rapidly increasing thickness at the edge problem and improvement opportunities

Find Root Cause

Some of the potential attribute was already discussed from previous phase. In order to truly understand and improve the Y' s, the rapidly increasing of rim thickness, root cause analysis such as 5 Whys and Fish bone diagrams were used.

$$\text{DPMO} = \frac{(\text{Number of Defects X } 1{,}000{,}000)}{((\text{Number of Defect Opportunities/Unit}) \text{ x Number of Units})}$$

Defects	19
Opportunities	75
Defect Opportunities per unit	4

DPMO	63333.33
Sigma Level	3.0

Figure 3 Baseline DPMO

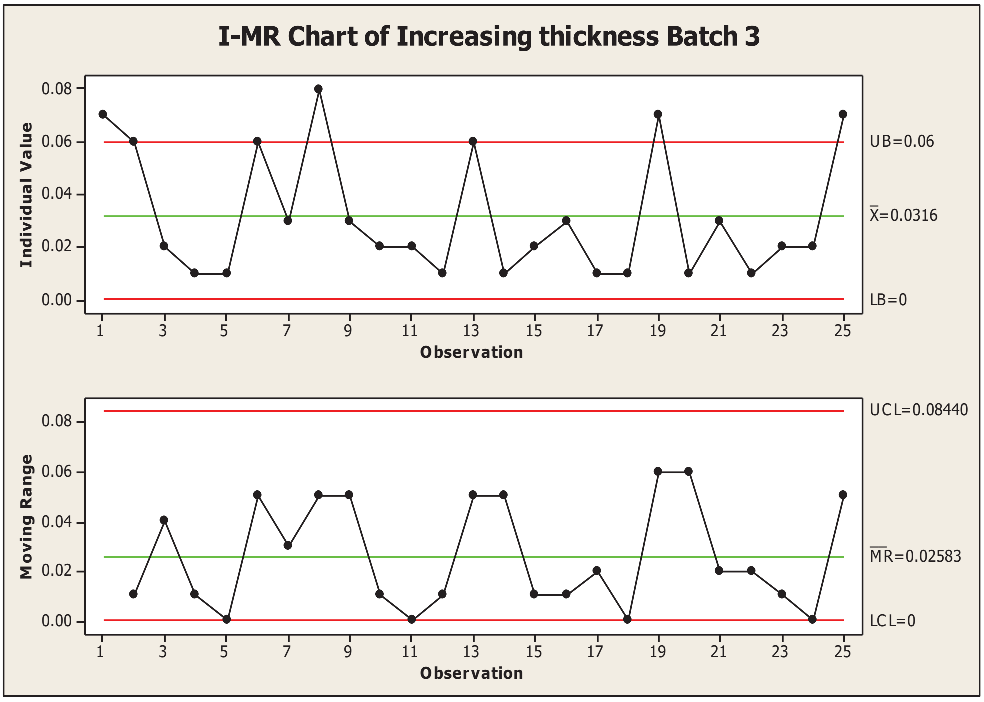

Figure 4 Control Chart

Fishbone Diagram and 5 Whys

The data from previous meetings were used in this phase in order to identify the potential factors which are the root of the problem. The simple fishbone diagram using, 6M categories, was formed in order to identify the root of the problem. After that, the team goes further in each category via using 5 Whys to dig deeper into the root of the potential cause [12].

From the Fishbone diagram and 5 Whys analysis, some of the low possibility or low severity was cut off from further analysis. The list below is the potential root cause of the problem.

1. Corrosion at cathode and anode
2. Unstable rack
3. Untight contact point
4. Bath temperature
5. High current density
6. Solution level
7. pH level
8. Chemical content
9. High humidity
10. Metal practical

Decision Matrix

After fishbone diagram and 5 Whys were done, the decision matrix was used in order to identify the priority of the selected factors. The team transfer the information from Fishbone diagram and 5 Whys into criteria and rating system. First the criteria was identify (Table 1). Then, the analysis was carried on by brainstorming in team and use rating system to rate each factor. Each person individually rated the factors. Then everyone compared the result and discussed the reason with each other [7].

Potential X's --Theories to be Test

X1: High bath temperature can increase the rim thickness rapidly.

X2: High Current density can increase the rim thickness rapidly.

X3: The unstable rack can increase the rim thickness rapidly

Design of experimental: DOE

As can be viewed in previous discussion, the rapidly increasing of thickness depends on many variables. A further analysis of these factors was done to identify which variables have significant impact to the product. Plating temperature, current density, and the degree of rack were the control variable that will be used in this section DOE.

Table 1 Decision Matrix for factors

Decision Factors		Corrosion at anode cathode	Untight contact point	Unstable rack	High bath temperature	High current density	Solution level	pH level	Chemical content	High humidty	Metal particle
Criteria	Wt.										
Impact	3	2	1	3	3	3	1	1	1	1	1
Ease of experiment	1	2	2	1	2	3	3	1	1	1	1
Time consuming	2	1	3	3	3	3	3	2	1	1	1
Cost	2	3	2	3	3	3	1	1	1	1	1
Technical support	1	3	2	3	3	3	2	2	1	1	2
Safty of operator	3	3	1	3	3	3	3	2	3	2	1
Potential to implement	3	3	2	3	3	3	3	1	1	1	1
Weighted score		37	26	43	44	45	34	21	21	18	16
Priority		4	6	3	2	1	5				

Criteria	Definition
Impact	How likely this factor is the cause of the problem
Ease of experiment	How eaily the experiment can be done to analysis this factor
Time consuming	How long it take to run the experiment
Cost	How much the experiment cause
Technical support	How ready is the equipment, instrument and tool
Safty of operator	How dangerous is the experiment
Potential to implement	How realistic to implement the solution if this factor was the root cause

Experimental

The two-level, full factorial design for three factors, namely the 2^3 design, was used in this experiment. This implied eight runs. Table 2 represents the 2^3 design for this experiment.

Table 2 Factorial design

Run#	A	B	C
1	−	−	−
2	+	−	−
3	−	+	−
4	+	+	−
5	−	−	+
6	+	−	+
7	−	+	+
8	+	+	+

	Factor	-	+
Temperature	A	60 C	65 C
Current density	B	0.1 A/sq.cm	0.12 A/sq.cm.
Degree of rack	C	0	15 degree

Key to Factor Selection

Factor A = Temperature ; B = Current density ; C = Degree of rack

Analysis a factorial design

For the 95% confidence interval, L = 0.05. P-values < 0.05 indicate the effect is significant. The P-values of current density and rack degree is less than 0.05 which indicates that the effect is significant (Figure 5). There is no sign of significance from the temperature effect.

The same result is also represented in normal plot of the standardized effects (Figure 6). The Rack, C, degree has greater effect than current density, B, then follows by the interaction between them, BC.

Analyzing a factorial design

For the main effect, rack degree and current density has a significant effect to the thickness (Figure 7). The temperature almost does not affect the thickness of the product because there is small difference of thickness between low and high level.

Analyzing Interactions

There was no interaction between the temperature with either the rack degree or current density (Figure 8). This is a sign of interaction between current density and rack degree. The response of thickness increases when both current density and rack degree is at high level.

DOE Conclusion

From this experiment, both current density and rack degree is a root cause of the problem. There is a clear sign which showed the effect to the thickness. The interaction between them also increases the response. These factors should be controlled to be at the low level in order to reduce the defect in the process.

Factorial Fit: Thickness versus Temperature, Current dens, Rack degree

Estimated Effects and Coefficients for Thickness (coded units)

Term	Effect	Coef	SE Coef	T	P
Constant		0.053833	0.001267	42.50	0.000
Temperature	-0.004333	-0.002167	0.001267	-1.71	0.106
Current density	0.025667	0.012833	0.001267	10.13	0.000
Rack degree	0.059000	0.029500	0.001267	23.29	0.000
Temperature*Current density	-0.000333	-0.000167	0.001267	-0.13	0.897
Temperature*Rack degree	-0.000333	-0.000167	0.001267	-0.13	0.897
Current density*Rack degree	0.011000	0.005500	0.001267	4.34	0.001
Temperature*Current density* Rack degree	-0.003667	-0.001833	0.001267	-1.45	0.167

S = 0.00620484 PRESS = 0.001386
R-Sq = 97.66% R-Sq(pred) = 94.75% R-Sq(adj) = 96.64%

Figure 5 Factorial Fit: Thickness versus Temperature, Current density, Rack degree

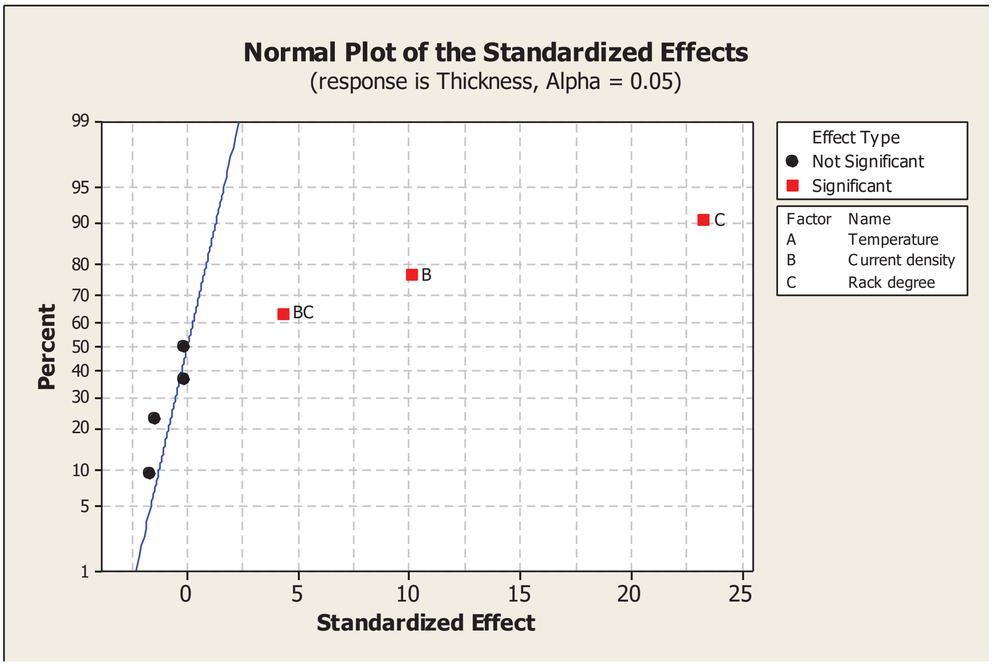

Figure 6 Normal plot of the standardized effects

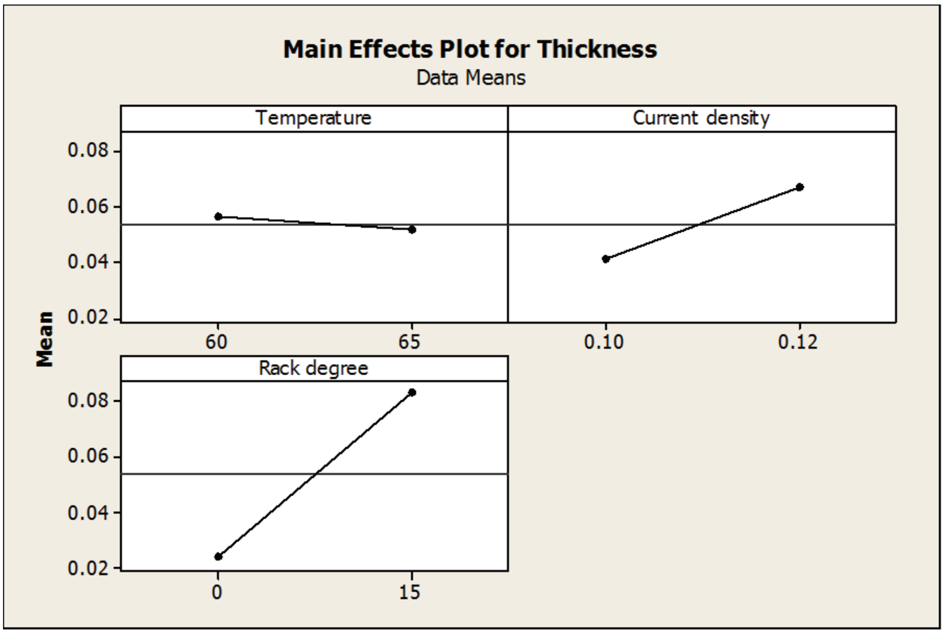

Figure 7 Main effects plot for thickness

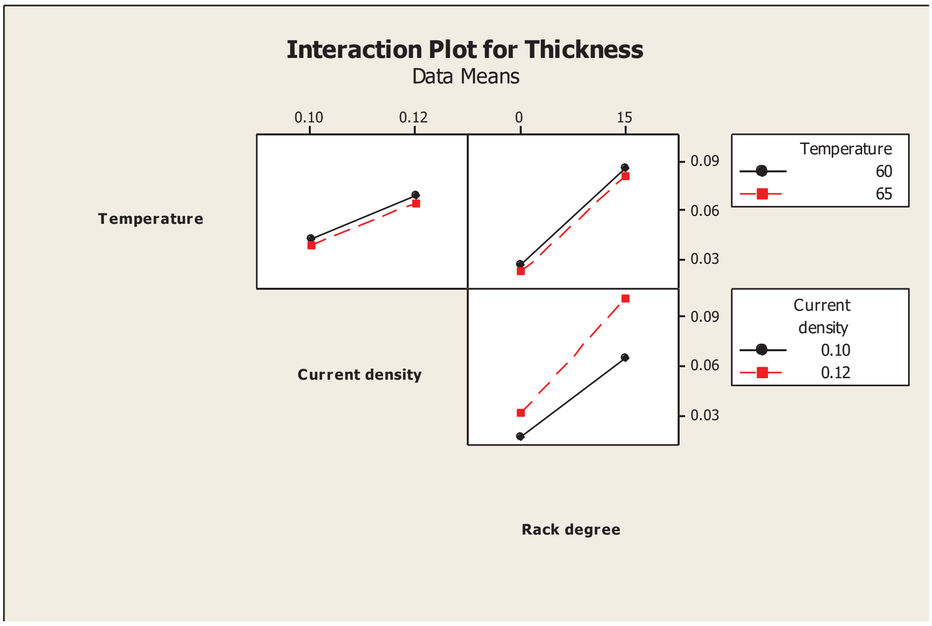

Figure 8 Interaction plot for thickness

2.4 Improve

In the previous phase, the factors which greatly influence the rapid increase of edge thickness have been found. Next phase was Improve, which involved developing the implementation of the solution.

Decision matrix

From the possible solutions, there were many solutions which could potentially solve this problem. These solutions were suggested via expertise, conventional solution in industry and textbook. However not all of them could be practically implemented, due to many reason, such as budget, order size, current technology, etc. The remaining four solutions could not be chosen or eliminated via quick analysis phase because there were many factors which should be concerned and each of them have no critical weakness like the first three. The team used decision matrix together with rating system [12].

Equipment design

From previous analysis and brainstorming the new equipment was very important in order to solve the current problems. From marketing research and supplier interview, there was no equipment that completely fit with our product. The company had two choices, develop by ourselves and outsource the developing.

In-house or outsource

The company already has the resource and material for developing the rack. The rack design normally involves standard testing such as conductive test, which can also be done via current tools and equipment. Although they are not a complex process, the design and drawing the model itself may take longer time than we expected. It also required knowledge and experienced in rack design field. This was both an advantage and disadvantage for both developing rack ourselves and outsourcing it. In order to help the team decide, Abetti's Matrix (Figure 9) had been used.

From Abetti's Matrix, the equipment developing process is important to the business. It increases the ability to compete in the market and also increase the efficiency in the team. The model suggests investing and developing this process. The company will gain a huge benefit via developing the rack ourselves because the company is a R&D company. The others product which company designed in the past may have suffered from the similar situation. If the company has the ability to develop the equipment, it will strongly support the core of the company aspect.

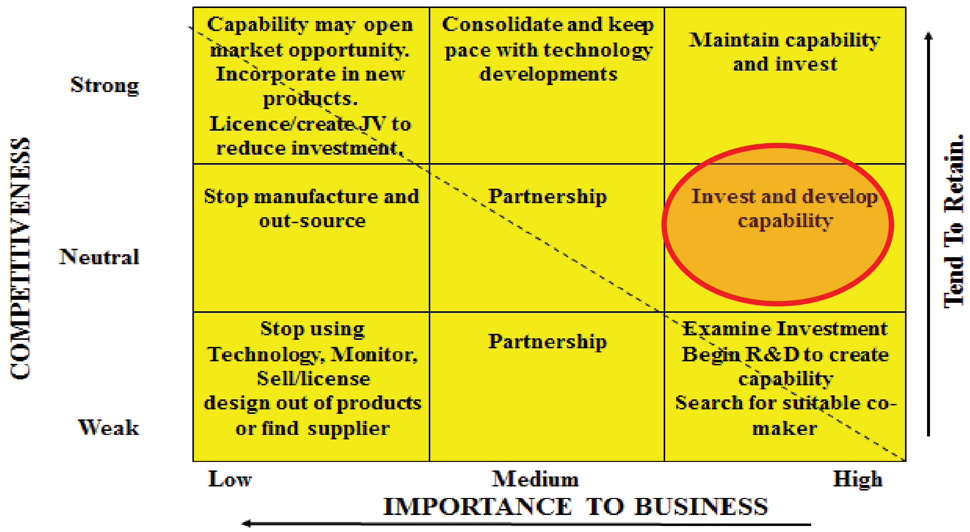

Figure 9 Abetti's Matrix for Testing stage

2.5 Control

In this phase, the team made sure that the result from this project will sustain. The main focus was to design the control plan that suits the project and the company. Most of the data and information was already mention in other phases such as FMEA, so the control plan was like an official version of the process procedure [10].

3. RESULT AND DISCUSSION

The objective of this research is to understand the root cause of the problem in order to develop the solution that best suit the company's current state. The project followed the DMAIC methodology and aligned the mindset of the team with company strategy. As a result of the project, the team was able to achieve the goal of the project, Table 3. The current defect rate after implementing the solution in phase 4 was zero percent.

The company also gained indirect benefits from this project. The first one was the IP about the new equipment and product. The second one was the investment from investor through pitching using this project result to support the business strategy.

Table 3 Overall Project status

Phase	Y=f(x)goal	Result
Define	Identify Y's	Thickness at the rim was chosen as the business Y.
Measure	Identify X's	The rapidly increasing of thickness at the edge of the cell, X's, can represent the cell and it is the factor that drive Y's.
Analysis	Identify the root cause of X's and improvement opportunities	Rack degree and current density were the root cause of the problem
Improve	Define changes required to X's to reach optimal Y	The new rack design together with the dummy significantly reduce the variant of the process and defect
Control	Manage X's and monitor Y	The control plan and important technical sheet

CONCLUSION

Although Six Sigma and DMAIC methodology focuses on reducing the variance of the process, but they can also increase the possible of finding new innovation. In a stable market environment, the aspect of variance reduction of Six Sigma is proved to be very effective. However, it is not very effective in the high level dynamic market with changing of technology all the time. In this situation, the aspect of understanding the customer and the process becomes more important to the business. The VOC and CTQ usually used in Six Sigma process which gives company an in depth understanding in term of customer perspective. The analysis of process, SIPOC and process mapping, tells company the strength and weakness of the current process. When combined these two aspect, it is clear that DMAIC can enhance the innovative thinking in the organization, not only for existing customer but also the new customer [13].

This is very important to the success of the project. As mentioned before, the product is very unique and new to the market. Due to the product itself is already considered to be an innovation, it is very difficult to find the existing available solution for the problem. The clearly understanding of the problem and its root is required in order to design a method or even the innovation one to success.

ABBREVIATION

R&D	Research and Development
DMAIC	Define, Measure, Analysis, Improve, Control
CTQ	Critical to quality
VOC	Voice of customer
MSA	Measurement system analysis
Gage R&R	Gage repeatability and reproducibility
ANOVA	Analysis of variance
VAR	Variance
COMP	Computing
SD	Standard deviation
SV	Standard Variance
Toler	Tolerance
DPMO	Defects per million opportunities
6M	Method, Mother nature, Man, Measurement, Machine, Materials
FMEA	Failure Mode Effects Analysis

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