Application of Minitab-based Six Sigma to improve Functional Circuit Test throughput rates

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Abstract. With the increasing demand for quality from customers, it is an important way for companies to improve quality by studying Six Sigma management methods and applications. In this paper, Company Z uses Six Sigma theory combined with Minitab software to analyse problems through Six Sigma tools such as MSA, C&E matrix, FMEA, double sample T, regression analysis and engineering capability analysis to improve the one-time throughput rate of FCT（Functional Circuit Test）for T products as an application case[1]. It served as a case study and inspiration for the in-depth implementation of Six Sigma in Company Z. It also provides an example of improvement and experience for other companies implementing Six Sigma, with a view to contributing to the development of Six Sigma in Chinese enterprises.

Keywords: Six Sigma, Minitab, quality improvement, FCT straight-through rate

1 Project selection and definition phase

1.1 Description of the background of the chosen topic and setting of objectives

T products as the main product of Z company, the annual production volume is about 1.5 million. After mass production, its automated FCT test throughput rate has been around 95% for a long time, limiting OEE (Overall Equipment Effectiveness) and causing a waste of resources. In view of this, the objective of this Six Sigma project was to improve the FCT test throughput rate of T products. The project team extracted and studied 110,000 sets of product FCT test data in March 2022 and found that 5.4% of PCBAs failed to pass the test in one go. By further breaking down the fault classification, it was found that 70% of the failures were due to excessive flux residue on the test pads, resulting in poor contact after the test probes were in constant contact with the test pads and the test probes were stuck with rosin. The percentage of failures was 2.2% and the sigma level was only 3.51, indicating that the problem of flux sticking to test probes needs to be addressed urgently. Therefore, in this project, the key quality characteristic CTQ is "Reduce the rate of sticky flux probes in FCT" and is assigned the

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variable Y, which is calculated as follows: Y=$\frac{\text{Number of test probes}}{\text{Total number of test probes}} * 100\%$ (number of test probes = number of errors reported during testing due to sticky flux probes, total number of test probes = number of product tests) Number * number of test probes per board (3 points) * total number of tests).

This compares to a defect rate of 0.55% for the same type of problem at the pilot stage and a best value of 0.5% for similar products within the company. The project team evaluated 0.50% as the target for improvement and 0.40% as the challenge target.

1.2 Scoping

Firstly, the relevant production processes that affect the throughput rate of FCT were analysed by SIPOC (Supplier Input Process Output Customer) method. Five processes were initially identified for this project: solder paste material, surface mount, reflow, test pad cleaning and functional testing.

2 Project measurement phase

2.1 Analysis of the measurement system

In order to accurately capture the actual level of accuracy and reliability of the status quo Y, we first verified the conformity of Y's measurement system. The group selected 50 probes, mixed individual defective probes stuck by rosin into them, randomly selected a total of 3 employees from A/B/C for consistency checking, using Minitab software[2] for discrete MSA (Measurement Systems Analysis)[3] can conclude that:

①The detection rate of the 3 inspectors for non-conformity is greater than 96%, and the detection capability meets the requirements.

②The KAPPA of all three inspectors is > 0.7, which means that the detection rate of the equipment for defective probes is consistent and the measurement system is effective.

In summary, according to the MSA discriminatory guidelines the measurement system meets the requirements, the data obtained is scientific and reasonable and can be trusted.

2.2 Identification and analysis of potential impact factors

According to the scope of the process study defined in the first step of the project, the project team used the fishbone diagram tool to list out the relevant influencing factors according to the 4M1E method, and identified eight main factors that affect Y, such as operator capability, test pad cleaning method, PCBA appearance inspection method, reflow chain speed, solder paste thickness, reflow oven temperature, solder paste stirring time, and solder paste flux content. The eight factors were then analysed and evaluated using the FEMA (Failure Mode Effects Analysis) method[4], from which the key factors affecting Y were identified. (Figure 1)

Potential Failure Mode & Effects Analysis										
Process		Potential Failure	Potential Failure Effects	S	Causes	O	Current Control Methods	D	RPN	Improvement Plans
1	Supply Solder Paste	Excessive rosin residue on the PEBA surface	During the functional test, the rosin is transferred to the test probe, which affects the first-pass rate of the test	7	The flux content in the solder paste is too high	3	Use fixed well-known brand solder paste, and do experimental evaluation before use	2	42	No abnormalities, excluded
2					The mixing time of the paste is not suitable	2	Using automatic mixer, the automatic control time of the equipment is about 150 S	4	56	No abnormalities, excluded
3	SMT Printing				The SMT paste thickness is not suitable	3	The thickness of the solder paste is controlled by the stencil, the control standard is 0.12±0.03mm, and 100% automatic control inspection by equipment	3	63	No abnormalities, excluded
4	Reflow Soldering				The reflow chain speed is not suitable	5	The reflow chain speed is 1200± 300mm/min, and automatically controlled by equipment (timing sampling record)	5	175	Further verify the rationality of the chain speed
					The temperature of the reflow soldering zone is not suitable	4	Welding area temp.> 225℃ (45-60 S), automatic equipment control (timing sampling record)	6	168	Further verify the rationality of the temperature of the welding area
5	Veneer Inspection				The criteria for determining the amount of rosin residue are not specified	5	None	7	245	The work instructions specify that the criterion for determining the amount of rosin residue is "no obvious rosin residue by visual inspection", and a diagram is provided
6	Test Pad Cleaning				The cleaning method of the test pad is not perfect	6	Cleaning work instructions for guidance	7	294	Additional control chart monitoring to the cleaning effect of the test pad
					Insufficient proficiency of personnel	3	Personnel training qualified to work	3	63	No abnormalities, excluded

Fig. 1. Analysis of potential factor failure modes

2.3 Identification and validation of potential key impact factors

The FMEA analysis described above identified a total of 8 relevant factors. Through the screening of the RPN values, non-critical factors such as flux content of the solder paste, stirring time, thickness control, and operator competence were first excluded. The primary factor of PCBA appearance inspection method was also improved by means of a quick win improvement. Initially, the key factors such as cleaning flux dissolution ability, reflow chain speed and reflow temperature were derived and carried forward to the next stage for further analysis and improvement.

3 Project analysis phase

In this project, 3 important factors such as reflow chain speed, reflow temperature and cleaning agent solubility were identified separately from the measurement analysis in the previous phase. In this phase further analysis was carried out to find out the individual or interactive effects of these factors on Y.

3.1 Reflow chain speed analysis

Based on the product characteristics, the chain speed range was taken to be 1200 ± 300 mm/min. After recording the chain speed for 30 groups (50 pieces per group), the experimenter used Minitab software to carry out probabilistic statistics and process capability analysis (Figure 2).

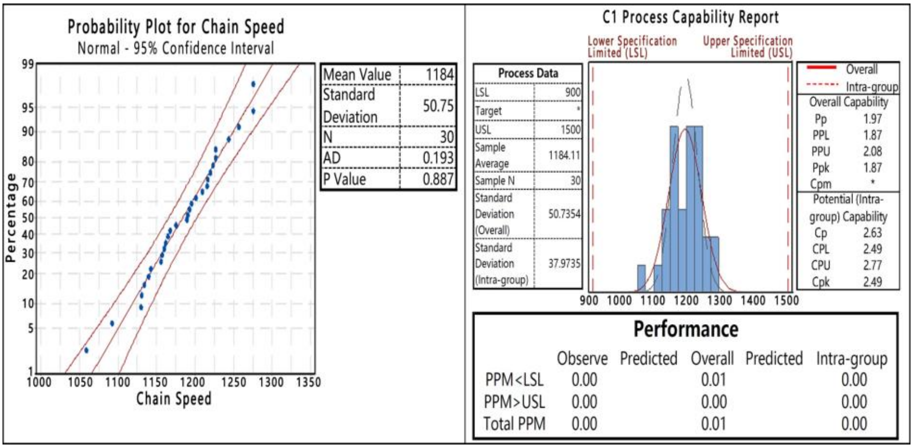

Fig. 2. Reflow chain speed control process capability

From the engineering capacity of the reflow chain speed, Cpk = 2.49 is much greater than 1.33, indicating adequate engineering capacity. To further verify the correlation between chain speed and Y, we selected two conditions within the specification range of chain speed, low speed (950 mm/min) and high speed (1450 mm/min), and did an ANOVA to verify the variation of Y under different chain speed conditions. After analysis (Figure 3), P=0.001 < 0.05 indicates that reflow chain speed and Y have a significant correlation as a key factor, and the project team will further verify the reasonable design value of chain speed in the next stage.

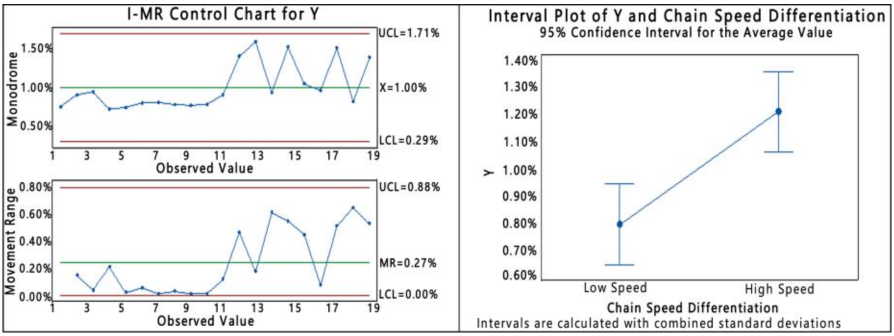

Fig. 3. Reflow chain speed variance analysis

3.2 Reflow temperature analysis

The reflow soldering zone temperature was >225°C (50 seconds) as per production requirements. With the same analysis as above, the team first verified the stability of the soldering zone temperature by using the Minitab software process capability analysis, Cpk = 1.45 is greater than 1.33, indicating that the overall temperature fluctuations are controllable and the process capability is adequate. The project team then further verified the correlation between reflow temperature and Y, selecting low temperature (215°C) and high temperature (245°C) and producing 15 consecutive groups (50 wafers per group) respectively. Minitab gave a verification result of $P < 0.05$, indicating a significant correlation between solder zone temperature and Y, the exact value of which will be determined after entering the next stage of analysis.

3.3 Analysis of detergent dissolution capacity

The cleaning agent concentration range as specified is 50% to 85% (the higher the ratio, the better the cleaning ability, but environmental considerations as well as cost need to be taken into account). The current production used a ratio of 50% and the group group selected 50%, 60% and 70% to verify the fluctuation of the test pads on Y after cleaning as a way to verify the correlation between the two. The results of the correlation analysis through the Minitab software showed that $P < 0.05$, indicating that the percentage of stock solution has a significant correlation with Y.

4 Project improvement phase

After the above stages of defining, measuring and analysing, the team identified the significant factors affecting Y as reflow chain speed, reflow temperature and cleaning agent dissolution capacity. The next step was to quantify and improve these significant factors[5].

4.1 Design and implementation of the experimental programme

In order to optimise the values of each factor, the values of each factor were quantified and assigned to the three factors, and then a full factorial experiment with three factors at 2 levels and 1 centre point was conducted using Minitab software. The results of the experiment are shown below. (Figure 4)

Standard Serial Number	Operation Serial Number	Central Point	Blocks	Reflow Chain Speed	Reflow Soldering Area Temp.	The Solubility of Cleaning Agent	Y
1	1	1	1	900	225	0.7	0.48%
2	2	1	1	1200	225	0.5	0.65%
3	3	1	1	900	250	0.5	0.51%
4	4	1	1	1200	250	0.7	0.58%
5	5	1	1	900	225	0.7	0.47%
6	6	1	1	1200	225	0.5	0.66%
7	7	1	1	900	250	0.5	0.52%
8	8	1	1	1200	250	0.7	0.57%
9	9	0	1	1050	237.5	0.6	0.37%

Fig. 4. Full factorial simulation experiment

From the above experimental data it can be concluded that when the reflow chain speed is 1050mm/min, the reflow temperature is 237.5°C and the cleaning agent solubility is 0.6. the optimum value of 0.37% can be obtained for Y. Further analysis of variance and residual analysis was carried out on the experimental results to fit the model. According to the data analysed by Minitab software, the P-values of the model are less than 0.05, which proves that the model is valid and the total regression effect is significant.

4.2 Validation of experimental results

Following the design improvement plan for the three-factor experiment described above, the project team tracked the fluctuation of Y for 26 batches (100 pieces per batch). After Minitab statistical analysis, the binomial process capability report for Y showed (Figure 5) that the defect rate for Y after improvement was 0.396% and the Six Sigma level was 4.2, a significant improvement over the pre-improvement defect rate of 2.2% and the Six Sigma level of 3.51.

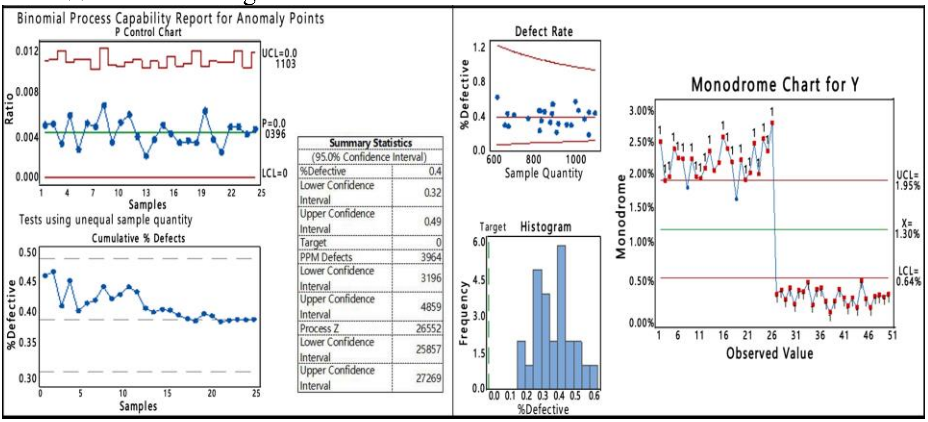

Fig. 5. Binomial process capability report for Y

5 Project control phase

5.1 Standardised control

The main task of the control phase is to fix the improvement content of the previous phases of work in the form of documents such as operating instructions and control plans, and to control and manage them with a controlled system. The whole process is controlled in a closed loop.

5.2 Project outcomes

Based on the level of Y of 0.4% after this improvement, the project saves approximately $410,000 per year in labour costs, $1,445,000 in costs after the comprehensive efficiency improvement of equipment, and $131,500 in indirect savings in site, delivery and logistics costs, for a comprehensive return of $1,986,500 per year.

6 Conclusion

As one of the current research hotspots, Six Sigma management has gradually been recognised by the wider business community as an effective way of relying on quality to achieve benefits. It has also developed into one of the best practice methods for strategic improvement, business change and problem solving[6]. In this paper, the process approach of Six Sigma DMAIC is combined with Minitab statistical analysis software to effectively improve the FCT straight-through rate of Company Z's T products and achieve more significant economic benefits. It also has far-reaching significance in promoting the formation of a top-down, data-driven quality culture in the company.

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