Electro-deposition painting process improvement of cab truck by Six Sigma concept

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Abstract. The case study company is a manufacturer of trucks and currently facing a high rework cost due to the thickness of the electro-deposited paint (EDP) of the truck cab is lower than standard. In addition, the process capability is very low. The Six Sigma concept consisting of 5 phases (DMAIC) is applied to determine new parameter settings for each significant controllable factor. After the improvement, EDP thickness of the truck cab increases from $17.88\mu\text{m}$ to $20\mu\text{m}$ (i.e. standard $= 20 \pm 3\mu$). Moreover, the process capability indexes ($C_p$ and $C_{pk}$) are increased from 0.9 to 1.43, and from 0.27 to 1.43, respectively. This improvement could save the rework cost about 1.6M THB per year.

1. INTRODUCTION

The electro-deposited process (EDP) is one of the most important painting processes used in automotive industry to apply coatings to metal fabricated products. It has been widely used to coat bodies and parts of passenger cars, trucks and heavy equipment. The reason why they need EDP coating because it is protected corrosion and being one of the main primers that makes the surface smooth before going through the topcoat process. The data from January - June 2016 of the case study company showed that the highest rework cost about 1.9M THB is belong to EDP layer of truck cabs having lower thickness than the standard which impacts directly to the quality of products.

To solve the issue, this research applies the Six Sigma methodology because it is enables organizations to improve the quality, processes capability and finally it can be reduced the rework cost. The Six Sigma methodology is consists of 5 phases. In Phase 1, Define, important problem is selected and clearly defined. In Phase 2, Measure, the measurement system analysis is analyzed in terms of its accuracy and precision. In Phase 3, Analysis, all key process input variables are brainstormed and statistically tested whether they are significantly affected the problem. In Phase 4, Improve, the Design of Experiments technique is performed to find out the optimal settings of the key process factors. Finally, in Phase 5, Control, a confirmatory experiment is performed to confirm the result after improvement, and then the control plan and work instruction are updated.

2. DEFINE PHASE

Define phase is the step to articulate the problem, goal and project scope. Regarding the historical data of the EDP process collected from January 2.016 to June 2016 in Fig. 1 show that 89.91% or 1.9 MTHB of rework cost comes from the EDP lower thickness issue. The forecast data in Fig. 2 shows that 60% of main products is belong to the product Model SR. To meet customer requirement and company standard (EDP thickness of whole cab $= 20 \pm 3\mu$), this paper will consider on the EDP lower thickness issue by focusing on the whole cab area as shown in Fig. 3 and the main model is belong to the SR model.
Figure 1. Rework cost of EDP Painted Cab

Figure 2. Production forecast data
Figure 3. Identify of truck cab painted area

3. MEASUREMENT PHASE
Two main steps focused in this phase are measurement system analysis (MSA) and root cause selection for further elimination. A large number of potential root causes of the problem are identified in Fig. 4 by the fishbone diagram [1].

Figure 4. Fishbone diagram
3.1 Measurement system analysis (MSA)
MSA is an experimental and mathematical method of determining how much the variation within the measurement process contributes to overall process variability. This approach is used to analyse the repeatability and reproducibility of 2 operators who perform self-inspection on the finished good for 15 units. The result shows that %SV is 10.85 (Figs. 5-6). Since %SV is between 10 - 30 percent error, it could be concluded that the measurement system is acceptable.

![Figure 5. Gage R&R result](image1)

![Figure 6. Gage R&R report](image2)

3.2 Problem Identification Analysis
A fishbone diagram or cause-and-effect matrix is a visualization tool for categorizing the potential causes of the problem in order to identify the root causes [2]. It’s useful in brainstorming sessions to lead the discussion. After the working team has brainstormed all the possible causes for the problem, the facilitator helps the group to rate the potential causes according to their levels of importance. All potential root causes with their corresponding scores are ranked according to the Pareto concept (80:20) as show in Fig. 7. From 80% of the parameter that could be the root causes of the EDP issue. They are include seven factors as flowing lower voltage, a few dipping time, lower temperature EDP, tank leaking, lower EDP concentration, cab dirty and the discharge system of machine is not good enough as shown in Table 1. Three factors, i.e. lower voltage, a few dipping time and lower temperature EDP, are selected for further study in the analysis phase. Four remaining factors are not selected because tank leaking factor is can secure with the alarm system, lower EDP concentration is very high cost impact, and cab dirty and discharge system of machine not good enough are tested with hypothesis test and the result show that they are not significant.
Figure 7. Pareto chart of Cause and Effect Matrix

Table 1: Potential Root Cause

| Potential Root Cause                      | Implement | Remark                        |
|------------------------------------------|-----------|-------------------------------|
| Lower voltage                            | Yes       | N/A                           |
| A few Deeping time                       | Yes       | N/A                           |
| Lower temperature                        | Yes       | N/A                           |
| EDP Tank leaking                         | No        | Andon alarm                   |
| Lower EDP concentration                  | No        | High Cost impact              |
| Cab dirty                                | No        | Hypothesis Test (no significant) |
| The discharge system of machine is not good enough | No   | Hypothesis Test (no significant) |

4. ANALYSIS PHASE
This phase applies the experimental design method by adopting $2^k$ fractional factorial design to prove which factors have significant effect to the EDP issue [3]. From the previous phase, the factors involved in the experiment are voltage, dipping time and temperature. In other words, $2^k$ fractional factorial design is performed with 3 factors and 2 levels each as shown in Table 2.
Table 2: factors level of $2^k$ fractional factorial design

| No | Factors     | Units | Levels of factors |
|----|-------------|-------|-------------------|
|    |             |       | Low (-1) | High (1) |
| 1  | Voltage     | V     | 280       | 320      |
| 2  | Dipping Time| Min   | 4         | 6        |
| 3  | Temperature | °C    | 27        | 29       |

After the tests are conducted, the results from the experiments [4] are analysed using the Minitab software as shown in Fig. 8-9. All of 3 factors, i.e. voltage, dipping time and temperature, obtain P-value less than 0.05, meaning that all main effects are significant at 95% confident interval. The interaction between voltage and dipping time has P-value less than 0.05, meaning that interaction between voltage and dipping time is also significant at 95% confident interval, but interaction between voltage and temperature, dipping time and temperature are found not significant at 95% confident interval. As a result, all significant factors need further investigation to find their suitable settings in the next phase.

![Figure 8](image1.png)  
**Figure 8.** ANOVA result of $2^k$ fractional factorial design test

![Figure 9](image2.png)  
**Figure 9.** Normal Probability Plot of the standardized effect.

5. IMPROVEMENT PHASE

According to the analysis phase, 3 main factors including voltage, dipping time and temperature have statistically affected to the EDP issue [5]. The propose of this phase is to find new setting point for each factor by using Response Optimizer in the Minitab software (Central Composite Design Concept) as shown in Table 3.

Table 3: factors level of response optimizer (CCD)

| No | Factors     | Units | Levels of factor |
|----|-------------|-------|------------------|
|    |             |       | -2   | -1  | 0  | 1   | 2    |
| 1  | Voltage     | V     | 260  | 280 | 300| 320 | 340  |
| 2  | Dipping Time| min   | 3    | 4   | 5  | 6   | 7    |
| 3  | Temperature | °C    | 26   | 27  | 28 | 29  | 30   |
The results of the experiments show in Fig. 10 that the new setting point of voltage is 300 V, dipping time is 5.6 min and temperature is 30°C. In addition, under the new setting points the EDP thickness is increased to 20μ which meet the EDP thickness standard of 20±3μ.

Figure 10: Response optimizer result of new setting point.

6. CONTROL PHASE
The new settings of the significant factors are implemented in the current process and it can prove that the quality of product is improved, i.e. the EDP thickness increases from 17.8μ to 20μ which meet the company standard. The process capability is improved from 0.90 to 1.43 and Cpk is increased from 0.27 to 1.43 in Fig. 11-12. To control the quality of the product and process to be sustainable after the improvement, the new work instruction for operational and control chart are written. Moreover, related operators are retrained to have a clear idea about how he should work.

Figure 11: Process capability before improvement.  Figure 12: Process capability after improvement.
7. CONCLUSIONS
This research presents the application of the Six Sigma method to improve the Electro Deposition Painting (EDP) process in an automotive business. The research follows the DMAIC steps to perform the process and product improvements. In define phase, the project goal is to have the average EDP thickness of 20μ with minimized rework cost. In the measurement phase, MSA is analyzed and found that %SV or P/TV is 10.85 which means the measurement system is acceptable. Three main factors including voltage, dipping time and temperature are selected to perform the C&E matrix. In the analyse phase, 2^k fractional factorial design is conducted and the results show that main effects of voltage, dipping time and temperature are significant. In the improvement phase, the Response Optimizer in the Minitab software (CCD Concept) is used to find the new setting points. It is found that the new setting point produces the EDP thickness at 20μ. In the control phase, the new work instruction for operational and control chart are created. After improvement, the EDP thickness is increased from 17.8μ to 20μ, Cp is increased from 0.90 to 1.43 and Cpk is increased from 0.27 to 1.43. More importantly, the company can save money about 1.6M THB per year from the rework cost.
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