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# Root cause analysis of bearing installation failure in a precision manufacturing company using an integrated FMEA–FTA framework

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## Abstract

A precision manufacturing company is committed to delivering high-quality, precise products that meet customer expectations and help it remain competitive in the global market. During the implementation of the Agile Tool project, several defects were identified, resulting in losses for the company. The number of defects produced is quite detrimental to the company because it can increase workload, operational costs, and production time, resulting in delays in the delivery of other scheduled production. This study was undertaken to analyze the factors contributing to the most significant defect in the production of Agile Tools, specifically the gearbox component. Utilizing the Failure Mode and Effect Analysis (FMEA) method to identify failures and employing Fault Tree Analysis (FTA) to ascertain the root cause of the primary failure factor. The highest RPN was found for bearings that cannot be installed, reaching 165.75, with various causes identified across the man, method, machine, and material domains. Based on the categorized aspects, the causes of the highest defect rates in the gearbox include new operators unfamiliar with the machine, human error, inappropriate machine speed settings, lack of machine maintenance, lack of machine cleanliness, and castings.

**Keyword:** Defect; FMEA; FTA; Waste

## 1. Introduction

A precision manufacturing company specializes in producing industrial machine spare parts, jigs, molds, plastic injection components, and prototypes. The company customizes its services according to customer needs and applies a made-to-order production system. Since each project is managed independently, the company frequently encounters unique production challenges. Therefore, the company aims to deliver high-quality, precise products that meet customer expectations while remaining competitive in the global market.

One of the company's ongoing projects was the Racket Tool. Producing the Racket Tool requires greater precision, especially for each of its 38 parts. Throughout the production process through January 2025, the Racket Tool project attracted considerable attention because the products failed to meet customers' specifications. Additionally, during production, the project incurred significant time and cost losses because the final products were NG (Not Good) and required repairs or remakes. After conducting control, various types of defects were found on each part, which became the main problem in this project. These issues affected the entire production process, resulting in other defects or products that could not be assembled with other parts. Table 1 shows data on defective items in the Racket Tool production.

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**Table 1** Data Part Defect

| No. | Part Name | Quantity | Total NG item | Percentage |
|---|---|---|---|---|
| 1 | Cigarette Hopper | 187 | 23 | 12,299% |
| 2 | Drum | 515 | 34 | 6,602% |
| 3 | Slider | 2263 | 97 | 4,286% |
| 4 | Rotation | 443 | 49 | 11,061% |
| 5 | Rotation Plate | 150 | 26 | 17,333% |
| 6 | Gearbox | 524 | 102 | 19,466% |
| 7 | Gearbox Plate | 635 | 47 | 7,402% |
| 8 | Premier Gear | 705 | 10 | 1,418% |
| 9 | Arm | 678 | 39 | 5,752% |
| 10 | Shaft 2 | 658 | 12 | 1,824% |
| 11 | Stopper Handle | 100 | 5 | 5,000% |

The gearbox component had one of the highest defect rates, with 102 faulty parts. These defects posed significant issues for the company, as they can lead to increased workload, higher operational costs, and longer production times, ultimately causing delays in delivering other scheduled products.

The appropriate approach method used to analyze the problem is Failure Mode and Effect Analysis (FMEA), which can explain the weighting with severity (S), occurrence (O), and detection (D) values to identify failures, evaluate the effects of failures, and prioritize failures based on the effects produced from the calculation of the Risk Priority Number (RPN) value in the production of the gear box part for sports equipment. The highest RPN value is used as input to the next method, Fault Tree Analysis (FTA), to identify the root cause of the highest failure factor. With this analysis, the aim is to identify the right solution to improve the quality of the gearbox part, thereby supporting the quality of sports equipment production, meeting consumer specifications, and increasing production efficiency. This can then be analyzed, and relevant improvement recommendations can be made related to the problem.

## 2. Materials and Methods

### 2.1. Data Collecting

In this study, several necessary data points were collected. Data collection was conducted utilizing three methodologies: original data used to ascertain the total number of defects, interviews, and questionnaires completed directly by the Person in Charge (PIC) of the badminton racket project in each department. The collected data are divided into two categories, primary data and secondary data. Primary data are data collected directly from an organization or the object being studied for the purposes of the relevant study, such as interviews or direct observations [1]. In this research, the primary data collected consisted of interviews with the project PIC, focusing on the causes and effects of gearbox defects in the badminton racket project. Additionally, questionnaires were distributed to PICs in related divisions, including Quality Control and Assembly, to more deeply explore the factors causing defects in gearbox parts. Meanwhile, secondary data are data obtained or compiled from previous studies or published by various agencies, usually in the form of official company archives [1]. Secondary data serve to support the primary data used in this research. The secondary data collected includes literature reviews, company profiles, and business process descriptions.

### 2.2. Data Processing

In this study, data processing used two methods, which was Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA). FMEA is a systematic method for identifying and preventing the occurrence of system, product, and process problems before they happen. The focus of this method is to avoid issues, improve safety, and increase customer satisfaction. In the manufacturing field, FMEA is widely used across various industries, including cement industries [2], the health care sector [3], automotive industrial equipment [4], and others. This method is used to identify potential failure modes based on past experiences with similar processes [5]. FMEA is also applied during the design phase to prevent future failures, making it easier for organizations to control processes before or during ongoing operations. FMEA begins with the conceptual design stage and continues throughout the product or service lifecycle. The result of a development FMEA is a set of actions to prevent or reduce the severity or likelihood of failure, prioritized from highest to lowest. FMEA assesses risk priority using the Risk Priority Number (RPN), calculated by multiplying occurrence (O), severity (S), and detection (D) of the failure [5].

Severity is a rating or level that refers to how serious the impact of a potential failure mode is. The impact of this rating ranges from 1 to 10, where 1 represents the lightest impact and 10 represents the worst impact. Table 2 is a general explanation of severity ratings.

**Table 2** Explanation of severity ratings

| Rank | | Criteria |
|---|---|---|
| 1-2 | Minor | It is unreasonable to expect that this minor failure would significantly impact the product or service. The customer will probably not even notice it. |
| 3-4 | Low | Low severity rating because of the failure's nature, resulting in only minor customer annoyance. The customer is likely to notice a slight decline in the product or service, a minor inconvenience in the next step, or some minor rework. |
| 5-6 | Moderate | Moderate ranking due to failures that lead to some dissatisfaction, making customers uncomfortable or annoyed. Such failures may result in unscheduled repairs or equipment damage. |
| 7-8 | High | High customer dissatisfaction resulting from the failure, such as an inoperable product or inconvenience. It does not pose safety concerns or violate government regulations. However, it could disrupt later processes or services. |
| 9-10 | Very high | Very high severity occurs when a failure impacts safety and violates government regulations. |

Occurrence indicates the failure frequency, such as how often defects happen in the insulator product. The failure frequency value shows how minor the issues caused by potential causes are. Table 3 is a general explanation of the occurrence rating.

**Table 3** Explanation of occurence ratings

| Rank | Criteria |
|---|---|
| 1-2 | Remote probability of occurrence. |
| 3-4 | Low probability of occurrence. |
| 5-6 | Moderate probability of occurrence. |
| 7-8 | High probability of occurrence. |
| 9-10 | Very high probability of occurrence. |

Detection is a means of controlling potential failures. It is a process control that will specifically detect the root cause of failures. Table 4 is a general explanation of the detection rating.

**Table 4** Explanation of detection ratings

| Rank | | Criteria |
|---|---|---|
| 1 | Very high: Controls almost certainly will detect the existence of a defect. | Remote likelihood that the product will be delivered. The defect is functionally obvious and readily detected. Detection reliability at least 99.99%. |
| 2-5 | High: Controls have a good chance of detecting the existence of a failure | Low likelihood that the product would be delivered with the defect. The defect is obvious. Detection reliability ≥ 99.80%. |

| | | |
|---|---|---|
| 6-8 | Moderate: Controls may detect the existence of a defect. | Moderate likelihood that the product will be delivered with the defect. The defect is easily identified (1/200 – 1/50). Detection reliability ≥ 98.00%. |
| 9 | Low: Controls are more likely not to detect a defect. | There is a high likelihood that the product would be delivered with the defect. The defect is subtle (1/20). Detection reliability > 90%. |
| 10 | Very Low: Controls are very likely not to detect a defect. | Very high likelihood that the product and/or service will be delivered with the defect. The item is usually neither checked nor checkable. Quite often, the defect is latent and would not appear during the process or service (1/10). Detection reliability ≤ 90%. |

The highest RPN value is then used for the next method, Fault Tree Analysis (FTA), to find the root cause of the highest failure factor. FTA is a graphical design methodology that offers an alternative to reliability block diagrams. It encompasses a broader scope than reliability block diagrams and differs from them in several respects. It employs a top-down, deductive approach structured around events rather than components. The primary benefit of emphasizing failures is that they are generally simpler to define than non-failures, and there are fewer mechanisms by which non-failures can occur. Typically, the focus is on significant failures or major disasters, designated as top events, which are positioned at the apex of the fault tree diagram [6]. Based on the results of this data processing, an analysis is then conducted regarding the defects occurring in the production of gearbox parts in the sports equipment project, as well as an analysis of the root causes that are the focus of this research.

## 3. Results and Discussion

### 3.1. Defect Data Collection

Based on field observations during the research period, several types of defects occurred, including no snap ring being installed in the hole in the gearbox (Figure 1a); the hole in the gearbox cracked (Figure 1b); the bolt hole was off-center (Figure 1c); the stopper bearing broke (Figure 1d); the hole in the gearbox was too thin (Figure 1e); and the hole in the gearbox cracked after being filled with a snap ring (Figure 1f).

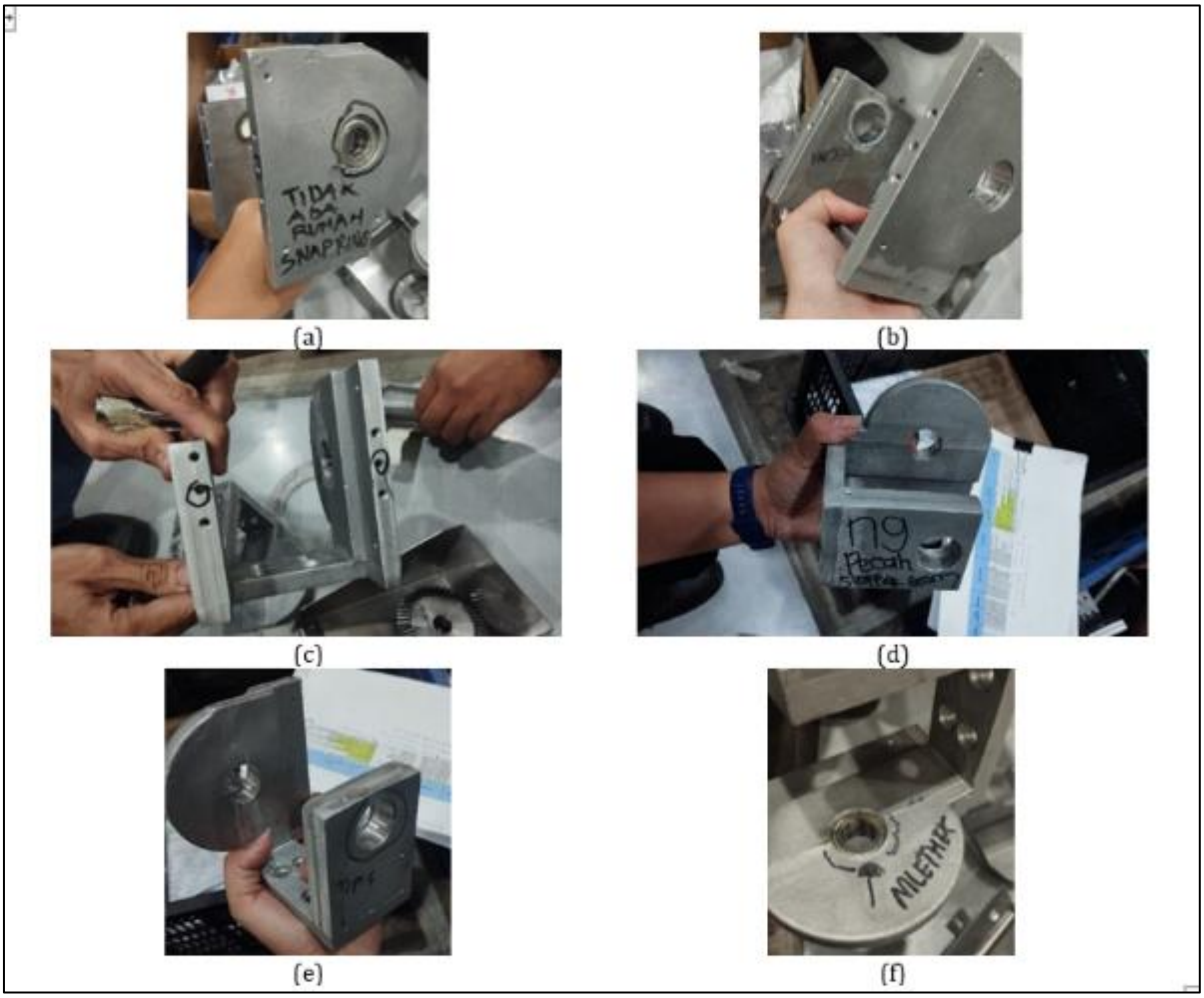


**Figure 1** Types of defects

### 3.2. FMEA Analysis

Table 5 presents an FMEA analysis of failures in the gearbox component to identify their causes and effects, represented as numbers across three assessment aspects: severity, occurrence, and detection.

**Table 5** FMEA analysis result

| Failure Mode | Failure Effect | Failure Cause | S | O | D | RPN |
|---|---|---|---|---|---|---|
| No snap ring groove in the gearbox hole | The snap ring cannot be installed. | An operation step was missed by the operator. | 7 | 4.5 | 3.5 | 110.25 |
| | The bearing can easily come loose from the hole. | An operation step was missed by the operator. | 7 | 3 | 3.5 | 73.50 |
| Bearing housing hole cracks during bearing installation | The bearing cannot be installed. | Casting material is prone to damage.<br>Excessive machining force/process. | 8.5 | 6 | 3.25 | 165.75 |
| Bolt holes on the left and right sides are not centered | Left and right points are not symmetrical. | Measurement does not match the drawing specifications. | 8 | 4 | 4 | 128.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Cannot be assembled with other parts. | Unstable operator handling during the manufacturing process.<br>Imprecise or vibrating machining process. | 9.25 | 2.25 | 2.75 | 57.23 |
| Bearing stopper breaks | Bearing may become defective due to contact with a damaged surface. | Casting material is prone to damage. | 5.75 | 2.75 | 3.5 | 55.34 |
| | Bearing moves freely, causing uncontrolled handle rotation. | Excessive machining force/process.<br>Unstable operator handling during machining. | 6.5 | 3.25 | 2.5 | 52.81 |
| The gearbox hole is too thin | The bearing stopper may break. | Casting material is prone to damage. | 8.5 | 5 | 2.5 | 106.25 |
| | The snap ring groove may crack. | Excessive grinding/rework on the gearbox body. | 8 | 2.5 | 2 | 40.00 |
| | Abnormal vibration occurs in the gearbox assembly during operation (e.g., when the handle or rotor rotates). | Excessive grinding/rework on the gearbox body. | 6.75 | 2.75 | 2.5 | 46.41 |
| Gearbox hole cracks after snap ring installation | Causes defects in adjacent parts due to collisions or interference. | Casting material is prone to damage. | 6 | 2.25 | 2 | 27.00 |
| | The snap ring comes loose from its groove. | The operator applies excessive force when installing the bearing. | 8.75 | 5 | 2.5 | 109.38 |

Based on the FMEA analysis, each failure occurring during the gearbox part manufacturing process in the racket tool project is influenced by the causes listed above. After calculating the RPN for each indicator (Severity, Occurrence, and Detection), the highest RPN was observed for the bearing that cannot be installed. During an interview with the company supervisor, it was revealed that if the bearing is not installed, several other parts cannot be assembled, rendering the product unusable.

### 3.3. FTA Analysis

Based on the FMEA calculation results, the highest RPN, 165.75, was found for the failure of the bearing that cannot be installed. This is a critical issue because it prevents other parts from being assembled with other components. Figure 2 is the FTA for the highest RPN.

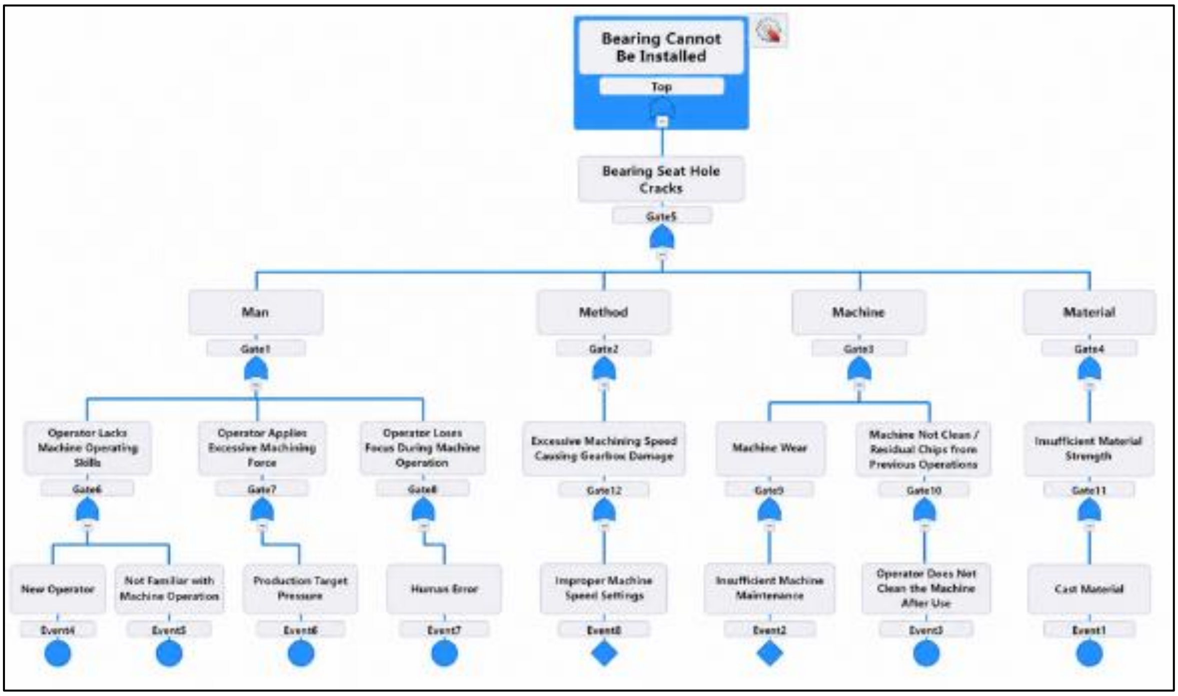


**Figure 2** FTA for the failure of the bearing that cannot be installed

#### *3.3.1. Man Factors*

In the man factor, the root cause of the problem lies in the operator's performance. The direct causes are operator errors. According to the FTA, the following are some of the causes of bearing failure that cannot be addressed:

Unskilled operator in operating the machine

The operator's lack of skill in operating the machine may be a contributing factor, as they are new and not yet accustomed to using it. In the company, many interns are entrusted with operating the machines, which significantly affects the final product because they are not yet used to operating them directly.

The operator who forces the machining process too much

Operators have targets or goals for completing a certain number of products each day, which affects the machining process. Machines also have targets to produce a specific quantity of products within a certain time, which can lead operators to continue production even when there are indications of defects.

The operator is not focused on operating the machine.

Because the work is still done by humans and machines, human error cannot be entirely avoided as a cause of defects, such as operators losing focus when operating the machines, especially as break or closing time approaches.

#### *3.3.2. Method Factors*

In the method factor, the aspect identified is the production process. This factor identifies the causes of problems during the production process by considering the methods implemented. In the FTA diagram shown above, the main cause is the machining process being too fast, which results in damage to the gearbox. This is due to the machine speed settings not being in accordance with the standards.

#### *3.3.3. Machine Factors*

Machine factors are one of the causes of bearing failure that cannot be addressed. This factor is useful for identifying machine failures when used as auxiliary tools during the product manufacturing process. The influence of machines becomes one of the main factors because machines are directly related to the product. In the FTA diagram, machine factors are found to have two main aspects causing failures, including:

Worn-out machine during use

Worn-out machines are closely related to machine maintenance, where operating machines in a worn condition or failing to maintain them causes failure during the bearing installation process.

The machine is not clean enough, or there are residual grams from the previous operation.

This is caused by the operator being less careful in cleaning the machine, leaving leftover grams from the previous operation, which also affects the machining results.

*3.3.4. Material Factors*

Material factors are one of the main causes contributing to bearing installation failure. This factor is categorized separately and is attributed to unstable materials. For the machining process, which can be considered quite lengthy and influential on other parts, the selection of material provided directly by the customer cannot be fully executed properly in the production process. This is because the material supplied is a casting, obtained by pouring molten metal into a mold, resulting in a material that is less strong or durable for further machining processes. If the casting material does not meet the established standards, it will impact the material's durability during machining and bearing installation.

### 3.4. Recommendation

Based on the analysis of the causes of bearing installation failure, improvement proposals can focus on human factors, work methods, machinery, and materials. In terms of human factors, the company needs to improve the quality of training for new operators and interns by conducting specialized training regularly and in a structured manner, especially during the first week of placement. The training should be delivered directly by expert staff or machine PIC with more intensive guidance, not only including a general introduction but also covering workflow understanding, machine functions, error risks, and product quality standards. Additionally, new operators should not be immediately assigned to complex tasks but given lighter duties first to allow them time to adapt to the characteristics of the machine and production process.

Regarding habits and the ability to operate machinery, the company needs to provide a more systematic training process for new operators. So far, new operators are often considered to have understood the basics of machine operation, but in actual conditions, they still need time to familiarize themselves with the characteristics of the machines used in the company. Therefore, training can be supplemented with learning media such as software simulations, instructional videos, or machine operation modules that can be studied independently. With these media, operators can understand machine operating procedures more safely before directly engaging in the production process.

To achieve production targets, the company needs to reevaluate them to better align with machine capacity, operator skills, and actual conditions on the production floor. Coordination between the marketing, PPIC, and production departments also needs to be improved to ensure that received orders remain realistic within the company's production capabilities. Additionally, operators should be given an understanding of material specifications, machine capacity limits, and the risks of damage if machines are pushed beyond standard limits. This way, operators not only focus on meeting quantity targets but also on product quality and machine safety.

In terms of work methods, the company needs to establish clear, easily understood standards for machine speed regulation for operators. The machine speed settings should be adjusted based on the material type, the machine's acceptable pressure, and the predetermined process standards. To support this, the company can develop a machine-speed monitoring system that leaders and supervisors can monitor. In the long term, the use of automation technology can also be considered to ensure that machine speeds consistently meet standards and to reduce the risk of errors caused by operator negligence.

In terms of machinery, the company needs to strengthen its maintenance system by conducting daily or weekly inspections before starting production. These periodic checks are important for detecting early signs of damage, such as component wear, abnormal machine noise, or decreased machine performance. Additionally, operators should be given basic training to recognize early signs of damage, enabling repairs to be made more quickly. The company can also place a simple checklist near the machines to help operators easily remember the inspection steps to perform before and after using the equipment.

Regarding machine cleanliness, the company needs to implement regular cleaning procedures before and after the production process. Cleaning the machine is important to prevent residual materials, dust, or dirt that could interfere with the bearing installation process. To encourage operators to be more disciplined in maintaining cleanliness, the company should provide cleaning tools at easily accessible points, especially around the machine area. This way, operators will have no obstacles in cleaning the machine and work area routinely.

In terms of material aspects, the company needs to establish clearer standards for raw material acceptance, particularly regarding the strength and suitability of the casting materials used in production. Although materials often come from customer requests or choices, the company still needs to educate customers about the risks of using materials that do not align with the machine's capabilities and production standards. Additionally, the company can perform random strength tests on materials before they enter the production process. This step aims to ensure that the materials used meet minimum standards, thereby reducing the risk of gearbox defects.

## 4. Conclusion

The conclusion of this study indicates that during the manufacturing process of the gearbox parts, several types of production failures were still found, such as the absence of a snap ring housing in the gearbox hole, cracked gearbox holes, misaligned bolt holes, broken stopper bearings, too-thin gearbox holes, and cracked gearbox holes after installing the snap ring. Based on the FMEA analysis of Severity, Occurrence, and Detection aspects, the highest RPN value was 165.75 for the failure of the bearing that could not be installed. Therefore, further analysis was conducted using the Fault Tree Analysis (FTA) method to identify the root causes of the problem. The analysis results show that these failures stem from four main factors: Man, Method, Machine, and Material. In the Man aspect, the main causes relate to operator performance, such as being less skilled in operating the machine, forcing the machining process, and lacking focus while working. In the Method aspect, the primary cause is improper machine speed settings, which cause the machining process to proceed too quickly and potentially damage the gearbox. In the Machine aspect, the issues stem from worn-out machines and insufficient cleaning due to residual material from previous processes. Meanwhile, in the Material aspect, the failure is influenced by the cast material that is less sturdy. Based on these root causes, improvement recommendations are provided for each aspect to ensure that future production processes run more smoothly and minimize the risk of product failure.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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