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FMEA and Statistical Process Control in Identifying Cause of Black Dot Injection Pipe

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Abstrak

PT UII is a manufacturing company that produces spare parts for two-wheeled and four-wheeled vehicles. From 2023 to 2024, the peak of the problem occurred in the Pipe Injection product for Gasoline Direct Injection (GDI) products, namely the Black Dot problem. This problem has been reported to the parent company, PT UII JPN, and it has been decided that this problem is a challenge for the PT UII group that cannot be completely eliminated by 2024. This problem has caused significant losses for PT UII. Black Dot on the end forming part of the pipe is caused by contamination during the annealing process on the end forming part, where the end forming part is treated to achieve a certain level of softness through a heating process. The Black Dot problem is the problem that causes the most losses for PT UII. Based on observations from 2024 to January 2025, improvements are needed using fishbone diagram analysis and FMEA evaluation of the annealing process. The fishbone diagram is a method used to identify the factors causing the black dot problem, and FMEA is a system designed to maintain control over the production process, aiming to determine the highest risk level for problems occurring in the production process and prepare corrective actions for each process.

Keywords: Failure: Defect, Failure Mode and Effect Analysis (FMEA), Fishbone Diagram, End Forming Pipe.

1. Introduction

The automotive industry is one of the key sectors supporting Indonesia's economy. This sector not only contributes significantly to the growth of the manufacturing industry, but also creates many jobs and has a significant impact on state revenue. However, in recent years, the national automotive industry has faced considerable challenges due to unstable global economic conditions, exchange rate fluctuations, and declining consumer purchasing power.

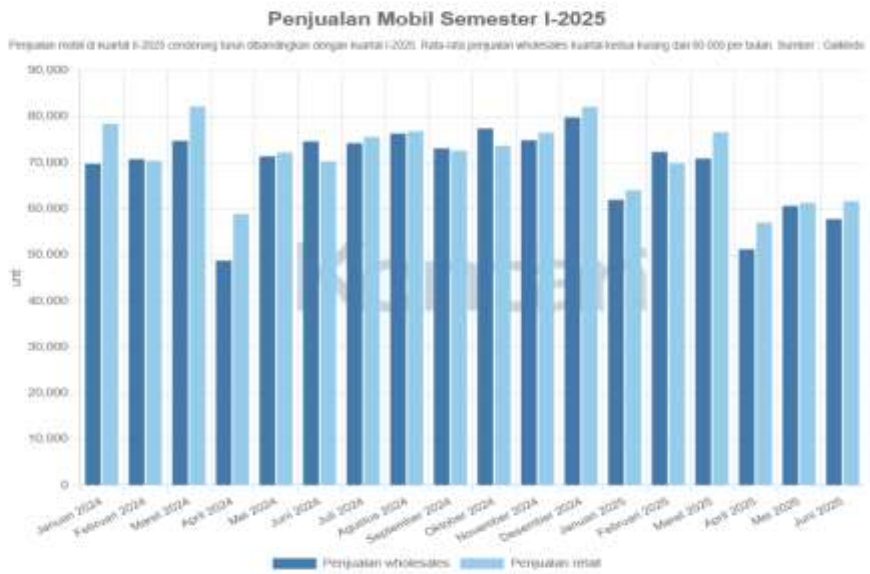

Figure 1. GAIKINDO car sales data for the first half of 2025.
https://pusatdata.kontan.co.id/infografik/132/Penjualan-Mobil-Semester-I-2025.

Based on data from the Indonesian Motor Vehicle Industry Association (GAIKINDO), in June 2025 there was a decline in vehicle distribution from manufacturers to dealers (wholesales) compared to the same period in 2024 [1].

Customer satisfaction is an important aspect that must be maintained by a company in order for it to survive in today's competitive manufacturing world[2]. Considering the nature of causal factors, FMEA provides more causal factors related to organization and technology. This study shows the importance of identifying all identifiable causes using the FMEA method[3]. Failure Mode and Effects Analysis (FMEA) is a systematic approach to identifying and analyzing potential failures and their effects in a system or process. However, experts in the field are needed to manually analyze the FMEA model in order to determine the risk reduction measures that must be implemented [4].

Failures that occur can be identified to prioritize control measures, so that improvements can be made appropriately and the right prevention methods can be prepared [5]. Targeting identified risks will enable integration into the continuous improvement process[6]. FMEA has proven to be effective in identifying potential problems and determining the best quality management (QM) measures to implement in the process [7].

FMEA has proven to be a valuable strategy for mitigating risk. However, success depends on addressing identified limitations and ensuring the implementation and maintenance of comprehensive corrective actions [8]. The method proposed in this study uses the FMEA method for the proposed improvement stage, explicitly applying the Failure Mode and Effects Analysis (FMEA) model to improve the effectiveness of prevention and control. FMEA analysis results in the development of targeted strategies for key prevention and control links [9].

However, the FMEA method has many shortcomings that pose challenges in practical application. Systematic updates and reviews are needed to maximize its effectiveness [10]. To improve upon conventional FMEA, this contribution proposes supplementing FMEA implementation with an individual multi-criteria compensation method that enables participatory action planning to improve management [11].

2. Methods

This research employed a quantitative descriptive case study conducted at PT UII. Data were collected through direct observation, interviews with quality, engineering, and production personnel, and analysis of internal defect records from 2024 to early 2025. Fishbone diagrams were used to identify root causes based on Man, Machine, and Method factors. FMEA was then applied by evaluating Severity (S), Occurrence (O), and Detection (D) to calculate the Risk Priority Number (RPN). During the defect search stage, quality control tools such as Pareto charts and fishbone diagrams are used, along with the Failure Mode Effect Analysis (FMEA) method to obtain the highest Risk Priority Number (RPN) value, which becomes the priority in the improvement proposal [12].

However, the study also emphasizes the importance of further evaluation of severity factors and the need to integrate cost-benefit analysis for more optimal implementation of mitigation measures [13]. Data was collected through field observations and interviews regarding risk. (RPN) highest, the three parameters are considered to have the same weight of influence on the level of risk, whereas in practice this is not always the case [14]. RPN provides a more objective and proportional approach by considering the weight factor of each parameter, so that the risk calculation results better reflect actual conditions in the field [15].

In general, the RPN value can be calculated using the following equation:

$$\mathbf{RPN = S \times O \times D}$$

S = Severity (the severity of the impact of failure)

O = Occurrence (the likelihood of failure occurring)

D = Detection (the ability of the system to detect failure)

wS, wO, wD = the weight of each parameter, which totals 1. The values for occurrence, severity, and detectability are averaged across all respondents and then multiplied to form a combined Risk Priority Number (RPN) for

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analysis [16]. A product defect is a condition in which a product does not meet the quality standards or specifications set by the company or customer. Product defects can occur due to errors in the production process, raw materials, equipment, work methods, or human factors (human error) [17].

The purpose of this study is to design and implement an efficient and reliable process in order to reduce waste [18]. This fishbone diagram helps teams understand the relationship between causes and effects, and makes it easier to find the root cause of the problem. The main purpose of creating a Fishbone Diagram is to find the root cause of a problem in a systematic and structured manner [19].

Table 1. Severity

Evaluation of General Process Severity Criteria (S)				
The potential impact of failure is assessed according to the following criteria				
S	Effect	Impact on the Plant	Impact on Delivery to Plant (As Known)	Impact on the End User (When known)
10	Very High	Failure may result in acute health and/or safety risks to factory or assembly workers.	Failure may result in acute health and/or safety risks to factory or assembly workers.	Affecting the safe operation of the vehicle and/or other vehicles, the health of the driver or passengers or road users or pedestrians.
9		Failure can lead to non-compliance with regulations in factories.	Failure can lead to non-compliance with regulations in factories.	Non-compliance with regulations.
8	High	100% of production affected to the point of having to be scrapped. Failure could result in regulatory non-compliance at the factory or possibly pose chronic health and/or safety risks to manufacturing or assembly workers.	Shutdown of a line larger than a full production shift: shipment halted: repair or replacement request required (Assembly to End User) in addition to regulatory non-compliance. Failure may result in regulatory non-compliance at the factory or may pose chronic health and/or safety risks to manufacturing or assembly workers.	Loss of the vehicle's main functions necessary for normal driving during its expected service life.
7		Products may need to be sorted and partially (less than 100%) scrapped, deviation from the primary process: reduction in speed line or addition of labor.	Line shutdown for more than 1 hour to a full production shift: delivery halted: field repair or replacement required (Assembly to End User) in addition to non-compliance with regulations.	Degradation of the primary functions of the vehicle necessary for normal driving during its expected service life.
6	Middle	100% of the production process may have to be redone and accepted.	Line shutdown for up to one hour.	loss of vehicle secondary functions.
5		Part of the production process may need to be redone and accepted.	Less than 100% of products affected: defective products likely to increase: sorting required: no line shutdown.	Degradation of secondary vehicle functions.
4		100% of the production process may have to be redone at the station before processing.	Defective products trigger a significant reaction plan: defective products cannot increase: sorting is not necessary.	Appearance, sound, vibration, harshness, or haptics (touch) that are very unpleasant.
3	Low	Part of the production process may need to be redone at the station before processing.	Defective products trigger a minor reaction plan: defective products cannot increase: sorting is not necessary.	Unpleasant appearance, sound, vibration, hardness, or haptics (touch).

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Evaluation of General Process Severity Criteria (S)				
The potential impact of failure is assessed according to the following criteria				
S	Effect	Impact on the Plant	Impact on Delivery to Plant (As Known)	Impact on the End User (When known)
2		Discomfort for the process, operation, or operator.	Defective products do not trigger a reaction plan; defective products cannot increase; sorting is not necessary; provide feedback to suppliers.	Appearance, sound, vibration, hardness, or haptics (touch) that are slightly unpleasant
1	Very Low	No visible effects	No visible effect or no effect	No visible effects

(Source: VDA FMEA)

Table 2. Occurrence

Occurrence Potential (O) for the Process			
O	Prediction of Occurrence Causes Failures	Types of Control	Prevention Control
10	Very High	None	No Control.
9	Very High	Behavior	Preventive controls have little impact on preventing the causes of failure.
8			
7	High	Behavior or Technical	Preventive controls are quite effective in preventing the causes of failure.
6			
5	Middle		Preventive controls are effective in preventing causes of failure.
4			
3	Low	Best Practice: Behavioral or Technical	More effective preventive controls to prevent causes of failure.
2	Very Low		
1	Very Low (*Extreme*)	Technical	Preventive controls are highly effective in preventing causes of failure due to design (e.g., part geometry) or process (e.g., fixture or tooling design). Production cannot proceed if there are causes of failure.

(Source: VDA FMEA)

Table 3. Detection

Detection Potential (D) for Process Design Validation			
D	Ability to detect	Detection method capabilities	Opportunities for Detection
10	Very Low	There are no established or known testing or inspection methods.	The failure mode will not or cannot be detected.
9		It is not possible that testing or inspection methods will detect failure modes.	Failure modes are not easily detected through sporadic audits.
8	Low	Testing or inspection methods have not been proven to be effective and reliable (e.g., the factory has little or no experience with the method, marginal R&R results are measured in comparable processes or applications, etc.).	Human inspection (visual, tactile, audible), or manual measurement (attributes or variables) that must detect failure modes or failure causes.
7			Machine-based detection (automatic or semi-automatic with notifications via lights, bells, etc.), or the use of inspection

Detection Potential (D) for Process Design Validation			
D	Ability to detect	Detection method capabilities	Opportunities for Detection
			equipment such as coordinate measuring machines that should detect failure modes or failure causes.
6	Middle	Testing or inspection methods have been proven to be effective and reliable (e.g., the factory has experience with the methods, R&R measurement results are acceptable at with a processor comparable to this application, etc.)	Human inspection (visual, tactile, audible), or the use of manual measurements (attributes or variables) that will detect failure modes or failure causes (including product sample inspection).
5			Machine-based detection (semi-automatic with notifications via lights, bells, etc.), or the use of inspection equipment such as coordinate measuring machines that will detect failure modes or failure causes (including product sample inspections).
4	High	The system has been proven to be effective and reliable (e.g., the factory has experience with the method in identical processes or applications), the R&R measurement results are acceptable, etc.	An automatic machine-based detection method that will detect failure modes in the downstream section, preventing further processing, or the system will identify non-compliant products and allow them to automatically move forward in the process until the designated area rejects them. Discrepant products will be controlled by a sound system that will prevent them from leaving the facility.
3			An automated machine-based detection method that will detect failure modes at the station, prevent further processing, or the system will identify non-compliant products and allow them to move forward automatically in the process until the designated area rejects unloading. Discrepant products will be controlled by a robust system that will prevent products from leaving the facility.
2		Detection methods have been proven to be effective and reliable (e.g., the factory has experience with the methods, error verification, etc.	Machine-based detection methods that will detect causes and prevent failure modes (discrepant parts) from being produced.
1	Very High	The failure mode cannot be physically produced as designed or processed, or the detection method has been proven to always detect the failure mode or failure cause.	

(Source: VDA FMEA)

3. Findings and discussion

3.1. In process Defect PT UII

The production process is inevitably accompanied by problems, such as a high number of non-conforming parts (NG), resulting in an excessively high NG ratio. This hinders the company's performance, with KPIs not being achieved each month. The excessive number of NG parts will certainly increase losses for PT UII.

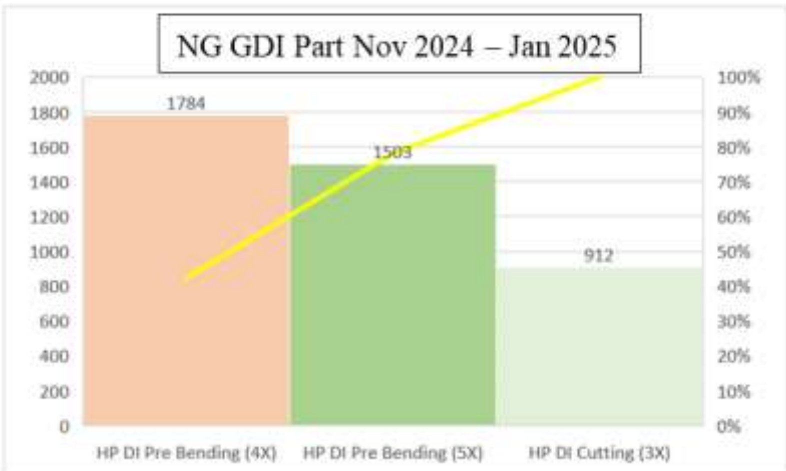

Figure 2. Defect in process GDI PT UII
(Source: Defect in process PT UII, 2025).

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Figure 3. NG black dot part GDI PT UII
(Source: NG In process PT UII,2025).

Based on the data in the table above, the NG that caused the greatest loss to the company was NG Black Dot, reaching IDR 116,900,000 from November 2024 to January 2025. Of course, this must be corrected immediately before the NG causes more losses.

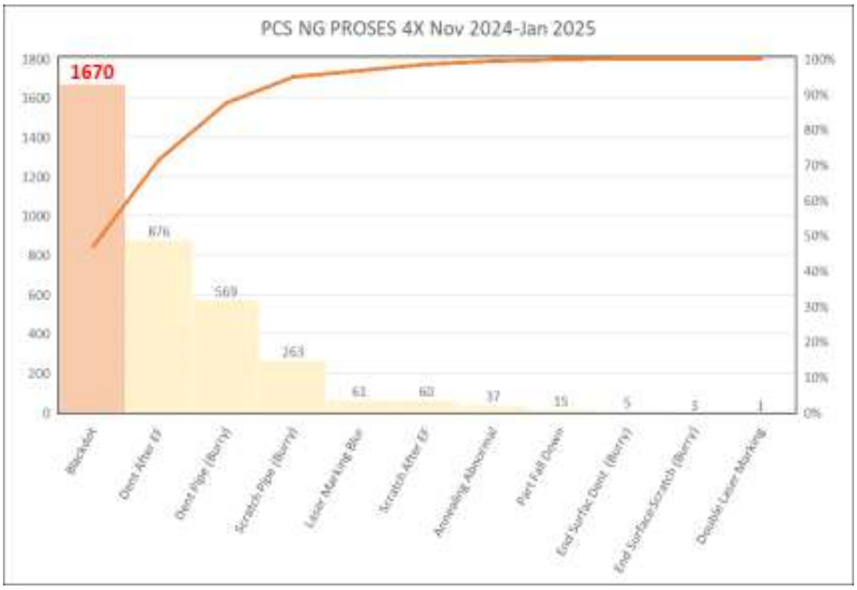

Figure 4. Pareto deffect in process GDI PT UII.

Based on the image above, PT UII is experiencing process problems that are causing significant losses due to the large number of defective products, particularly in high-pressure GDI pipes. The highest number of defective products is Black Dot, with data from November 2024 to January 2025 showing 1,670 defective black dot products. Given the substantial quantity, PT UII has formed a special team comprising members from several departments: Quality, Engineering, and Production. The team's objective is to reduce or even eliminate these defects.

3.2 FMEA Analysis

Identify problems by analyzing issues that occur in the relevant process, namely the End Forming Anneling process, using process flow analysis. By analyzing the process flow, it will be clear where the problems occur, so that the analysis can be more targeted and focused on the problematic process, without the need to analyze the entire process.

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Flow Process: GDI pipe.

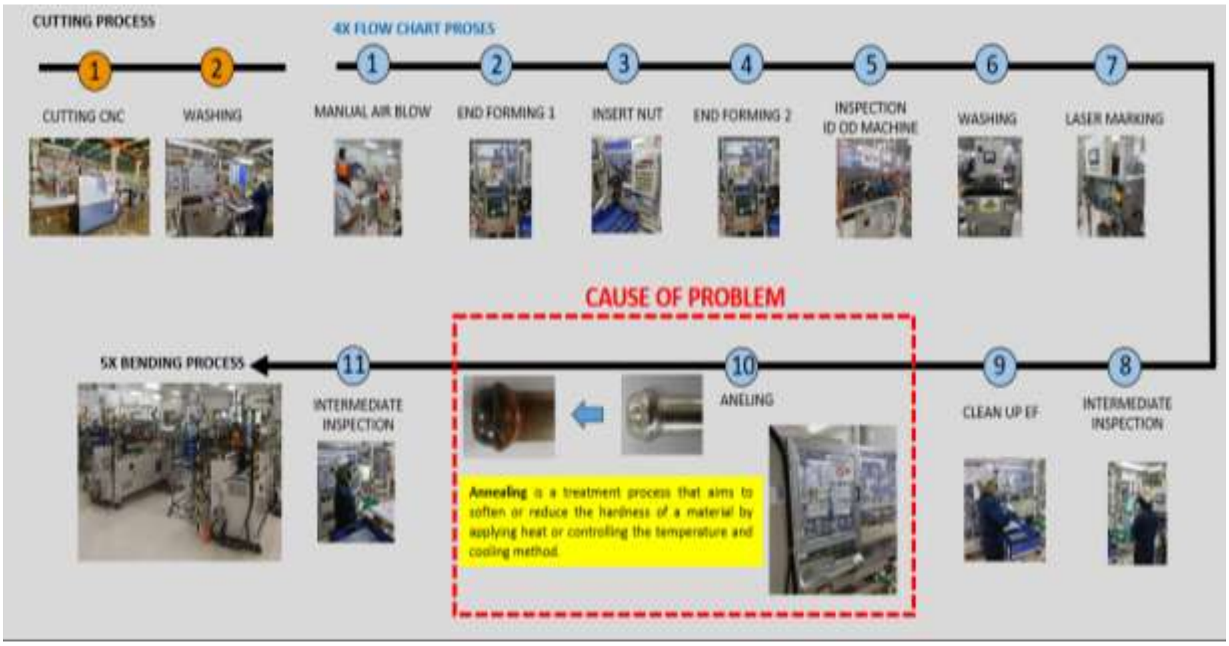

Figure 5. Flow process analize black dot problem GDI PT UII.

Based on the flow process above and the results of the analysis using a fishbone diagram, calculations and re-evaluations were carried out regarding the RPN value in the anneling process. The following are the results of the RPN value calculations for the product anneling process.

Calculate the RPN value using the formula: **RPN = R x P x N**

Tabel 4. Summary priority base on RPN result line GDI.

Process	Potential Failure Mode	Potential Cause(s) of Failure	RPN
Anneling process	Black Dot	Contamination	240
Inspection after anneling	Black Dot	Improve, forming operation and contamination	160
Inspection before anneling	Black Dot	Improve, Forming Operation	160

(Source: VDA FMEA) FMEA GDI Pipe PT UII,2024).

The data above shows three processes with the highest RPN values. At PT UII, the RPN value that will be recommended for improvement is greater than 120. This value must be improved immediately to reduce the RPN value by adding recommended actions to each of the above processes.

3.3 Analysis problems with fishbone diagram

Fishbone diagram, used to analyze the causes of problems, is generally grouped into specific categories. With a fishbone diagram, the causes of the black dot problem are analyzed. The PT UII team held an internal meeting to determine the root cause of the black dot problem that occurred in the anneling process, which caused black dots on the end forming of GDI pipes.

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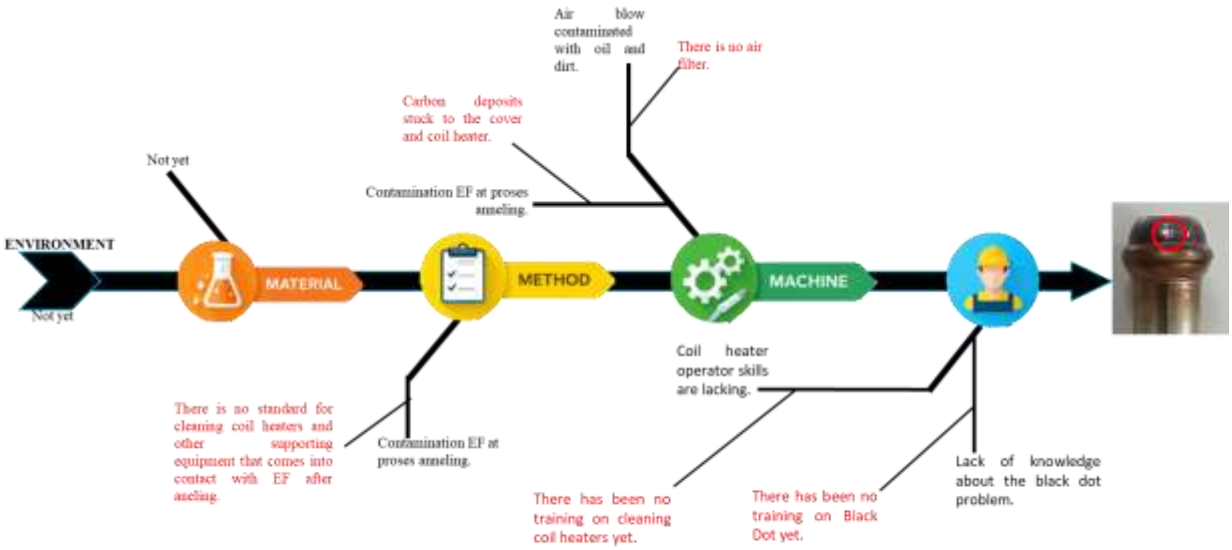

Figure 6. Diagram fishbone analysis black dot PT UII.
(Source: Report on corrective actions for black dot problems at PT UII, 2025).

PT UII uses a Keyence VHX7000 microscope to analyze the composition or content of black dots.

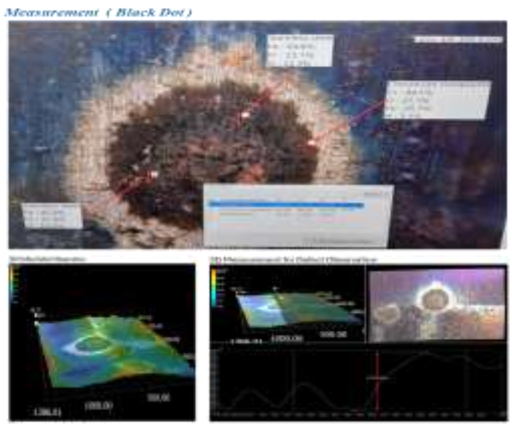

Figure 7. Problem black dot GDI pipe PT UII
((Source: Report on corrective actions for black dot problems at PT UII, 2025).

From the analysis results using the VHX7000 microscope, Black Dot contains 44.1% carbon, which adheres to the end forming pipe GDI during the combustion or annealing process.

Based on the fishbone diagram above, it can be seen that there are several factors causing the black dot problem during the anneling process, which is influenced by three main factors, namely:

Man: Lack of knowledge about the black dot problem, in terms of its causes and effects on vehicle functionality when the problematic product is used. Improvements made: Training on the black dot problem and training on the ideal coil heater cleaning method.

Method: There is no routine cleaning process for the machine, especially for the coil and coil heater cover, so that residue or carbon from combustion accumulates on the coil heater cover where the coil and cover are attached to each other. The post-annealing inspection process, which relies solely on visual inspection without any tools before and after the annealing process, has a high potential for problems in the outflow to the next process and even to customers. Improvements made: Additional cleaning of the coil heater at the beginning of the shift. Cleaning using a nylon brush and then wiping with a microdinner. During the inspection process, a magnifying glass with 4X magnification was added to the inspection area.

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Machine: The design of the coil heater cover that sticks to the coil causes the coil cover to burn and produce a buildup of combustion residue on the coil heater cover, which contaminates the pipe and causes black dot problems. The problem with the cooling or air blow process is that there is no filter on the air blow, so the air that is blown out contains oil dirt and corrosion from the air pipes in the machine. Repairs made: Modification of the coil heater cover so that the cover does not burn during the anneling process, as well as the addition of a filter and changing the air path to pass through the air filter before being blown out as a coolant in the end forming pipe area after anneling.

By using “why” analysis, it can be determined that a design error in the cover coil heater is the most likely cause of the black dot problem occurring in the anneling process.

a. Why does the black dot problem occur?
   Contamination from carbon residue occurs in the end forming section after anneling.

b. Why does contamination occur in the end forming pipe?
   The burnt cover coil heater produces carbon deposits on the cover coil heater.

c. Why did the cover coil heater burn?
   Because the cover coil heater was designed to be attached to the coil heater, making it easy to burn.

d. Why was the cover coil heater designed to be attached to the coil heater?
   The design was created by the mother company, and the annealing process was a new process.

3.4 Improvement

a. Man

Refresh training related to black dot problems, as well as the potential for black dots when sent to customers, will cause leaks and refresh training on the correct way to clean coil heaters. This refresh training will be carried out continuously with the aim of all operators involved in the production process understand the causes of black dots and how to handle them so that fewer black dots are produced.

b. Machine

1. Change in air blow path

This change in the air spray path was carried out by adding an air filter and new air hose. The air sprayed into the end forming area was previously filtered so that the air released did not contain impurities that would cause contamination during the anneling process in the end forming section, which would cause black dot problems in GDI end forming.

Flow instalization air blow with filter.

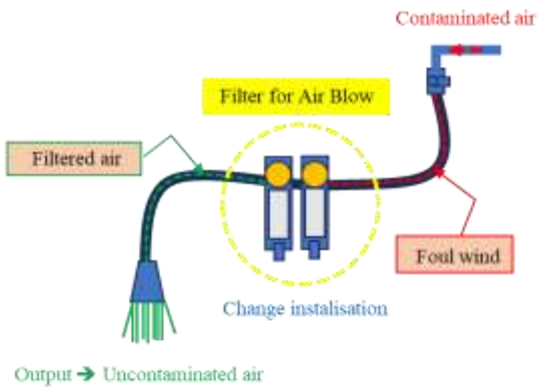

Figure 8. Scheme for changing the air blow machine anneling GDI route at PT UII.
(Source: Report on corrective actions for black dot problems at PT UII, 2025).

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2. Changes to the coil heater cover design

The design of the coil cover was changed so that during the combustion process in the coil heater anneling process, it does not touch the coil heater cover, thereby preventing carbon residue and contamination from occurring during the anneling process. Change Design coil heater cover.

Change design cover coil heater anneling.

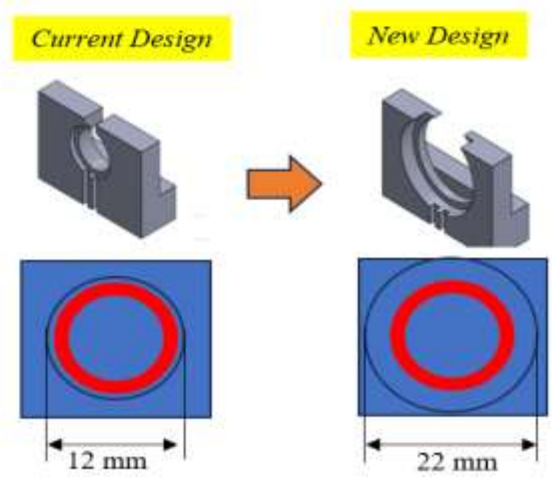

Figure 9. Changes to the design of the coil heater machine cover for PT UII's anneling GDI.
(Source: Report on corrective actions for black dot problems at PT UII, 2025).

c. Methode

Cleaning of the Coil Heater Cover and Upgrade of the Checking Method. This is done to clean carbon residue stuck to the coil heater, in order to reduce contamination during the annealing process. The inspection process has been upgraded from simply using the naked eye to using a magnifying glass so that black dots can be clearly seen with up to 4x magnification. This is done so that manpower inspection does not easily cause fatigue during the inspection process, because NG black dots are very small, so a magnifying glass with the right magnification is needed.

Figure 10. Magnifying glass PT UII.
(Source: Report on corrective actions for black dot problems at PT UII, 2025).

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Table 5. Recaculation RPN process End Forming line GDI after Improvement.

Process	Potential Failure Mode	Potential Cause(s) of Failure	RPN
Anneling process	Black dot	Contamination	112
Inspection after anneling	Black dot	Improve, forming operation and contamination	96
Inspection before anneling	Black dot	Improve, forming Operation	96

(Source: FMEA update after improvement PT UII, 2025).

Based on the above data, there was a decrease in the RPN value in the annealing process to 112 RPN, Inspection Before Annealing 96 RPN and Inspection After Annealing 96 RPN, so that the RPN value was in accordance with the internal standard determined by PT UII, which is below or less than 120 RPN. This indicates that the improvements made have reduced NG black dots and improved detection in the GDI product anneling process.

4. Conclusion

Failure Mode and Effect Analysis (FMEA) is an effective method for identifying, assessing, and managing risks in a system or production process, so that it can be used to improve quality and efficiency in the production process. Based on the analysis conducted in this report, it can be concluded that: Based on the fishbone diagram, it is known that NG black dot is caused by contamination during the anneling process. This contamination originates from the burnt coil heater cover, which produces carbon that sticks to the end forming, causing Black Dot on the end forming. This is reinforced by the results of analysis using a microscope, which shows that 44.1% of the black dot composition is carbon residue from the burnt coil heater cover. **Man:** Lack of knowledge regarding NG black dot. **Method:** The method of cleaning the coil heater cover is not optimal or tends to differ for each operator. **Machine:** The air blow used to cool the end forming does not use an air filter, so the air that is expelled contains dirt or contamination that causes black dots. The design of the coil heater cover is easily burned by the coil heater because the cover is designed to be attached to the coil heater. Based on the above explanation, "How can the Failure Mode and Effects Analysis method reduce the quantity of defective products in the production process? The FMEA method only systematically identifies potential failures from the beginning of the production process by conducting analyses related to failure modes, causes of failure, and the impact of those failures. Companies can assess the level of risk priority based on the Risk Priority Number value multiplied by the severity, occurrence, and detection of each factor. That way, companies can focus corrective actions on the causes of failure that have the highest level of risk. These corrective and preventive actions include improving work procedures and increasing quality control. PT UII management's target for reducing NG Black Dot is 30% of the actual data in the NG Black Dot monitoring table for the period February 2025 to December 2025, which shows a decrease from 0.37% to 0.04% or a decrease of 82%, exceeding the target set by PT UII management.

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