



Analysis of Defect in Safety Valves During the Leak Test Inspection Process

Final Project

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Approval sheet

The Final Project is structured to fulfill one of the requirements for obtaining a degree

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Abstract

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Keywords: Safety Valve, Leak Test Machine, Fishbone Diagram, FMEA, Quality Control.

Foreword

This section contains the author's introduction and acknowledgments to individuals and institutions that support this thesis.

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Analysis of Defects in Safety Valves During the Leak Test Inspection Process

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Abstract

Safety valves are important components in coffee machines that function to prevent excessive pressure by automatically releasing overpressure conditions. This study aims to analyze the causes of failures during the Safety Valve Leak Test Inspection Process and identify factors affecting inspection reliability. The research was conducted using direct observation, Fishbone Diagram analysis, and Failure Mode and Effect Analysis (FMEA). The investigation results showed that leak test failures originated from both actual Safety Valve defects and inspection-equipment-related problems. Several Safety Valve units exhibited sealing defects; however, the dominant cause of failure was leakage in the pneumatic tube of the Leak Test Machine. The damaged tube caused pressure instability during testing and generated false reject decisions. Fishbone Diagram analysis identified torn pneumatic tubing as the primary root cause, while FMEA indicated the highest Risk Priority Number (RPN) of 384. Corrective actions, including pneumatic tube replacement, preventive maintenance, and routine inspections, were implemented. Following these improvements, the defect rate decreased from 60% to 20%, while the highest RPN value was reduced from 384 to 96. The results demonstrate that Fishbone Diagram and FMEA are effective methods for identifying root causes, prioritizing corrective actions, and improving the reliability of the leak test inspection process.

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I. INTRODUCTION

The manufacturing industry continuously demands high product quality and operational reliability to ensure safety, efficiency, and customer satisfaction. Quality control processes play a critical role in identifying defects before products reach end users. In pressure-based systems, Safety Valves are among the most important protective components because they prevent excessive pressure accumulation that may lead to equipment damage, operational failure, or safety hazards [1]. Consequently, the performance and reliability of Safety Valves must be verified through rigorous inspection and testing procedures before deployment in industrial applications.

Safety Valves are widely utilized in various industries, including power generation, petrochemical processing, manufacturing systems, and household appliances such as coffee machines. Their primary function is to release excess pressure automatically when system pressure exceeds a predetermined limit. Failure of a Safety Valve can result in leakage, improper opening pressure, delayed response, or complete malfunction, potentially causing severe operational and economic consequences [2]. Recent studies have

emphasized that internal leakage remains one of the most common and critical failure modes in Safety Valves because it directly affects sealing performance and system reliability [3]. Furthermore, leakage defects may develop progressively due to material degradation, improper assembly, wear, corrosion, or manufacturing inconsistencies, making early detection essential for maintaining operational safety.

To ensure valve integrity, manufacturers commonly employ Leak Test Machines as part of the quality assurance process. Leak testing is a non-destructive inspection method used to determine whether a component can maintain pressure within specified limits. The method works by introducing compressed air into a sealed component and monitoring pressure changes over a predetermined holding period. Significant pressure reduction indicates potential leakage or structural defects within the tested component. Hu [4] demonstrated that automated Safety Valve testing systems provide highly accurate pressure measurements and improve consistency compared with conventional manual inspection methods. Therefore, leak testing has become one of the most effective approaches for evaluating the performance and reliability of pressure-sensitive components.

Although the Leak Test Inspection Process is designed to

identify defective Safety Valves, failures observed during inspection do not always originate from the product itself. In manufacturing environments, products that fail the leak test are generally assumed to contain defects in the Safety Valve. However, inspection results may also be influenced by the condition of the Leak Test Machine, including pneumatic leakage, unstable air pressure, or other equipment-related problems that can affect pressure stability during testing. These conditions may produce false reject decisions, causing products that actually meet quality requirements to be classified as defective. Therefore, investigation of leak test failures should consider both product-related defects and inspection-equipment-related factors.

Previous research by Kuchekar et al. [5] highlighted that failures in pressure relief valves are frequently associated with component mismatch, manufacturing defects, wear mechanisms, and assembly-related errors. Their findings demonstrated the importance of systematic failure analysis methods in identifying critical risk factors and improving product quality.

Several studies have proposed advanced techniques for leak detection and fault diagnosis in Safety Valves. Hou et al. [6] developed an acoustic emission-based method for identifying leakage sources in Safety Valves, while Li et al. [7] applied convolutional neural networks to detect internal valve leakage automatically. Similarly, Zhang et al. [3] investigated the acoustic characteristics of internal leakage in Safety Valves and demonstrated the potential of leakage signal analysis for defect identification. Although these approaches provide high detection accuracy, they generally focus on leakage detection technologies rather than investigating whether failures originate from the inspection equipment during routine Leak Test Inspection Processes [8].

In quality engineering, root cause analysis tools such as Fishbone Diagram and Failure Mode and Effects Analysis (FMEA) are widely used to identify, evaluate, and prioritize potential failure mechanisms. Fishbone Diagram facilitates systematic identification of contributing factors across categories such as human, machine, material, method, and measurement. Meanwhile, FMEA enables quantitative risk assessment through Severity (S), Occurrence (O), and Detection (D) ratings, allowing organizations to prioritize corrective actions based on the calculated Risk Priority Number (RPN) [7]. These methods have been successfully applied in various industrial sectors to improve product reliability and reduce defect rates.

Although previous studies have extensively investigated Safety Valve leakage detection and valve failure mechanisms, limited attention has been given to failures originating from the Leak Test Inspection Process itself. During routine production, products that fail the Leak Test are often immediately classified as defective Safety Valves without further investigation of the inspection system. In practice, however, failures may originate from both the product and the inspection equipment. Therefore, this study provides a different perspective by investigating the contribution of both Safety Valve defects and Leak Test Machine conditions to failures occurring during the Leak Test

Inspection Process. The novelty of this research lies in identifying the dominant source of failure through a systematic investigation and integrating Fishbone Diagram with Failure Mode and Effects Analysis (FMEA) to determine root causes and prioritize corrective actions.

Based on these considerations, this study aims to investigate failures occurring during the Safety Valve Leak Test Inspection Process by determining whether the failures originate from actual Safety Valve defects or from the Leak Test Machine. The study focuses on identifying the dominant root causes using Fishbone Diagram analysis and evaluating the associated risks through Failure Mode and Effects Analysis (FMEA) [9]. The findings are expected to provide practical recommendations for improving inspection reliability, reducing false reject decisions, enhancing product quality, and strengthening operational safety in manufacturing environments.

II. METHOD

A. Overview

This study employed a simulation-based case study to investigate failures occurring during the Safety Valve Leak Test Inspection Process in coffee machine manufacturing. The research methodology consisted of five main stages: observation of the Leak Test Inspection Process, defect data collection, investigation of failed samples, root cause analysis, risk assessment, and evaluation of corrective actions. These stages were systematically designed to determine whether the failures originated from actual Safety Valve defects or from the Leak Test Machine.

The study began with direct observation of the Leak Test Inspection Process and collection of defect data from the final inspection line. Based on production records, Safety Valve Leak Test Failure was identified as the dominant defect category. To investigate the source of these failures, representative samples were selected for detailed analysis. Each sample was inspected through visual examination, pressure verification, and repeated leak testing. When inconsistencies were identified during product verification, the investigation was extended to the Leak Test Machine to evaluate its operating condition.



Figure 1. Leak Test Machine

Following the investigation, Fishbone Diagram analysis was performed to identify the dominant root causes of failure.

Failure Mode and Effects Analysis (FMEA) was subsequently applied to evaluate the associated risks by assigning Severity (S), Occurrence (O), and Detection (D) ratings. Finally, corrective actions were implemented and evaluated by comparing inspection results before and after improvement. This methodology follows quality improvement practices commonly applied in manufacturing industries for defect investigation and process optimization [2].

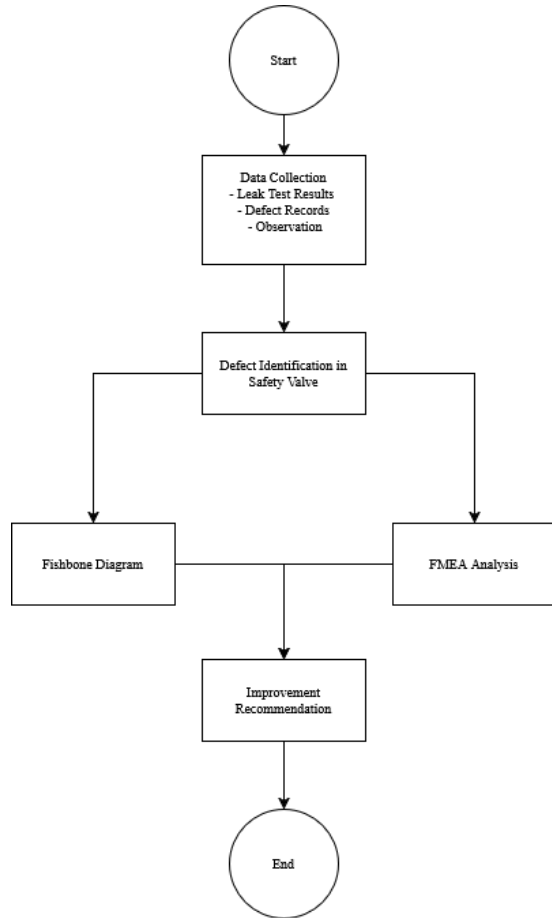


Figure 2. Research Flowchart

B. Data Collection

Data collection was conducted through direct observation of the Leak Test Inspection Process used during coffee machine production. The observation focused on product inspection activities, machine operating conditions, and defect records obtained from the final inspection process.

During the observation period, a total of 235 defective units were recorded during final inspection. Among these defects, 128 units were classified as Safety Valve Leak Test Failure, representing the dominant defect category. Since this research was conducted as a simulation-based study, twenty representative samples were selected from the Safety Valve Leak Test Failure category for detailed investigation. The selected samples were considered sufficient to represent the dominant failure condition observed during production.

Each selected sample underwent several inspection stages, including visual inspection of the Safety Valve, pressure

verification using a calibrated pressure gauge, and repeated Leak Test evaluation. The purpose of these inspections was to determine whether the observed failures originated from actual Safety Valve defects or from abnormalities occurring in the Leak Test Machine.



Figure 3 Safety Valve

The Leak Test Machine operates using pneumatic pressure testing principles, where compressed air is introduced into the Safety Valve and monitored for pressure stability during a predetermined holding period. A pressure reduction exceeding the specified limit indicates potential leakage or other abnormalities. The specifications of the Leak Test Machine used in this study are presented in Table 1

Table 1. Leak Test Machine Specifications

Parameter	Specification
Inflation Pressure	6.5 ± 0.5 psi
Holding Time	10 seconds
Allowable Pressure Reduction	< 0.05 psi
Safety Valve Opening Pressure	$22.5 \text{ psi} \pm 3 \text{ kPa}$
Maximum Pressure Reduction After Testing	1.25 psi

C. Root Cause Analysis Using Fishbone Diagram

After defect data and investigation results were obtained, root cause analysis was performed using the Fishbone Diagram (Ishikawa Diagram). This method was selected because it enables systematic identification of factors contributing to failures from multiple perspectives, including human, machine, material, method, and measurement [10].

The investigation initially focused on identifying possible defects in the Safety Valve components. However, when repeated pressure verification indicated that most Safety Valve samples satisfied the required specifications, further examination was conducted on the Leak Test Machine. The findings obtained from both product inspection and machine investigation were then organized into the Fishbone Diagram to determine the dominant root cause of failures observed during the Leak Test Inspection Process.

The analysis categorized potential causes into five major groups:

1. Human – operator errors during assembly and inspection.
2. Machine – improper machine calibration and maintenance.
3. Material – component defects and material inconsistencies.
4. Method – ineffective inspection procedures and work instructions.
5. Measurement – inaccurate pressure readings caused by sensor calibration issues.

The Fishbone Diagram provides a visual representation of the relationships between these factors and the occurrence of defects in safety valves during the leak test process.

D. Failure Mode and Effect Analysis (FMEA)

Following root cause identification, Failure Mode and Effect Analysis (FMEA) was conducted to evaluate potential failures and prioritize corrective actions.

The FMEA process includes:

1. Identifying potential failure modes.
2. Determining the effects of each failure.
3. Identifying possible causes of failure.
4. Assigning Severity (S), Occurrence (O), and Detection (D) scores.
5. Calculating the Risk Priority Number (RPN).
6. Developing corrective action recommendations.

The Risk Priority Number (RPN) is calculated using the following equation:

$$RPN = S \times O \times D$$

where:

1. Severity (S) represents the seriousness of the failure effect.
2. Occurrence (O) represents the frequency of failure occurrence.
3. Detection (D) represents the likelihood of detecting the failure before it reaches the customer.

Failure modes with higher RPN values were considered to have greater influence on inspection reliability and therefore required immediate corrective actions [7].

E. Evaluation and Improvement Analysis

The results obtained from the Fishbone Diagram and FMEA analyses were evaluated to determine the most critical factors affecting safety valve quality.

Failure modes with the highest RPN values were identified as priority areas for improvement. Recommended corrective actions include:

1. Enhancing operator training and inspection awareness.
2. Implementing periodic calibration schedules for Leak Test Machines.
3. Improving material quality verification procedures.
4. Updating inspection work instructions and standard operating procedures.
5. Performing regular validation of pressure measurement instruments.

The effectiveness of these recommendations was assessed

based on their potential to reduce defect occurrence and improve product reliability.

F. Comparative Risk Assessment

A comparative analysis was conducted to determine the relative contribution of each causal factor identified in the Fishbone Diagram. The comparison was based on the calculated RPN values from the FMEA analysis.

This stage provides insight into which factors have the greatest impact on safety valve failures and supports decision-making regarding quality improvement priorities. The findings are expected to assist manufacturing organizations in reducing defect rates, improving leak test effectiveness, and enhancing operational safety.

III. RESULT AND DISCUSSION

A. Defect Identification Results

The Leak Test Inspection Process is one of the most critical quality control stages in coffee machine manufacturing because it verifies the sealing performance and functional reliability of the Safety Valve before assembly into the final product. During the observation period, defect data from the final inspection process were collected to identify the dominant defect category requiring further investigation.

The final inspection records showed that a total of 235 defective units were identified during the observation period. The distribution of defects is presented in Table 3

Table 2 Final Inspection Defect Data

Defect Category	Quantity	Percentage (%)
Safety Valve Leak Test Failure	128	54.47
Torn Tube	48	20.43
Water Path Leak	39	16.60
CWT Port Leak	20	8.50
Total	235	100

Based on Table 2, Safety Valve Leak Test Failure was identified as the dominant defect category, contributing 54.47% of all recorded defects. Initially, all failed units were assumed to originate from defective Safety Valve components because they did not satisfy the required leak test criteria. Therefore, further investigation was conducted to verify whether the failures were caused by actual Safety Valve defects or by other factors affecting the inspection process.

B. Investigation Results

To investigate the dominant source of failure, 210 new Safety Valve samples were used for a detailed investigation involving visual inspection, pressure verification, and repeated leak testing. Each Safety Valve was first inspected visually to identify abnormalities such as sealing surface damage, spring

deformation, and assembly defects. Pressure verification was then conducted using a calibrated pressure gauge to confirm whether the Safety Valve maintained pressure within the specified operating range.



Figure 4 Pressure Verification Setup for Safety Valve Inspection

The investigation showed that most Safety Valve samples satisfied the required specifications and were able to maintain stable pressure during verification testing. Only a small number of samples exhibited actual defects, including minor sealing imperfections that could contribute to leakage.

Since the majority of Safety Valve samples performed normally during verification, the investigation was extended to the Leak Test Machine to determine whether inspection equipment contributed to the observed failures.

Visual examination of the Leak Test Machine identified damage in the pneumatic tube used during the pressure holding process.



Figure 5 Damaged Pneumatic Tube Identified During Investigation

The damaged pneumatic tube allowed compressed air to escape during testing, causing unstable pressure readings and generating false reject decisions. Consequently, products that

actually met the required specifications were incorrectly classified as failed during the Leak Test Inspection Process.

The investigation confirmed that failures originated from both product-related defects and inspection-equipment-related problems. However, the dominant contributor to the observed failures was leakage in the pneumatic tube, while actual Safety Valve defects were identified in only a limited number of samples.

Table 3 Investigation Results

Inspection Item	Finding
Safety Valve Condition	Mostly Normal, Several Defective Units Found
Spring Function	Normal
Valve Seat Condition	Minor Defects Detected in Several Samples
Pneumatic Tube Condition	Torn and leaking
Leak Test Result	Pressure Drop Detected

These findings indicate that the high number of Safety Valve Leak Test failures recorded during final inspection did not necessarily represent actual product defects. Instead, a considerable proportion of failures were associated with pressure instability caused by the damaged pneumatic tube of the Leak Test Machine.

C. Leak Test Results Before Improvement.

Following the investigation, the performance of the existing Leak Test Machine was evaluated using the 210 selected simulation samples before any corrective actions were implemented. The objective of this evaluation was to determine the actual performance of the inspection process under the existing machine condition and to verify whether the observed failures were consistent with the investigation results.

Each Safety Valve sample was tested using the standard operating parameters of the Leak Test Machine as presented in Table 1. The inspection results are summarized in Table 4

Table 4 Leak Test Results Before Improvement

Sample	Result
Pass	79
NG	132
Total	210

The defect rate before improvement was calculated as follows:

$$Defect Rate = \frac{79}{132} \times 100$$

$$Defect Rate = 62.86\%$$

D. Root Cause Analysis Using Fishbone Diagram

To identify the dominant factors contributing to failures during the Safety Valve Leak Test Inspection Process, a Fishbone Diagram (Ishikawa Diagram) was developed based on the investigation results and direct observations conducted throughout this study. The Fishbone Diagram was selected because it provides a systematic approach for identifying possible causes of failure from multiple perspectives, including Man, Machine, Material, and Method [10].

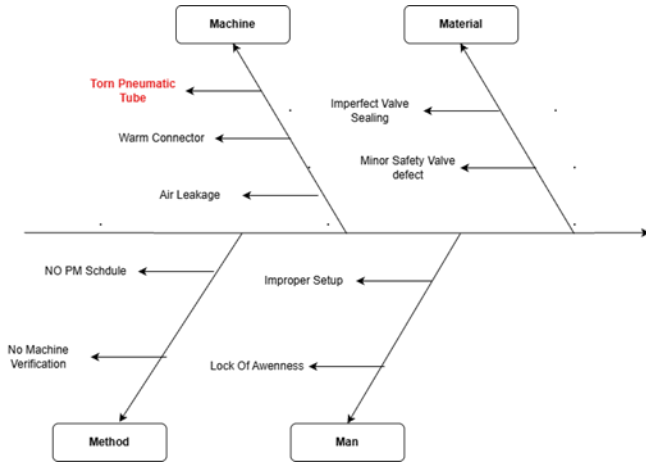


Figure 6 Fishbone Diagram

Based on the investigation findings, the potential causes identified in each Fishbone category are summarized as follows:

1. **Man:** Improper Setup, Incorrect machine settings prepared by the operator prior to testing, which can affect inspection parameters. Lack of Awareness (written as "Lock of awareness" in the diagram), Insufficient awareness or experience from the operator during machine preparation and the inspection process, causing abnormal conditions (like a leaking tube) to go unnoticed.
2. **Method:** No PM (Preventive Maintenance) Schedule, the absence of a regular maintenance schedule allowed the pneumatic components (like the tube and connector) to deteriorate over time without being noticed. No Machine Verification, there was a lack of consistent checklists or procedures to verify the machine's condition and pressure stability before starting the production/inspection process.
3. **Material:** Imperfect Valve Sealing & Minor Safety Valve Defect: The investigation found that a small number of samples actually had minor sealing imperfections that could contribute to leakage. However, these product-related defects were relatively low in occurrence compared to the machine-related issues.
4. **Machine:** This category focuses on issues related to the inspection equipment itself. Based on the investigation, this was identified as the primary source of the leak test failures. Torn Pneumatic Tube, the main culprit causing the problem. A damaged tube allows compressed air to escape during the pressure

holding stage, creating unstable pressure readings and false reject decisions. Worn Connector, the connector attached to the pneumatic tube showed signs of wear, which also contributed to air leakage. Air Leakage, the direct consequence of the torn tube and worn connector, leading to the machine's failure to maintain stable pressure during testing. Improper machine setup and lack of operator awareness during machine preparation and inspection.

Among these categories, the Machine factor was identified as the dominant root cause because the damaged pneumatic tube directly affected pressure stability during testing. Although several actual Safety Valve defects were identified, their occurrence was relatively low compared with failures caused by pneumatic leakage. Therefore, the majority of products rejected during the Leak Test Inspection Process were not caused by defective Safety Valves but by instability in the inspection equipment.

The Fishbone Diagram demonstrates that failures occurring during the Leak Test Inspection Process originated from both product-related defects and inspection-equipment-related problems. However, the dominant contributor was the Machine category, particularly the damaged pneumatic tube, which generated air leakage and resulted in false reject decisions. These findings provide the basis for the subsequent Failure Mode and Effects Analysis (FMEA), which prioritizes corrective actions according to the associated level of risk.

E. Failure Mode and Effect Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) was performed to evaluate the potential risks associated with the failure modes identified during the Fishbone Diagram analysis. The assessment was conducted by assigning Severity (S), Occurrence (O), and Detection (D) ratings to each failure mode, followed by the calculation of the Risk Priority Number (RPN) to determine the priority of corrective actions [7].

Table 5 Failure Mode and Effect Analysis (FMEA)

Failure Mode	Potential Cause	S	O	D	RPN
Pressure Drop During Leak Test	Torn Pneumatic Tube	8	8	6	384
Unstable Air Pressure	Worn Pneumatic Connector	7	6	5	210
Air Leakage During Holding	No Preventive Maintenance	6	5	5	150
Improper Machine Setup	Operator Error	5	4	4	80
Minor Valve Sealing Defect	Imperfect Valve Sealing	3	3	2	18

Insignificant Pressure Fluctuation	Minor Air Settling	2	1	1	2
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As presented in Table 5, Pressure Drop During Leak Test caused by a Torn Pneumatic Tube obtained the highest RPN value of 384, indicating that it was the most critical failure mode affecting the Leak Test Inspection Process. The damaged pneumatic tube caused air leakage during the pressure holding stage, resulting in unstable pressure measurements and increasing the likelihood of false reject decisions. The second highest RPN was associated with Unstable Air Pressure caused by a Worn Pneumatic Tube Connector, while Air Leakage During Holding and Improper Machine Setup were classified as lower-priority failure modes.

To improve the transparency of the risk assessment, the justification for each Severity (S), Occurrence (O), and Detection (D) rating is presented in Table 6.

Table 6 Justification of Severity (S), Occurrence (O), and Detection (D) Ratings

Failure Mode	S	Severity Justification	O	Occurrence Justification	D	Detection Justification
Pressure Drop During Leak Test	8	Causes unstable pressure during testing, resulting in false reject decisions and significantly affecting inspection reliability.	8	Frequently observed during the investigation due to the torn pneumatic tube and became the dominant failure mode.	6	Leakage was not immediately detected during routine inspection and was only identified after detailed investigation.

Unstable Air Pressure	7	Produces inconsistent pressure readings that reduce the accuracy of the Leak Test Inspection Process.	6	Occurred repeatedly because of wear on the pneumatic connector, although less frequently than the torn pneumatic tube.	5	Pressure fluctuations can be detected through repeated testing but are difficult to identify during normal production.
Air Leakage During Holding	6	Reduces pressure stability during the holding period and affects inspection consistency.	5	Occurred occasionally due to the absence of preventive maintenance, allowing pneumatic components to deteriorate over time.	5	Leakage can be identified through routine machine verification, but such inspections were not consistently performed.
Minor Valve Sealing Defect	3	Has a small effect on testing parameters but does not stop machine operation; pressure reduction remains within allowable limits.	2	Occurred rarely; identified in only a very small number of samples during detailed investigation.	2	Easily detected before it affects the testing process through visual inspection of the valve seat.

Insignificant Pressure Fluctuation	2	Almost no effect on machine operation or test results; pressure reduction strictly maintained at < 0.05 psi	1	Almost never occurs; represents ideal operating conditions with strict preventive maintenance.	1	Very easy to detect instantly through automated machine indicators and error-proofing systems.
Improper Machine Setup	5	Incorrect machine settings may affect inspection parameters but generally have a lower impact than equipment failure.	4	Occurred infrequently and was mainly associated with operator setup before production.	4	Can be easily detected through machine setup verification and standard operating procedures before testing.

Based on the detailed assessment presented in Table 6, the high RPN assigned to Pressure Drop During Leak Test was attributed to its significant impact on inspection reliability, its frequent occurrence during the investigation, and the difficulty of detecting pneumatic leakage through routine inspection. In contrast, Improper Machine Setup obtained the lowest RPN because its occurrence was relatively infrequent and could be identified through standard machine setup verification before production.

Overall, the FMEA results are consistent with the findings of the Fishbone Diagram analysis, confirming that the Machine category—particularly the torn pneumatic tube—was the dominant contributor to failures during the Leak Test Inspection Process. Therefore, corrective actions were prioritized to restore the reliability of the Leak Test Machine through pneumatic tube replacement, routine machine verification, and implementation of preventive maintenance.

F. Proposed Corrective Actions

The damaged pneumatic tube was replaced with a new tube that met the required operational specifications.

Based on the Fishbone Diagram and Failure Mode and Effects Analysis (FMEA), corrective actions were developed to address the dominant failure modes identified during the Leak Test Inspection Process. Since the highest RPN value (384) was associated with the torn pneumatic tube, the primary corrective

action focused on restoring the reliability of the Leak Test Machine.

The first corrective action involved replacing the damaged pneumatic tube and the worn pneumatic tube connector to eliminate air leakage during the pressure holding stage. This improvement was expected to restore pressure stability and improve the accuracy of the Leak Test Inspection Process.



Figure 7 Pneumatic Tube After Replacement

In addition to component replacement, a preventive maintenance schedule was established to ensure periodic inspection of pneumatic components and to minimize the risk of future leakage. Routine machine verification before production was also introduced to confirm pressure stability and ensure that the Leak Test Machine operated within the specified inspection parameters.

Furthermore, operators were instructed to perform machine setup verification before production and to use an inspection checklist to identify potential abnormalities before conducting leak testing. These actions were intended to improve inspection reliability and reduce the occurrence of false reject decisions.

The proposed corrective actions are summarized in Table 8.

Table 7 Proposed Corrective Actions

Failure Mode	Corrective Action	Expected Outcome
Pressure Drop During Leak Test	Replace torn pneumatic tube	Stable pressure during testing
Unstable Air Pressure	Replace worn pneumatic tube connector	Consistent air supply
Air Leakage During Holding	Implement preventive maintenance schedule	Reduced pneumatic leakage
Improper Machine Setup	Machine verification and operator checklist	Improved inspection reliability

G. Leak Test Results After Improvement

After replacing the damaged pneumatic tube and implementing maintenance controls, another 210 samples were tested.

Table 8 Leak Test Results After Improvement

Sample	Result
Pass	207
NG	3
Total	210

Calculation:

$$\text{Defect Rate} = \frac{207}{3} \times 100$$

$$\text{Defect Rate} = 1.43\%$$

The results demonstrate a significant reduction in defect rate after improvement.

H. FMEA After Improvement

Following implementation of corrective actions, FMEA was performed again to evaluate the effectiveness of the improvements.

Table 9 Ranking of Risk Priority Number (RPN) After Improvement

Failure Mode	S	Severity Justification	O	Occurrence Justification	D	Detection Justification	RPN
Pressure Drop During Leak Test (Pneumatic Tube)	8	Pressure instability still has a significant impact on inspection reliability if it occurs.	2	Occurrence was drastically reduced (only 3 NG from 210 samples) after tube replacement and strict preventive maintenance implementation.	3	Daily inspection and preventive checklists improve monitoring capability, allowing early detection before testing.	48
Safety Valve Seat Imperfect	7	Actual leakage may still affect	2	The occurrence rate is extremely low, as	3	Improved inspection procedure	42

Sealing		product performance and customer satisfaction.		most failures were previously caused by the machine, and material quality is strictly controlled.		res and visual checks increase the probability of early detection.	
Improper Operator Inspection	5	Incorrect inspection practices may still affect the decision-making process.	1	Reduced significantly through operator training, increased awareness, and standardized setup checklists.	2	More easily detected through standardized inspection procedures and supervision.	10

Calculated as $S \times O \times D$. The sharp drop in the RPN values (for example, the pneumatic tube issue dropping to 48) serves as strong evidence that the corrective actions successfully mitigated the risks in the inspection process.

I. Comparison Before and After Improvement

Table 10 Performance Comparison

Indicator	Before	After
Investigated Units	210	210
Defective Units	132	3
Non-Defective Units	79	207
Defect Rate	62.86%	1.43%
Highest RPN	384	168

The defect rate decreased from 62.86% to 1.43%, representing a reduction of 61.43 percentage points. significant risk mitigation after corrective actions were implemented.

The number of defective units also decreased from 132 units to 3 units, representing a reduction of 129 defective units. These findings confirm that pneumatic tube leakage was the dominant contributor to leak test failures. However, the presence of several actual Safety Valve defects demonstrates that

inspection-equipment reliability and product quality must be controlled simultaneously to achieve an effective quality assurance system.

The application of Fishbone Diagram and FMEA successfully identified critical failure sources and supported the development of targeted improvement actions that enhanced the reliability of the Leak Test Inspection Process.

IV. CONCLUSION

This study analyzed failures occurring during the Safety Valve Leak Test Inspection Process in coffee machine manufacturing using Fishbone Diagram and Failure Mode and Effect Analysis (FMEA) methods.

The results showed that while a few Safety Valve units exhibited actual sealing defects, the dominant cause of failure was leakage in the pneumatic tube of the Leak Test Machine. This damaged tube caused pressure instability during testing, leading to a high number of false reject decisions. Fishbone Diagram analysis identified the torn pneumatic tubing as the primary root cause. FMEA results further confirmed this finding, with the torn pneumatic tubing producing the highest Risk Priority Number (RPN) of 384, indicating the most critical failure mode within the inspection process.

Corrective actions—including pneumatic tube replacement, preventive maintenance implementation, daily inspection checklists, and enhanced operator training—were successfully carried out to address the identified issues. Following these improvements based on a test of 210 samples, the number of defective units decreased drastically from 131 units to only 3 units. The defect rate was successfully reduced from 62.38% to 1.43%, representing a significant reduction of 60.95 percentage points. In addition, the highest RPN value dropped sharply from 384 to 48, demonstrating a massive reduction in inspection-related risks and a highly effective enhancement in the reliability of the Leak Test Inspection Process.

These findings highlight that the reliability of inspection equipment plays a crucial role in ensuring accurate quality control decisions. Therefore, both product quality and inspection-system reliability must be continuously monitored and improved to minimize defects and enhance manufacturing performance. The application of the Fishbone Diagram and FMEA proved highly effective in identifying root causes, prioritizing corrective actions, and achieving a near-zero defect rate in the leak test inspection process.

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