# Quality Analysis of Nital Etch Inspection Process With Six Sigma and Kaizen Approach to Reduce Product Defects

Rendiyatna Ferdian[1] and Arief Setia Budi[2]

[1, 2] Industrial Engineering Department, Widyatama University, Bandung, Indonesia
rendiyatna.ferdian@widyatama.ac.id, arief.setia@widyatama.ac.id

**Abstract.** PT XYZ is an aircraft component manufacturing company headquartered in the United States. One of the departments at PT XYZ is Non-Destructive Test Department, where defects are often found in one of the processes, Nital-Etch Inspection (NEI). The observations for June 2022 until June 2023 show that the average percentage of product defects in the NEI process is 17.28%, which exceeds the company's maximum limit of 5%. The purpose of this research is to analyze the Nital Etch process and reduce defects using Six Sigma and Kaizen approaches. The initial identification found five types of defects in the NEI process, grinding burn, local softening of cylindrical components, thin layers, lack of hardness in general, and cracking. The largest deviation was grinding burn, with value of 16,465 Defect per Million Opportunities (DPMO) and 3,63 sigma level. Based on the analysis, the causes of grinding burn defects are the human factor, which is operator's negligence and lack of supervision, the lack of operator ability and knowledge in operating the machine, and the work fatigue factor. Improvements were made by improving the supervision process for operators, providing regular training, implementing a certification program for grinding operators, creating a balanced work schedule, conducting regular health checks, and designing the workplace to be more ergonomic to reduce physical fatigue. The results of the implementation improvement carried out for 2 weeks, resulted in a decrease in the average product defect to 7.02%.

**Keywords:** Nital-Etch Inspection, Defect, Six Sigma, Kaizen.

## 1 Introduction

PT XYZ is one of the manufacturing companies that produce aircraft components. One of the quality control processes in the aircraft component manufacturing industry is using the Non-Destructive Test (NDT) method. NDT is a testing and analysis technique used by industry to evaluate the properties of a material, component, structure, or system, to detect differences in characteristics or defects without altering or causing functional impairment. In the NDT department, the process that most often finds product defects is the Nital-Etch Inspection (NEI) process. NEI method uses the effect that different components of material, have different susceptibility to acids, thus causing the damaged areas to look different, i.e. mostly darker [1].


V. Mardiansyah and B. A. Prasetyo (eds.), *Proceedings of the Widyatama International Conference on Engineering 2024 (WICOENG 2024)*, Advances in Engineering Research 252,
https://doi.org/10.2991/978-94-6463-618-5_30

The average percentage of product defects found at PT XYZ from June 2022 to June 2023 was 17.28%, which exceeded the maximum limit set by the company of 5%. A high percentage of product defects can affect subsequent processes, whereas in the Kaizen concept defective products should not be continued at the next stage of the production. The process that produces defective products has the potential to produce a rejected final product and interfere with the company's overall production process. Meanwhile, the Six Sigma approach is based on a keen understanding of facts, data, and statistical analysis, as well as a strong attention to managing, improving, and reinvesting in the business [2]. The structured and sustainable Six Sigma approach makes it easy to measure the success of quality improvement, maintain the company's operational excellence, and make it easier to identify potential sources of failure while reducing defects. Based on the problems that have been described, the purpose of this study is to control the quality of the Nital-Etch Inspection process with the Six Sigma and Kaizen approaches to reduce the level of product defects.

## 2 Literature Review

Non-Destructive Testing (NDT) encompasses various methods to inspect materials and structures for flaws without causing damage, ensuring reliability and safety in industrial applications [3]. In some modern techniques, NDT evaluates structural integrity utilizing methods like visual testing, ultrasonic testing, radiographic testing, and infrared thermography for effective maintenance and diagnosis [4].

Nital-Etch Inspection is a critical process used to identify defects in materials, particularly in metals like Nitinol, which is known for its unique properties. This inspection method involves treating the material with a nital etchant solution, followed by image analysis to detect flaws. Automated systems have been developed to enhance nital etch inspection efficiency. These systems utilize image-capturing devices to obtain images of the treated surface, which are then analyzed by algorithms to identify defects [5].

Six Sigma is a data-driven methodology aimed at improving quality by reducing process variation and defects across various industries. Its application spans manufacturing, healthcare, and service sectors, demonstrating its versatility and effectiveness in enhancing operational efficiency. Key Principles of Six Sigma called DMAIC that stands for Define, Measure, Analyze, Improve, and Control. This framework is widely applied across various industries to enhance quality and efficiency. Define, is a process to identify the problem and project goals [6]. The measure is a process to collect data to establish baselines [7]. Analysis is a process to investigate data to find the root causes of defects [8]. Improve, is a process to develop solutions to address root causes. In medical product manufacturing, DMAIC led to a 60% reduction in defects and rework costs. The last process is control, which is to implement controls to sustain improvements, ensuring ongoing quality management across sectors [9]. Statistical Tools and techniques such as Pareto analysis, fishbone diagrams, and control charts are commonly employed to analyze and improve processes, particularly in complex industries [10].

Six Sigma has been effectively utilized in many sectors, factors such as process standardization and assurance significantly influenced patient satisfaction levels during

COVID 19 [11]. A Lean Six Sigma (LSS) strategy was implemented in a dental college, reducing treatment times and improving service quality, demonstrating its adaptability in healthcare environments [12]. In manufacturing, a hybrid LSS approach was developed to address defects in the reamer production process, resulting in a notable increase in sigma levels and operational efficiency [13]. The halal food industry has also adopted a Six Sigma framework to reduce defects and ensure compliance with halal standards, showcasing its versatility across different sectors [14]. While Six Sigma is widely recognized for its effectiveness in quality improvement, some critiques suggest that its rigid structure may not accommodate the dynamic nature of certain industries, potentially limiting its applicability in rapidly changing environments.

## 3 Methodology

The stages carried out in this study are through the DMAIC stage. The steps of the research are explained in detail as follows:

**Define**

Define is the phase of defining the problem and identifying the customer's needs. Common statistical tools used in this phase are causality plots and Pareto diagrams. Two statistical tools are used to identify problems and determine the priority of problems [15].

**Measure**

The Measure stage in the Six Sigma methodology, namely calculating the calculation of Defect per Million Opportunities (DPMO) and determining the sigma level.

*Defect per Unit (DPU)*

The DPU value is used to measure how much of a product does not meet quality standards. The formula used to calculate DPU is:

$$DPU = \frac{Number\ of\ Defect}{Total\ Production} \quad (1)$$

*Total Opportunities (TOP)*

TOP is the total number of opportunities at which defects can occur in a process or product, where to calculate TOP the following equation is used:

$$TOP = Total\ Production \times Chance\ per\ Unit \quad (2)$$

*Defect per Opportunities (DPO)*

The DPO value helps in evaluating the relative level of defects in a process or product. The lower the DPO value, the higher the quality level of the process or product.

$$DPO = \frac{Total\ Defect}{TOP} \quad (3)$$

*Defect per Million Opportunities (DPMO)*

DPMO is a metric used in six sigma to measure the level of defects in a process. The DPMO shows the average number of defects found per one million occasions.

$$DPMO = DPO \times 1.000.000 \quad (4)$$

*Sigma Level*

The calculation of sigma value conversion is carried out with the following equation:

$$Sigma\ Level\ (\sigma) = \phi^{-1}\left(\frac{1-DPMO}{1.000.000}\right) \quad (5)$$

Where is the value of $\phi^{-1}$ is a function of the inverse normal distribution.

After obtaining a sigma level value, then an evaluation of the quality of the process or product can be carried out. The higher the sigma value, the better the quality due to the lower level of defects.

**Analyze**

This stage uses a fishbone diagram also known as an Ishikawa diagram. This diagram is used to help in identifying and understanding the potential root cause of the problem.

**Improvement**

The improvement stage, using the Five M-Checklist tool can help to detail and analyze the improvement plan to be implemented. By using this method, it is hoped that it can answer key questions related to the changes to be implemented to ensure the sustainability of the improvements made.

*Five M-Checklist*

The second method used in the improvement stage is the Five M-Checklist which is used to understand and control the factors that affect quality in the production or management process. This method refers to five important elements, namely Man, Machine, Material, Method, and Measurement.

**Control**

The last stage in the research is to ensure that the improvements that have been implemented can be maintained sustainably. In this study, the control stage uses the 5S method in the Kaizen concept which includes Seiri (sort), Seiton (stabilize), Seiso (Shine), Seiketsu (standardize), and Shitsuke (self-discipline).

## 4 Result and Analysis

**Define**

Identification of Critical to Quality (CTQ) values is carried out by collecting the voice of customer and the company's existing specification standards. The determination of the CTQ value is carried out to identify the type of defects and non-conformities in the Nital Etch Inspection process. Figure 2 until Figure 6 shows some of the defective results obtained during observation.

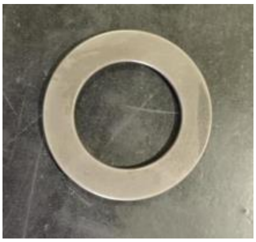

**Fig. 2.** Grinding Burn, a condition in which there are soft spots and light and dark areas that contrast with the background of the material.

**Fig. 3.** Local Softening of cylindrical components, where the color conditions are dark with a lighter background.

**Fig. 4.** Thin layers, shown with light zones against a darker background or vice versa.

**Fig. 5.** Less hardness, a condition where there are dark straight lines or dots.

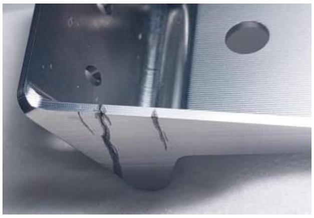

**Fig. 6.** Cracks, where there are dark serrated lines and sometimes burn conditions.

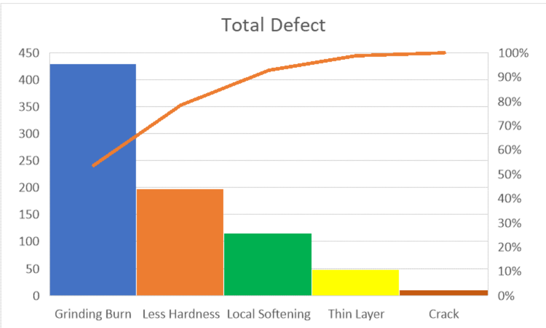


**Fig. 7.** Number of product defects per type defect

Figure 7 shows the number of product defects per type of defect. The type of defect with the largest percentage is grinding burn with a percentage of 52.63% followed by less hardness with a percentage of 24.75%. These two types of defects are a concern for improvement.

**Measure**

At this stage, measurements were made of two types of defects that were most dominant in the Nital etch inspection process, grinding burn and less hardness. The calculation results are shown in Table 1.

**Table 1.** Value of measurement

| Defect | DPU | TOP | DPO | DPMO | Sigma Level |
|---|---|---|---|---|---|
| Grinding burn | 0,082 | 26.055 | 0,016 | 16.465 | 3,63 |
| Less Hardness | 0,038 | | 0,01 | 7.599 | 4,01 |

Based on American company standards, the sigma value for the type of less severe defect is still at the average, while for grinding burn is below the average of American companies of 4.00. Based on these conditions, the stages of process improvement are focused on the type of grinding burn defect.

**Analyze**

This stage was carried out using a fishbone diagram to see the cause of the type of grinding burn defect in the Nital Etch Inspection process. This diagram is the result of discussions with production supervisors and quality engineers. The identification results are shown in Figure 8

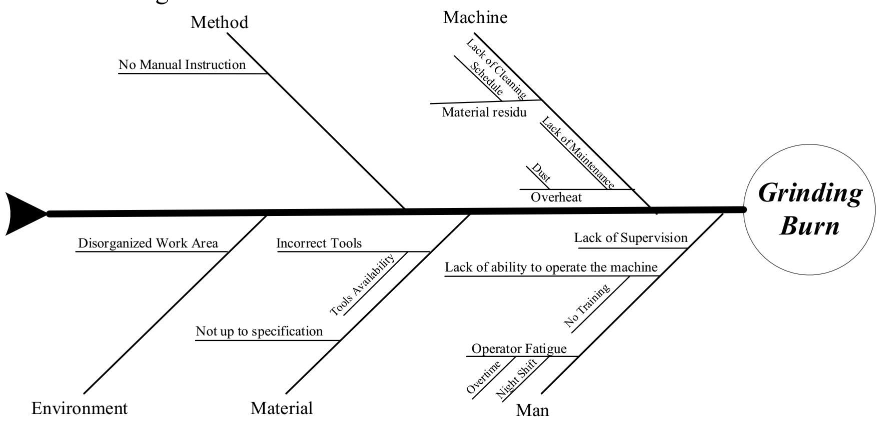


**Fig. 8.** Fishbone diagram identification of grinding burn defect

One of the main factors that cause grinding burn defects is the lack of supervision of grinding machines, so that many human errors occur. The operator's ability and knowledge in operating the machine also have an effect on causing defective products. Another factor is operator fatigue caused by night shifts and overtime hours.

**Improve**

The improvement stage of this research uses one of the Kaizen tools Five M-Checklist, where this tool focuses on the five key factors involved in each process, which Man, Machine, Material, Methods, and Environment. The results of the analysis with the Five M-Checklist are shown in Table 2.

**Table 2.** Five M-Checklist Analysis

| Factor | Problem | Improvement Plan |
|---|---|---|
| Man | Lack of supervision of operators | Providing supervision to operators to minimize errors |
| | Lack of operator ability in machine operation | Providing regular training, as well as conducting certification activities for operators on duty |
| | Operator Fatigue | Create a balanced work schedule, conduct regular health checks and design a more ergonomic workplace |
| Machine | Overheat | Make a schedule and ensure that maintenance activities are carried out regularly |
| | Material residu | Cleaning the duct regularly after the machine is used |
| Material | Not up to specification | The quality control process in the previous part for material selection |
| | Wrong use of tools | Create written work instructions for easy operator understanding |
| Method | No material instruction | Create detailed written work instructions |
| Environment | Disorganized work area | Applying the 5S concept to the work area |

Based on the Five M-checklist tools that have been made, several factors that often arise and cause defective products include operator negligence and lack of supervision of the running of the grinding machine. The operator fatigue factor is also a concern for companies to be able to reduce defective products in the Nital Etch Inspection process.

**Control**

The last stage in the research is control, where this stage uses another kaizen tool, namely 5S. This tool is used to increase efficiency and productivity by creating a clean, organized, and organized work environment. In manufacturing companies, the implementation of 5S can bring many benefits such as improved product quality, reduced waiting time, and improved work safety.

*Seiri (sort)*

Iri is the process of removing unnecessary items from the work area. This concept is carried out by identifying tools, materials and items that are not used to be then removed. Companies also need to create the necessary storage systems to make them easy to reach.

The impact of the lack of application of seiri is difficulty in finding the desired item or tool, thus causing a waste of time to search. The movement of workers also became limited because of the large number of items that were placed out of place. Lastly, it can lead to a decrease in the quality of the products produced.

*Seiton (Set in Order)*

The second concept used is seiton, this concept is the process of storing goods that are needed regularly so that they are easily accessible. Companies need to define a clear place for each tool and material. Use labels, shelves, and markings to ensure each item is easy to find and return to its place after use.

The impact of this concept is a waste of time to find the necessary tools and materials, increasing the likelihood of lost or damaged items. Some of the objects that need to be arranged are work equipment, raw materials, and documents.


**Fig. 9.** Implementation of name labels and periodic audit checklists

*Seiso (Shine)*

The concept of seiso is to clean the workplace regularly to maintain cleanliness. Regular scheduling is carried out to clean the machines, equipment, and work areas used. This concept also needs to involve all employees to maintain cleanliness and order in their respective work areas.

The impact of not implementing the Seiso concept includes that the work environment becomes uncomfortable, so it has the potential to reduce motivation and work productivity. Causing damage to work equipment that is not used and not cleaned regularly.

*Seiketsu (Standardize)*

The concept of seiketsu is carried out to implement standards and maintain the application of the previous 3S concept (Seiri, Seiton, and Seiso). Standard operating procedures need to be made for sorting, structuring, and cleaning activities. This concept also needs to ensure that all employees understand and follow the standards that have been set. Companies need to use checklists and audits regularly to ensure workers' compliance with the standards that have been made.

*Shitsuke (Sustain)*

The last stage in control is Shitsuke, which is maintaining and reinforcing good habits that have been formed beforehand. Companies need to conduct continuous training and socialization on the importance of implementing the 5S concept. Companies need to give awards and recognition to employees who comply with and implement the 5S concept well. The company also needs to conduct periodic evaluations and adjustments to ensure the sustainability of the 5S program.

## 5 Conclusion

Based on the results of the processing and analysis carried out, there are several conclusions obtained, including there are five types of defects in the NEI process, namely grinding burn, local softening of cylindrical components, thin layers, less hardness, and cracking. The type of defect that has the largest contribution is grinding burn with a DPMO value of 16,465 and a sigma value of 3.63. The biggest factor causing grinding burn defects is the human factor, namely operator negligence, lack of supervision and operator ability to operate the machine, and work fatigue.

Several improvement proposals have been implemented in the company from June 5, 2024 to June 28, 2024, including providing socialization to grinding operators, as well as creating a balanced work schedule to reduce physical fatigue. The implementation for approximately 2 weeks succeeded in reducing the product defect rate from the previous 17.28% to 7.02%. Even so, further research needs to be carried out to see how much influence the implementation of the results of this study has on the results of defect reduction.

## References

1. B. Karpuschewski, O. Bleicher and M. Beutner, "Surface Integrity Inspection on Gears Using Barkhausen Noise Analysis," Procedia Engineering, vol. 19, pp. 162-171, 2011.
2. H. Sirine and E. P. Kurniawati, "Pengendalian Kualitas Menggunakan Metode Six Sigma (Studi Kasus pada PT Diras Concept Sukoharjo)," Asian journal of Innovation and Entrepreneurship (AJIE), vol. 02, no. 03, pp. 254-290, 2017.
3. S. Kumar and D. Mahto, "Recent Trends in Industrial and Other Engineering APplications of Non Destructive Testing: A Review," International Journal of Scientific & Engineering Research, vol. 4, no. 9, pp. 183-195, 2013.
4. A. Kroworz and A. Katunin, "Non-Destructive Testing of Structures Using Optical and Other Methods: a Review," Structural Durability & Health Monitoring, vol. 12, no. 1, pp. 1-18, 2018.
5. J. P. Nissen and E. Hohman, "Automated Nital Etch Inspection System". 24 January 2014.
6. Supriyati and Hasbulah, "Analisis Cacat Painting Komponen Automotive dengan Pendekatan DMAIC-FMEA," Operations Excellence: Journal of Applied Industrial Engineering, vol. 12, no. 1, pp. 104-116, 2020.
7. M. E. D. M. d. Reis, M. F. d. Abreu, O. d. O. B. Neto, L. E. V. Viera, L. F. Torres and R. D. Calado, "DMAIC in Improving Patient Care Process: Challenges and Facilitators in Context of Healthcare," IFAC-PapersOnLine, vol. 55, no. 10, pp. 215-220, 2022.
8. S. V. Patil, B. R. K. and G. Nayak, "Quality Improvement of Recycled Aggregate Concrete using Six Sigma DMAIC Methodology," International Journal of Mathematical, Engineering and Management Science, vol. 5, no. 6, pp. 1409-1419, 2020.
9. M. Ülen and M. Gülmez, "Six Sigma Approach to Improve Service Quality and a Practice Study in Hospitality Sector," Business and Management Studies: An International Journal, vol. 8, no. 3, pp. 3150-3182, 2020.
10. [K. Mohinuddin, V. Vivekanand and C. Jayakumar, "Literature Review on the Usage of Six Sigma technique for Improvement of Quality in Soft Drink Beverage and Bottling Industries," in IOP Conference Series: Materials Science and Engineering, 2021.

11. K. B. N. R. Mohamed, P. R. M., S. P. S., J. R. A. and R. Anderson, "Six Sigma in Health-Care Service: a Case Study on COVID 19 Patient's Satisfaction," International Journal of Lean Six Sigma, vol. 12, no. 4, pp. 744-761, 2021.
12. A. Noronha, S. Bhat, E. V. Gijo, J. Antony, A. Laureani and C. Laux, "Performance and Service Quality Enhancement in a Healthcare Setting through Lean Six Sigma Strategy," International Journal of Quality & Reability Management, vol. 40, no. 2, pp. 365-390, 2021.
13. S. Khrisnan, K. Mathiyazhagan and V. R. Sreedharan, "Developing a Hybrid Approach for Lean Six Sigma Project Management: A Case Application in the Reamer Manufacturing Industry," IEEE Transaction on Engineering Management, vol. 69, no. 6, pp. 2897-2914, 2022.
14. I. Vanany, K. H. Tan, N. Siswanto, N. I. Arvitrida and F. M. Pahwalan, "Halal Six Sigma Framework for Defects Reduction," Journal of Islamic Marketing, vol. 12, no. 4, pp. 776-793, 2020.
15. R. Firmansyah and P. Yuliarty, "Implementasi Metode DMAIC pada Pengendalian Kualitas Sole Plate di PT Kencana Gemilang," Jurnal PASTI: Penelitian dan Aplikasi Sistem dan Teknik Industri, vol. 14, no. 2, pp. 167-180, 2020.