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Quality improvement of printed circuit board: A case study of copper in hole

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ABSTRACT

The objective of this research is to reduce defective from copper in drilled hole of printed circuit board by adjusting 1) operating speed and retake rate of drill bit in CNC drilling step, 2) vacuum pressure for copper dust of dust collector in CNC drilling machine, 3) pressure and duration in cleaning step with high pressure ultrasonic and 4) life time of drill bit through uses of quality control circle methodology and simple quality improvement tools. Having adjusted this set of factors as a whole, defective from copper in hole was reduced significantly from 12.81% to 0.66% resulting in higher production capacity from lower defective. For future research, it is suggested to study the impact of individual factor and its most suitable value on copper in hole problem with more sophisticated quality improvement and statistical tools.

Keywords: defect reduction; quality improvement; copper in hole; printed circuit board; quality control circle

1. INTRODUCTION

Due to dynamic changes in technology and customer demands, electronics and electrical machine industries are highly competitive in quality, delivery, flexibility and cost. As a result, their supportive supply chains such as printed circuit board (PCB) industry must adapt themselves to respond to customer demands in downstream electronics and electrical machine industries. In free trade and globalization era, such adaptability is highly critical for electrical component industry in Thailand to compete with that in other countries such as Malaysia, Vietnam, Taiwan and China. Simultaneously, there are more opportunities in the global market for Thai electrical component industry if it enhances competitiveness through better quality, faster delivery, more flexibility and lower cost performance.

Electronics component and related industries are crucial industries of Thailand. In 2015, the export value of computers, optical readers and integrated circuits, micro assemblies ranked first and forth in top Thailand's exported products with value of 11.6 billion USD and 7.6 billion USD, respectively (Workman, 2016). To further strengthen these industries, Thai government has established Electrical and Electronics Institute since 1998, which is a dedicated organization having mission to directly develop and promote electrical and electronics industries in Thailand (EEI 2016). Moreover, there are still supports from other governmental agents such as Department of Skill Development, Department of Industrial Promotion, Office of Industrial Economics and Department of International Trade Promotion. Case company in this study received development fund from Department of Industrial Promotion to participate in this quality improvement project. Thailand Productivity Institute

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was also responsible for managing and overseeing this project. This research study aims to reduce defect from copper in drilled hole in PCB with employee participation through quality control circle (QCC) activity and use of simple quality improvement tools.

2. CASE COMPANY

Downstream electronics and electrical machine industries need a number of parts from upstream suppliers in electronics component industry for assembly; therefore, quality is critical to purchasing decision of customers. If only one sub-component has quality problem, it will not only affect quality of those electronics and electrical machines but also cause a production and delivery delay.

The case company in this study is a leading PCB and printed wiring board (PWB) manufacturer in Thailand. It has initial authorized capital of 65 million baht. The company has been established since 1990 and is located in Samut Sakhon province to produce single side PCB and double side PCB for 70% domestic and 30% export market, approximately. This company has been certified ISO 9001, ISO/TS 16949, ISO 14001, OHSAS 18001, TLS 8001 (Thailand Labor Standard) and particularly UL796 FILE E-115789, which is a specific safety standard for PCB from the US. It also received various national quality and productivity improvement awards such as Kaizen Award, Occupational Health and Safety Award and Intensive Development Award. The case quality problem in this research was copper in drilled hole in PCB, because it was the most critical problem that the largest customer of the company required for quality improvement.

3. QUALITY IMPROVEMENT AND METHODOLOGY

Many studies with different techniques have been carried out to improve PCB quality. For instance, Huang (2015) investigated drilling burr generation in PCB by using drilling experiments and finite element method, high-speed photography technology and scanning electron microscope. Then, he found that lower feeding speeding, smaller drill point angle and smaller chisel edge significantly decrease burr. Zheng et al. (2013a) studied tool wear mechanism and chip formation of drilling PCB fixture holes. They suggested that drilling speed and feed rate have significant effect on chip morphology. Shi et al. (2011) investigated drilling fore in PCB micro drilling process and found that drilling force is very sensitive to drill breakage. Moreover, Zheng et al. (2013b) studied the cutting mechanism of drilling PCB and to decrease burr size. As a result, they found that enter burr is mainly caused by burr bending and the generation of exit burr is more complicated.

This research applied contemporary QCC methodology and had the researchers as consultants. Conceptually, QCC empowers shop floor operators for group association to identify problem in their working area and its root causes in order to resolve such problem (Olberding, 1998). It promotes sustainable quality improvement through employee involvement and skill development even after the project finished (Canel and Kadipasaoglu, 2002; Piczak, 1988). QCC methodology follows Plan-Do-Check-Act (PDCA) continuous improvement cycle (Salaheldin and Zain 2007; Bushell, 1992). Simple but powerful quality improvement tools and techniques were applied in this action research for employee involvement (Tennant et al., 2002). These tools and techniques are highly effective in resolving the quality problem and are easy to understand. They include seven quality control tools (Ishikawa, 1976; Trehan and Kapoor, 2011), 5W1H and 5Why analysis, and flow process chat, for example. According to the suggestions of Bamford and Greatbanks (2005), the researchers and working team did not attempt to apply as many advanced tools as possible but selected only proper and necessary tools for improvement. In Thailand, Vanichchinchai (2013) successfully applied QCC and basic quality improvement tools with employee involvement to increase raw material yield of the world's biggest canned tuna manufacturer. Moreover, the researchers found from their experiences that official appointment by top management can effectively motivate commitment, participation and responsibility in quality improvement project more than unofficial request for cooperation. Therefore, the researchers requested the managing director who is the top executive of the company to appoint the team members and assign clear role and responsibility of individual member officially.

3.1 Data collection

PCB defective data from past one year was gathered with check sheet and visually displayed with graphs. According to 80/20 rule, the working team and the researchers used Pareto diagram (Jacobs and Chase, 2011) to select the most critical PCB quality problem for improvement. It was found that copper dust which is invisible with bare eyes in drilled hole of PCB, as shown in Figure 1, caused the highest defective rate at 52.95% of all defectives and accounted for 12.81% of all drilled PCB. Other kinds of defects were contamination, scratch, and shift drill, for instance. Formerly, the customer allowed to have little copper chip in drilled holes. Then, copper in hole had not been a main quality problem. But, from last year, the major customer had concentrated more on this copper in hole problem. Therefore, the customer upgraded the quality specification and did not allow having copper in drilled hole, even if it was very little. As a result, PCB which had passed previous quality standard became out of specification as shown in Figure 2. This caused the copper in hole issue to become the most serious quality problem of the case company.

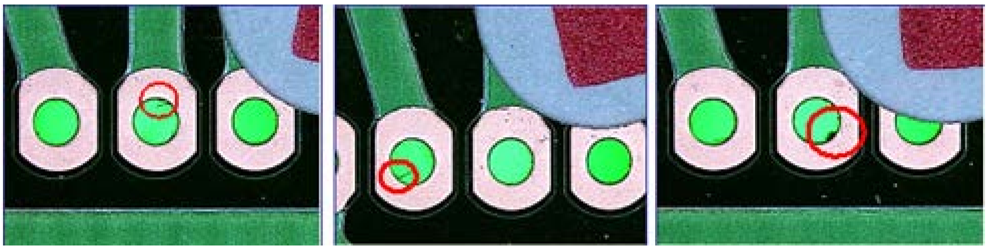

Figure 1 40 times expansion of copper in hole with micro measuring device

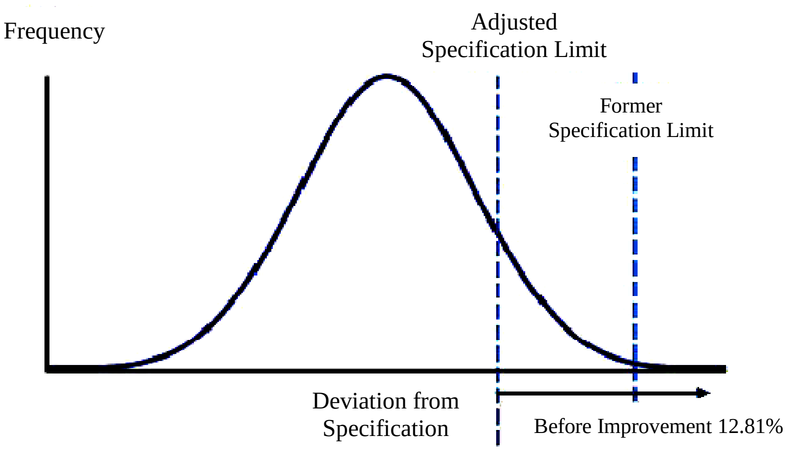

Figure 2 Adjusted specification limit and higher defective rate

The researchers and working team employed flow chart to study PCB manufacturing process (Gryna et al., 2007). More necessary data was collected by fact-based management principle (Hosotani, 1992) or 3Gen principle (in Japanese: Genba = real place, Genbutsu = real item and Genjitsu = real data). It was found that the major PCB manufacturing processes are as follows:

Cutting → Drilling with CNC machine → Cleaning dust in drilled holes with high pressure ultrasonic → Copper clothing → Inspection

3.2 Analysis and root cause identification

The working team used fishbone diagram (or cause and effect diagram) together with fact-based management principle, 5W1H and 5Why analysis (Gitlow et al., 2005) so as to get as many causes of copper in hole problem as possible. Then, four major and most likely causes of problem were identified, verified and confirmed as follows:

(1) In the process of drilling with CNC machine, drilling process and drilled copper plate are shown in Figure 3. Operating speed of drill bit and retake speed of drill bit might be too high. The operating speed and retake speed were 58 krpm and 20 m/min respectively. Therefore, the working team consulted external CNC drilling machine suppliers and drill bit suppliers for more proper speeds. Then, suggested operating and retake speeds obtained from suppliers were compared with existing speeds used by the company. It was found that both existing operating speed and retake speed were significantly higher than suggested speeds.

(2) Vacuum for cleaning dust and copper chip in drilling step with CNC drilling machine might be insufficient in the operation of cleaning dust in drilled holes with high pressure ultrasonic. Then, the working team re-checked vacuum value of CNC machine and found that it was significantly lower than specified value. Besides, the working team inspected condition of vacuum tube and found two leakages at joints to CNC machine and to vacuum cleaner. From dust bag inspection, the dust bag was also blocked and full of dust because it was cleaned once a day only. These measures are shown in Figure 4.

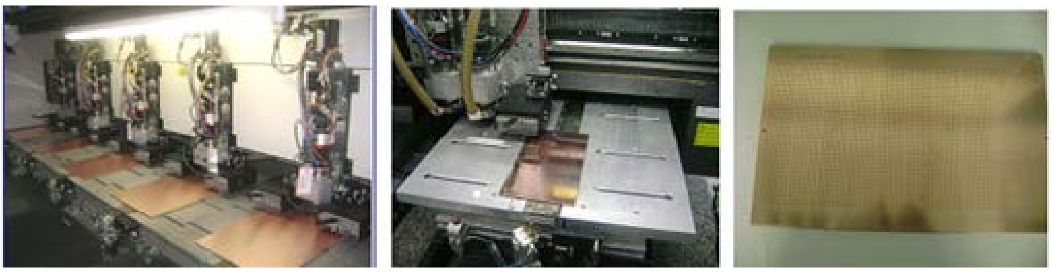

Figure 3 Drilling process and drilled copper plate

Figure 4 Vacuum test, vacuum tube and dust bag inspection

(3) Water injection pressure for cleaning copper with high pressure ultrasonic in the step of cleaning dust in drilled holes with high pressure ultrasonic might be too low and cleaning time might be too short. These processes are shown in Figure 5. Then, the working team verified and found that such pressure was only 20 bar which is rather low for PCB requiring very high cleaning standard. A reason of low injection pressure was improper machine condition due to ineffective machine maintenance.

(4) Besides, drill bit might be insufficiently sharp due to too high pre-set the maximum number of hits of drill bit before change in the process of drilling with CNC machine. The working team inspected condition of drill bit when the number of hits almost reached the maximum number of hits with micro measuring device capable of 160 times expansion. As shown in Figure 6, it was found that the cutting edge of drill bit was chip. Checking by expanding drilled hole surface as shown in Figure 7, the surface of the hole was also rough.

Figure 5 Feeding, cleaning and keeping in cleaning process

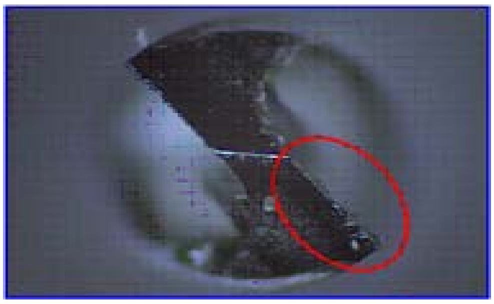

Figure 6 Expansion of drill bit at near the maximum number of hits

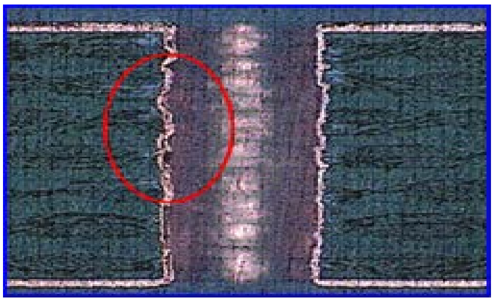

Figure 7 Expansion of drilled hole surface at near the maximum number of hits

3.3 Improvement and standardization

From data analysis, inspection and verification of the main sources of copper in hole problem, the working team and the researchers identified controllable factors that could be finished by limited duration of this action research for improvement as follows:

(1) Operating and retake speeds were adjusted according to the suggested value by suppliers. The operating speed was decreased from 58 krpm to 52 krpm, while retake speed was reduced from 20 m/min to 18 m/min.

(2) Two leakages at tube of vacuum cleaner of CNC drilling machine were repaired and cleaned. Dust bag cleaning measure was reset by shaking the dust bag from one time per shift to twice per shift so as to prevent against dust block. Vacuum rate was always checked by integrating it into regular house-keeping or 5S activity and self-maintenance activity (or autonomous maintenance) of the company.

(3) Copper dust cleaner with high pressure ultrasonic was fixed and maintained for better operating condition. Water injection pressure for cleaning copper chip was increased from 20 bar to 45 bar. Speed of conveyor for moving PCB into and out of ultrasonic cleaner was reduced from 1.2 m/min to 0.8 m/min for more cleaning time.

(4) The maximum number of hits of drill bit was reset according to specification of individual job by reducing the maximum number of hits of drill bit for job with highly sensitive specification. Therefore, the maximum number of hits of drill bit of the case PCB was decreased from 2,000 hits to 1,500 hits. Then, that drill bit will still be used for other jobs or products with lower specification until the number of hits reaches 2,000 so as to efficiently utilize the drill bit and to control operating cost.

4. RESULTS AND DISCUSSION

Having implemented aforementioned improvement measures, average three month defectives from copper in hole had been significantly reduced from 12.81% to 0.66% (94.8% decrease) as shown in Figure 8. 12.15% reduction of PCB defectives which cannot be reworked led to significant raw material cost saving and shorter production lead time. Moreover, overall production capacity was higher because of lower defective rate although operating speed and retake speed were decreased. The working team, therefore, set factors and values applied in this action research as new operational standard and documented in ISO 9001 quality management system of the company so as to audit for sustainability in quality improvement. Besides, employees of the case company had developed more quality improvement knowledge and skill through this action research project. The case company also had more efficient PCB manufacturing system and standard which are important foundations for further continuous and sustainable development. These results confirmed that QCC with simple tools can improve quality of not only products but also people, according to Vanichchinchai (2013), Canel and Kadipasaoglu (2002), Tennant et al. (2002) and Piczak (1988).

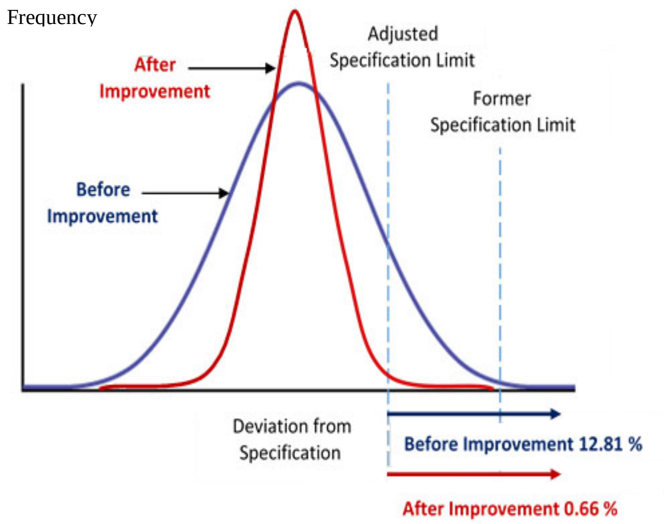

Figure 8 Reduced defective rate after improvement

5. CONCLUSION

Effect from each factor causing the copper in hole problem could not be studied in this research because of time constraint that the customer urgently required the case company to resolve this problem and supply products. Such defect had been decreased with many factors such as operating and retake speed of drill bit in drilling step, vacuum for cleaning chip in drilling step, pressure and duration for cleaning with high pressure ultrasonic, and the maximum number of hits of drill bit. These sets of improvement measures that affect the copper in hole in PCB issue were applied in an integrated manner, because they had been verified by experts. Besides, the measures such as dust bag cleaning did not affect other manufacturing performance dimensions such as production capacity or cost much. Thus, they fundamentally should be implemented to improve shop floor for better working condition. However, it is reasonable to conclude that drilling and feeding speeds significantly affect drilling quality in accordance with Huang (2015), Zheng et al. (2013a) and Shi et al. (2011). Although this research can significantly reduce copper in hole problem according to the target of the company, the company still can further improve and sustain by strictly following the new operational standard. Future research may study the effect of individual factor and optimum value such as optimum operating speed and retake rate for the copper in hole problem. Six-sigma methodology or more advanced quality improvement tools and techniques such as statistical quality control, process capability, design of experiment might be employed for analysis, improvement and evaluation. Side effects of the initiated improvement measures to other performance dimensions, such as production capacity, delivery, flexibility and cost, must be carefully assessed when implementing such measures.

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