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Defective Reduction on Dent Defects in Flexible Printed Circuits Manufacturing Process

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ABSTRACT : This research presents methods to reduce defectives due to dent defects in flexible printed circuits manufacturing process. The DMAIC phases of Six Sigma quality improvement approach were applied to solve the problem. It was found that the variables that statistically affect the dent problem were 1) method to polish stainless steel plate, 2) method to store stainless steel plate, 3) method to clean stainless steel plate, 4) fisheyes/ foreign matters in the TPX release film. The dent defects were reduced by 1) changing from dry polishing method to wet polishing method, 2) storing stainless steel plates on storing tables and covering them by dust protectors, 3) improving cleaning equipment, 4) determining the relationship between the diameter of fisheyes/foreign matters in the release film and the defective proportion to encourage quality improvement of the vender. After the improvement, the defective proportion due to dent defects was reduced from 947 DPPM to 442 DPPM or 53.3% reduction. This improvement decreased defective cost of 666,529 baht per year
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Keywords - Six Sigma, Curing Process, Defective Reduction, Dent Defects, Printed Circuits

I. INTRODUCTION

Flexible printed circuits industry has high growth rate and high competition. To keep and increase market share, continuous improvement is highly needed. Six Sigma is a powerful quality improvement approach intending to reduce the cost of poor quality by finding hidden causes of defectives using systematic and statistical tools. Thus, the solutions to problems were then developed systematically. This paper applied Six Sigma approach to reduce defective proportion due to dent defects of flexible printed circuits via a case study company.

The case study factory has the key role in producing flexible printed circuits, which functioned as connectors of the electronic equipments such as ICs, capacitors, resistors and other electronic parts. To produce a flexible printed circuit, CCL (Copper clad laminates) is used as the main material in the circuits forming process. When the circuit lines are formed, it would be carried out in the cover coat process, in which the unused areas of the CCL would be covered to prevent from rust and short circuit with Cover Lay (CL) film. CL film is an electric insulating, durable and flexible material that would reinforce the copper plate's strength. The CL film is cured in the curing process using high temperature and pressure to melt the CL's glue, which is thermo setting adhesive glue. The glue would set itself after being put through high temperature. The curing process would make the CL film connect to the CCL permanently for preventing the oxidation reaction and rust. When the process is completed, the flexible printed circuits are strong and ready to get through the next manufacturing process.

II. RELATED THEORY.

The quality improvement in manufacturing processes is an important strategy to drive organizations towards the international level. One of the most popular approaches for quality improvement in the present is Six Sigma. Six Sigma is a philosophy to run business focusing on getting rid of errors in manufacturing processes in order to achieve the target. The means is to improve continuously and to make profits by getting rid of variances to reduce defectives. This can reduce production cost and increase customers' satisfaction towards the product quality. Six sigma consists of five phases (DMAIC) with the following objectives [1]. The Define phase is to study the customers' requirements, understand the problem, determine the project objective and scope. The Measure phase is to evaluate the measurement system, then measure the current system to identify the potential causes of the problem. The Analyze phase is to perform experiments to test the significance of the causes of problem or the key process input variables (KPIVs) with inferential statistics to find out whether such variables are significantly affect the problem. The Improve phase is to generate the improvement method or the suitable levels of the KPIVs obtained from the Analyze phase. The Control phase is to determine the way for controlling the KPIVs and monitoring the responses for continuous improvement.

There were many researches that applied Six Sigma approach to do quality improvement in various industries such as the research of Kumar and Sosnoski [2] that presented reflective practice using DMAIC Six Sigma steps to systematically improve shop floor production quality and costs. Shrivastava et al. [3] studied the assembly process of the vehicle engine and applied Six Sigma to reduce engine defects. Lo et al. [4] implemented the DMAIC procedures to improve the surface precision of optical lenses in the injection-molding process. Chakravorty [5] presented an effective Six Sigma implementation model in a network technology company. They provided a model to effectively guide the implementation of Six sigma programs to reduce variation or waste from the operations. Rojanarowan and Senprom [6] applied Six Sigma to reduce scratch defects on glass molds of eye-glasses plastic lens. Rojanarowan and Senjuntichai [7] also applied Six Sigma approach to reduce the oil contamination of machining parts. Kuptasthien and Boonsompong [8] implemented Six Sigma improvement methodology in a mass manufacturing of printed circuit cables.

III. METHODOLOGY AND RESULTS

This research follows the DMAIC phases of Six Sigma to reduce defectives due to dent defects. The methodology and results in each phase are shown in the following subsections.

1. DEFINE PHASE

According to the preliminary data analysis of the single-sided flexible printed circuits products from January to June 2012, it was found that the dent defect caused the highest proportion of defectives. The defective proportion due to dent is 0.094% or 947 DPPM. The total loss value was 848,206 baht per year. This defective proportion corresponds to the Z Score or σ-Level Long Term (Z_{LT}) of 3.11, or as the Ppk of 1.04, and Z Short Term (Z_{ST}) of 4.60, or as the Cpk of 1.54. The project objective is to improve the Ppk to be at least 1.33.

2. MEASURE PHASE

The visual inspection was used to collect the dent defect data. Thus, it was important to test whether the performance of the appraisers who did the inspection was reliable. The Attribute Agreement Analysis was performed by choosing 30 sample works from the manufacturing process. The performance of the three appraisers was evaluated using the indices, which were Kappa Statistics, Operator Effectiveness Index(O_E), False Alarm Index (I_{FA}), and Miss Rate Index (I_{MISS}). The Kappa statistics had the range between 0.40 – 0.75, which were lower than the acceptable standard of higher than 0.75. These results suggested that the appraisers had the moderate level of conformity. Table 1 shows the performance regarding O_E, I_{FA}, and I_{MISS}.

Table 1 Attribute Agreement Analysis of the measuring system

Decisions	Operator Effectiveness Index: O_E	False Alarm Index: I_{FA}	Miss Rate Index: I_{MISS}
AIAG's criteria [9]	≥ 0.9 or 90%	≤ 0.05 or 5%	≤ 0.02 or 2%
Appraiser 1	80%	6.67%	13.33%
Appraiser 2	63.33%	33.33%	6.67%
Appraiser 3	76.67%	13.3%	26.67%

Since all appraisers did not pass the criteria for all indices, thus it could be concluded that the measuring process or the visual inspection process lacked of efficiency. Thus, the inspection process should be improved by performing limit sample and training appraisers to be more comprehensive in the Inspection Standard Specification. After improving the inspection process, all appraisers performance pass the criteria and reliable enough to generate inspection results.

Then, the researcher studied the problem in the current process to narrow down the problem by identifying the Key Process Input Variable (KPIVs) of the dent problem. The product model MC-010 was picked to study since it has the highest quantity of dent defects. The researcher determined six check points along the production processes and checked all locations and areas on 10 lots of work pieces that the dent defects appeared including the scrap area to find out the production process and the area that had the most dent defect. It was found that 73.6% of dents occurred on the base film of product. It was also found that most defects (50%) were found after the single side cover lay curing process (CURCS) Next, the researcher identified the causes of dent defects and found that 40% of defectives due to dent were caused by the compressing stainless steel plate used in the curing process. In addition, the dent defects were also caused by foreign matters in TPX Release film (23%) as shown in Fig.1.

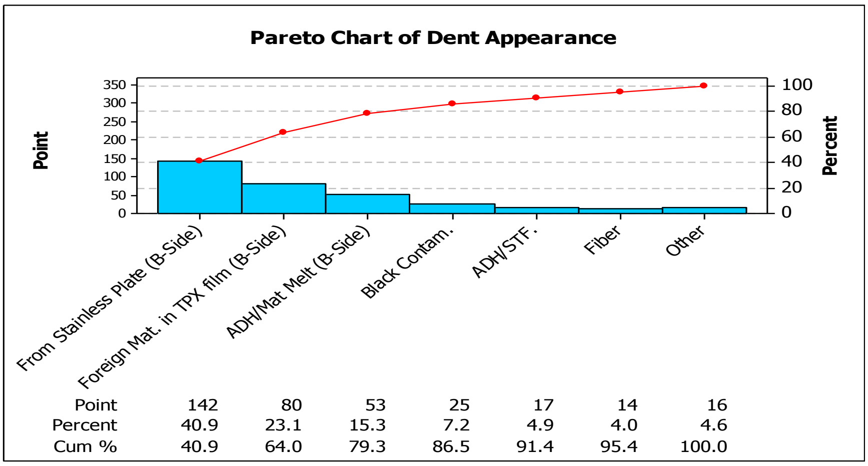

Fig.1. Pareto chart of dent appearance

The researcher did brainstorming to find out the KPIVs using the Cause & Effect Diagram. Then, the KPIVs were reduced to 12 more important variables using the Cause & Effect Matrix. Next, Failure Mode & Effects Analysis or FMEA were analyzed to further reduce the number of variables. It was found from the analysis that there were main four variables affecting the dent problem. These four variables were tested and analyzed in the next phase. These variables were 1) method to polish stainless steel plate, 2) method to store stainless steel plate, 3) method to clean stainless steel plate, 4) fisheyes/ foreign matters in the TPX release film.

3. Analysis Phase

The researcher performed experiments to prove that whether those four variables statistically affect the defective proportion due to dent defects. The details of experiments are shown below.Variable 1: method to polish stainless steel plates and Variable 2: method to store stainless steel plates

The stainless steel plate has a function of receiving heat from the base plate of hot press machine and distributing the heat to the work pieces. The work pieces were put between the cushion materials as shown in Fig. 2. During the curing process, high pressure and temperature were required. Thus, the stainless steel plate was supposed to be so hot that the cushion materials or melted dust may be stained on the stainless steel plate as shown in Fig. 3. It can be seen that the stainless steel plates were next to the product with only the TPX Release film (cushion) inserted between them. Thus, if the stainless steel plates were not clean or had foreign matters, they could cause the dent defects the product. Therefore, the stainless steel plates had to be polished with sandpaper every two weeks to clean out the contaminated particles. After the stainless steel plates were cleaned, they were stored for a period of time before being used in the next lots in the curing process.

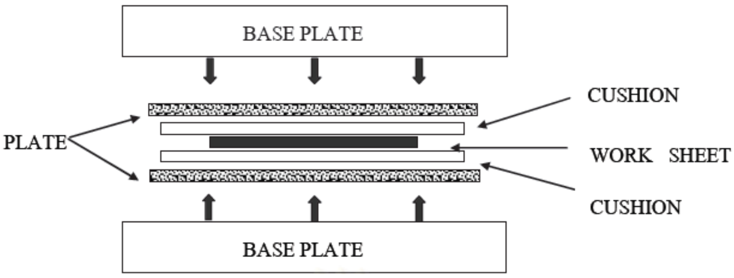

Fig.2. Curing structure

Fig.3. Contamination on stainless steel plate

The researcher designed an experiment to test the effectiveness of current polishing method and storing method. The defective proportion due to dent was recorded for each of the three polishing and storing conditions. The three conditions were 1) the stainless steel plate that had been used for two weeks, 2) the stainless steel plate that had just been polished, 3) the stainless steel plate that had been polished and stored for two weeks. The Chi-Square test was used to test the difference of the defective proportions among the three conditions. The work pieces of 24,000 were used as sample size to provide the power of test over 0.80. The statistical analysis result revealed the p-value of 0.218 suggesting that there was no difference of the defectives proportion among the three methods. This could be concluded the current methods to polish and store the stainless steel plates were still not appropriate because the current polishing method could not effectively clean the contaminated particles and the polishing and the storing method still caused the high defective proportion.

Variable 3: method to clean stainless steel plates Before improvement the stainless steel plates were cleaned by having operators using their hands to wipe the dust free cleaning cloths with alcohol on the steel plates. It was hypothesized that this cleaning method was not effective since the cleaned area may not be thorough. The researcher developed the new cleaning equipment which can clean the whole area of the steel plates. Thus, an experiment was performed to test whether the defective proportion from the cleaning method before improvement was significantly higher than the improved method. The p-value of 0.041from the two proportion Z-test suggested the conclusion that the improved cleaning method is significantly effective.

Variable 4: Fisheyes and foreign matters on TPX Release film. A TPX Release film acted as a helping compressive material connected to the base film of the flexible printed circuits. Its main duty was to prevent the product from contacting with the stainless steel plate directly. The foreign matters in TPX Release film caused by the compound of TPX Release film that was incompletely melted or the embedded foreign matters in the TPX Release film as shown in the Fig.4. These foreign matters were errors in the manufacturing process of the supplier company. It was hypothesized that the bigger size of the foreign matter, the higher defective proportion due to dent. The research analyzed this relationship with Logistic Regression.

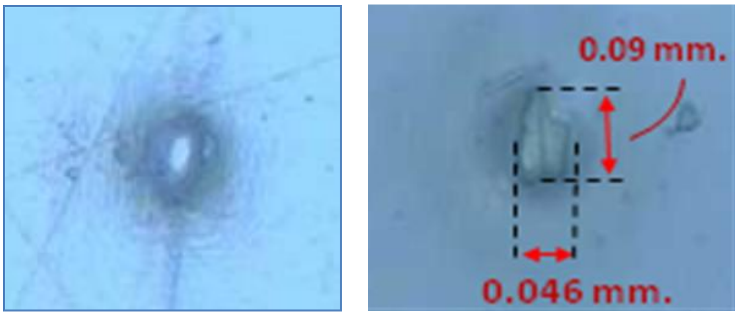

Fig.4. An example of a fisheye/foreign matter in TPX Release film

According to the regression analysis at the significance level of 0.05, it was found that the size of the foreign matters in the TPX Release film was the variable affecting the dent defects on the flexible printed circuits. The relationship between the foreign matter size and the defective proportion is shown in Fig.5. The critical level of the fisheyes/ foreign matters size variable in the TPX Release film depended on the thickness of the flexible printed circuits. It can be seen from Fig.5. that the higher diameter of the foreign matters in the TPX Release film, the higher defectives due to dent.

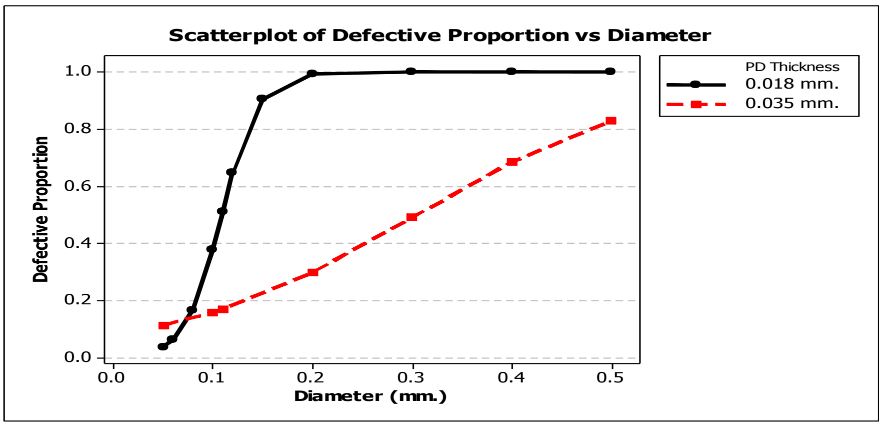

Fig.5. Logistic regression graph showing the relationship of the diameter of foreign matter in TPX Release film and defective proportion due to dent.

4. IMPROVE PHASE

In this phase, the improvement methods to reduce dent defects caused by the abovementioned variables were developed and implemented. Variable 1: Stainless steel plate polishing method was improved by changing from dry polishing method to wet polishing method. Wet polishing method enabled the contaminated particles to be removed easier. Variable 2: Stainless steel plate storing method was improved by applying the storing tables and the dust protectors. Variable 3: Stainless steel plate cleaning method was improved by applying cleaning equipments which can clean the whole plate effectively. Variable 4: Foreign matters in TPX Release film; the researcher informed the supplier company about the evidence that the size of foreign matters significantly affects the defectives proportion. As a result, the supplier company decided to further improve its TPX production process to reduce the occurrence of fisheyes and foreign matters in the TPX Release films.

5. CONTROL PHASE

After the improvement, a control plan and working standards were set up to control those significant variables. Since the interested response is the defective proportion, then the p control chart was set up to monitor the defective proportion due to dent after improvement. The defective proportion of March 2013 was shown in the Fig.6.

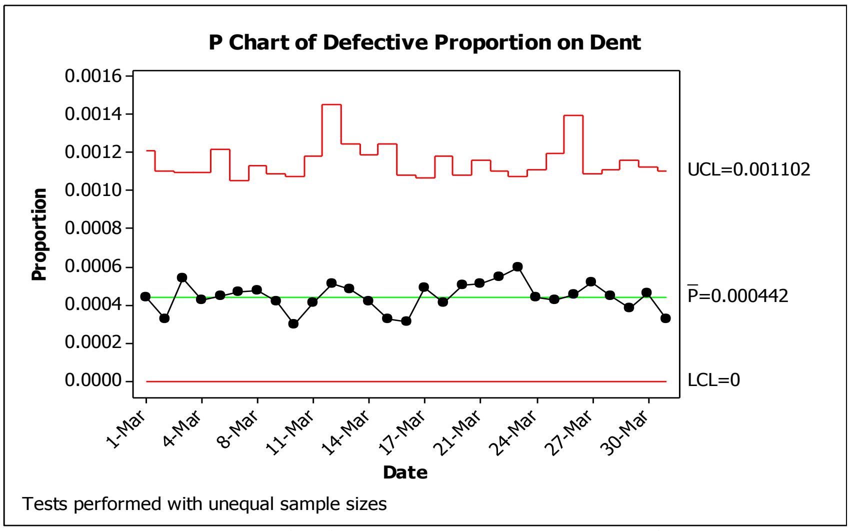

Fig.6. Control chart of defective proportion on dent as of March 2013

IV. CONCLUSION

This research aims to reduce defectives due to dent defects on flexible printed circuits. The DMAIC phases of Six Sigma quality improvement approach were applied. In the Define phase, it was found that defective proportion due to dent defects was 947 DPPM, causing the defective cost of 848,206 baht per year. In the Measure phase, the attribute agreement analysis was performed to evaluate the performance of the defect inspectors and led to the improvement of the inspector performance. Next, the process capability was evaluated and revealed the Ppk of 1.04. In this phase, the Key Process Input Variables (KPIVs) of the problem were narrowed down using the Fishbone Diagram, the Cause-and Effect Matrix, and the criteria of Failure Mode and Effects Analysis. It was found that the variables that affect the dent problem were 1) method to polish stainless steel plate, 2) method to store stainless steel plate, 3) method to clean stainless steel plate, 4) fisheyes/ foreign matters in the TPX release film. Then, the hypotheses tests were performed to verify that the significance of the abovementioned KPIVs. In the Improve phase, new improvement methods to those KPIVs were developed. The dent defects were reduced by 1) changing from dry polishing method to wet polishing method, 2) storing stainless steel plates on storing tables and covering them by dust protectors, 3) improving cleaning equipment, 4) determining the relationship between the diameter of fisheyes/foreign matters in the release film and the defective proportion to encourage quality improvement of the vender. In the Control phase, a control plan and new working standards were set up. After the improvement, the defective proportion due to dent defects was reduced from 947 DPPM to 442 DPPM or 53.3% reduction. The Ppk after improvement was 1.61, suggesting that the improvement result achieved the specified target. This improvement could save the defective cost of 666,529 baht per year.

The main steps in the DMAIC of Six Sigma methodology can be applied to any defective reduction project. The methodology to reduce defectives due to dent presented in this paper can be applied to the cases where the process, the product and related materials are relevant.

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