FTA-FMEA and Pokayoke Analysis to Reduce Stamping Machine Breakdown Time

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Abstract. Maintenance has an important role in the industrial sector as it maintains efficiency and productivity and extends the life of the equipment and machinery used. Mold is one of the important components in the manufacture of mosquito coils where the readiness of the forming and supporting components affects the quality and if damaged will have a detrimental effect on productivity. This research aims to reduce mold breakdown on the 901-line stamping machine so that OEE increases by using a combination of the Fault Tree Analysis (FTA) and Failure Modes and Effect Analysis (FMEA) methods and the Pokayoke method. In the analysis of the FTA and FMEA methods, 7 points were found to cause mold breakdown, including uncontrolled bronbos usage period, loose teflon mold pole lock bolt, worn teflon mold, loose mold shaft lock bolt, worn mold shaft lock bolt, worn endless belt, loose mold nut asbolt. The result of the development of the Pokayoke method, which changes the round end face of the mold shaft to a square one, is an error-proof design. With a square mold shaft end, the mold can be mounted directly to the cross section of the mold post, which is also square, without the need to rotate the machine to change its position.

Keywords: Mold, Breakdown, FMEA, FTA, Pokayoke.

1 Introduction

1.1 Background

Today, the world economy presents challenges to industries that result in major changes. A company's success is determined by how well it meets customer needs and builds stronger customer loyalty. A production system is bound to experience reliability-related issues due to factors such as aging, lack of an effective preventive maintenance program, errors caused by operators, and most importantly, random machine failures. There is a significant risk of significant disruption of the production process due to disasters such as stoppage of the production process and changes in the parameters of the production process resulting in a decrease in product quality [1].

The company in Surabaya is a manufacturing company that produces mosquito coils. Where the products are distributed at home and abroad. This mosquito repellent product

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is a spiral mosquito coil. At the beginning of the manufacturing process, it consists of various materials that are mixed in a mixer, then printed on a stamping machine, dried on an oven machine and finally wrapped on a wrapping machine.

According to data from the second quarter of 2022-2023, it shows that OEE in line 901 is 78.8% where the biggest contributor to the decline in OEE is caused by breakdowns, which is 9.8% for all areas while the stamping area is 8.4%, namely in the setting of mold components is the biggest contributor with a duration of 1882 minutes. With breakdown data of this magnitude, there can be losses in the form of scrap of 1.7%. In addition, with a 901-line OEE target achievement of 85.80% and a difference between actual and target achievement of 7%, researchers want to reduce this difference to improve the 901-line OEE. Not only the 901 lines, but it is also hoped that this research can help the company overcome the problems that exist in the stamping area.

2 Methodology

This research uses the FTA and FMEA methods because both methods are carried out before the event or are more preventive, in contrast to the Root Cause Analysis (RCA) method which is carried out after the event or is more reactive. The FTA and FMEA methods also have their respective functions, namely FTA is used to analyze possible sources of risk before losses occur, while FMEA is used to analyze a risk of failure. According to [14] that the FMEA method is a bottom-up method, and the FTA method is a top-down method which proposes to combine the two methods to complement each other.

The results of the FTA and FMEA research are then used to make improvements using Pokayoke. It is expected that this method will provide the best solution, at least reducing the repair time of mold components or resolving installation errors made by operators or technicians. This solution can automatically increase the OEE expected by the company. Poka-Yoke refers to methods designed to prevent or detect human error in manufacturing processes or management systems. And Pokayoke is a part of the method that uses other tools (sensors) or modifies machines to find out non-conformities made by employees/operators [4,5,11].

2.1 Fault Tree Analysis (FTA) Method

Fault Tree Analysis (FTA) is a technique used to analyze and identify causal factors (both human and non-human/machine) that can cause system failure while according to [9] that FTA is used to identify and find the cause of failure in data collection methods.

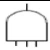
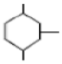
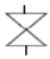
According to [24] stated that Fault Tree Analysis is function-oriented or better known as the “top-down approach” because this analysis starts from the top-level system and continues downward [19]. This method is carried out with a top-down approach, starting with the assumption of failure from peak events and then detailing the underlying causes of failure [10]. So, it can be interpreted that FTA is a method in the form of a logic diagram that represents the relationship between an event and the cause of the event, deductive in nature carried out with a top-down approach.

Fault trees are used as a graphical representation of the relationship between the causal factors of a failure. The fault tree consists of various components, such as root causes, core failures, and other contributing factors. These components are connected by logical operators, such as AND, OR, and NOT, to describe the relationship between them.

By using FTA, we can systematically identify and analyze potential causal factors of failure. This helps in developing risk control strategies and system improvement efforts to prevent or reduce the likelihood of failure.

According to [18] Fault Tree Analysis is a method in the form of a logic diagram that represents the relationship between an event (usually a system failure) and its cause event (usually a component failure). Gate symbols are used to show the relationship between events in the system. Each event in the system can personally or jointly cause other events to appear. The relationship symbols used in FTA can be seen in Table 1 below:

Table 1. Logic Gate Symbols

No	Gate Symbol	Name and Description
1		And gate. Output event occurs if all input events occur simultaneously.
2		OR gate. Output event occurs if at least one input event occurs.
3		k out of n gate. Output event occurs if at least k out of n input events occur.
4		Exclusive OR gate. An output event occurs if one input event, but not both, occurs.
5		Inhibit gate. Input produces output if conditional event exists.
6		Protory AND gate. Output event occurs if all input events occur from both right and left.
7		NOT gate. Output event occurs if input event does not occur.

Besides that, according to [3] there are 5 steps in conducting an analysis using the FTA (Fault Tree Analysis) method, namely:

1. Define study boundaries and a problem/failure
2. Identify components, their roles and processes.
3. Detect the function and type of failure and root cause
4. Draw a graphical model of the fault tree.
5. Analyze the minimum cut set of the fault tree.

The following are the benefits of Fault Tree Analysis (FTA), among others:

1. FTA provides a visual depiction of the causal factors and events that can lead to system failure. This makes understanding the complex relationships between system components easier.
2. FTA helps quantify the likelihood of failure, improves decision-making and risk management, and encourages teams to make proactive improvements.
3. Fault tree analysis helps the team stay organized while assessing the system level and perform effects analysis methodically as you can only analyze one output event at a time.
4. FTA differs from other methods for failure mode and effects analysis (FMEA) because it takes human error into account. This can help the team determine if the problem is related to errors in standard operating procedures.
5. FTA identifies the most common failures, helping the team decide which problems should be addressed immediately.

The following are the limitations of Fault Tree Analysis (FTA), among others:

1. The accuracy and success of FTA depends heavily on the skills of the analysts, their ability to find the root cause of failure, and their understanding of the complexity of the fault tree.
2. FTA is best suited for the analysis of smaller systems as large and complex systems will most likely require large and complex fault trees, which will make the analysis challenging and time-consuming.
3. The accuracy of the probabilities calculated in the fault tree will be affected by the quality and availability of failure data.
4. Fault tree analysis allows you to examine one top event at a time.

2.2 Failure Mode and Effect Analysis (FMEA) Method

FMEA is a structured procedure to identify and prevent as many failure modes as possible. FMEA is used to identify the sources and root causes of a quality problem [6]. FMEA (Failure Mode and Effect Analysis) is a structured procedure to identify and prevent as many failure modes as possible. FMEA is used to identify the sources and root causes of a quality problem. Damage analysis is one of the analytical techniques that is currently developing, the purpose of this analysis is to determine the causes of specific damage from equipment, equipment, processes and raw materials used and to determine preventive measures so that damage does not recur.

Soon, it is also expected that FMEA can improve design and improve processes and fabrication methods, while in the long term it can be used for material development and as a cutting-edge method for evaluating and predicting material performance and for improving maintenance systems. According to [13] Failure Mode and Effects Analysis (FMEA) is a popular technique used to improve the reliability of products, services and manufacturing processes by analyzing potential failures and causes of failure before they occur so that they do not occur to customers.

A failure mode is anything that includes a defect/failure in design, a condition outside the limits of established specifications, or a change in the product that causes a disruption in the function of the product. The basic philosophy of FMEA is: "prevent before it happens". According to [2] that FMEA is very well used in quality management systems for any type of industry. According to [27] states that FMEA is a tool to determine, identify, and eliminate potential errors or problems in a system, design, or process before the product reaches consumers. It can be concluded that FMEA is a method or tool that is inductive and bottom-up used to determine, identify and eliminate potential errors or problems in a system, design, or process before the product reaches consumers.

The FMEA method can be used to review the design of products, processes or systems by identifying weaknesses and then eliminating them. According to [23] stated that there are several important parts in the FMEA method as follows:

1. Failure mode is a part of FMEA that is used to find out how a system can be damaged.
2. Failure effect is part of FMEA which is used to determine the effect of damage to the system.
3. Cause of failure is the FMEA part used to determine the cause of damage to the system.
4. Risk evaluation is the FMEA part used to find out the most important problems that must be considered and get a solution.

[25] state that there are several advantages and disadvantages of the FMEA method. The advantages of the FMEA method include:

1. Can increase the reliability of the safety level of facilities, equipment / systems.
2. Can measure the level of work risk conventionally based on three parameters namely Severity, Occurrence, and Detection.

The weaknesses of the FMEA method include:

1. FMEA statements are often subjective and qualitative, so they are not clear in scientific language.
2. The three parameters (severity, occurrence, detection) usually have the same importance when they should have different importance.
3. The RPN values resulting from the multiplication of S, O, and D are often the same, while presenting different risk values.

According to [16] the steps of the FMEA method are:

1. Identify the course of the production process.
2. Identifying potential failure modes of a production process.
3. Identifying the potential impact of production failure.
4. Identify the causes of failures in the production process.
5. Identify detection modes in the production process.
6. Provide a rating assessment for severity, occurrence and detection values.
7. Calculation of the RPN value by multiplying the severity, occurrence and detection values.
8. Provide suggestions for improvements for failures that occur.

[7] states that the value of severity, occurrence, detection as in the **Table 2** below

Table 2. FMEA scale for Severity, Occurrence and Detection.

Rank	Severity		Occurrence		Detection	
	Effect	Criteria	Probability	Rates	Probability	Rates
10	Hazardous	Failure is hazardous, and occrs without warning	Extremely high: Failure almost inevitable	≥ in 2	Absolute uncertainty	The potential cause of failureor subsequent failure mode is no detected
9	Serious	Failure involves hazardous outcomes standards	Very high	1 in 3	Very remote	Very remote chance to detect a potential cause of failure or subsequent failure mode
8	Extreme	The system is inoperable	Repeated failures	1 in 8	Remote	Remote chance to detect a potential cause of failure or subsequent failure mode
7	Major	The system may not operate	High	1 in 20	Very low	Very low chance to detect a potential cause of failure or subsequent failure mode
6	Significant	Some functions may not operate	Moderately high	1 in 80	Low	Low chance to detect a potential cause of failure or subsequent failure mode
5	Moderate	The equipment requires repair	Moderate	1 in 400	Moderate	Moderate chance to detect a potential cause of failure or subsequent failure mode
4	Low	The equipment does not require repair	Relatively low	1 in 2000	Moderately high	Moderately high chance to detect a potential cause of failure or subsequent failure mode
3	Minor	Minor effect on system performance	Low	1 in 15000	High	High chance to detect a potential cause of failure or subsequent failure mode
2	Very minor	Very minor effect on system performance	Remote	1 in 150000	Very high	Very high chance to detect a potential cause of failure or subsequent failure mode
1	None	No effect	Nearly impossible	1 in 1500000	Almost certai	Potential cause of failure or subsequent failure mode could almost certainly be detected

In failure mode and effect analysis (FMEA), the occurrence, severity, and detection scores of failures are used to calculate the risk priority number (RPN). The RPN value is used to rank the failures [8]. FMEA assesses each risk factor on three scales namely Severity (S), Occurrence (O) and Detection (D) [22]. Each of these factors can be rated on a scale of 1 to 10. Different approaches have been proposed to improve FMEA analysis [20]. RPN calculation is one of them. The result of the assessment is a list of all risk factors and a calculation of the risk priority number (RPN). Severity x Occurrence x Detection = RPN - Risk Priority Number.

2.3 Pokayoke Method

The term "Poka-Yoke" comes from the Japanese words Poka (a mistake that one can make) and Yoke (to prove or prevent). The PokaYoke method was introduced by Shigeo Shingo in 1961, when he was one of the engineers at Toyota Motor Corporation. In other words, this method aims to prevent defects and errors that stem from mistakes. Shigeo Shingo as a statistical process control system expert at the Japanese company realized that such a solution would never improve the manufacturing process.

Japanese organizations began to implement Zero Quality Control (ZQC). One of the elements that implemented ZQC principles was the Poka-Yoke method. Company management realized the great potential of Poka-Yoke as a means of flexibility and easy accessibility [15]. One cannot prevent all mistakes, but it can make it easier to do the job right, even though mistakes will still occur. Instead of allowing the process to continue after a mistake is made, PokaYoke can be used to stop it [21].

Pokayoke technique starts by analyzing the process for potential problems, identifying parts based on dimensional, shape, and weight characteristics, detecting process deviations from procedures and nominal norms [17]. While [12] gave a statement that problems are identified and solved by the poka-yoke technique with to improve quality, cost savings and product safety more objectives are given below, to improve product quality, to increase product productivity, to save product production time and to increase production flexibility.

The stages of using the Pokayoke method according to [26] can be seen in Fig. 1 below.

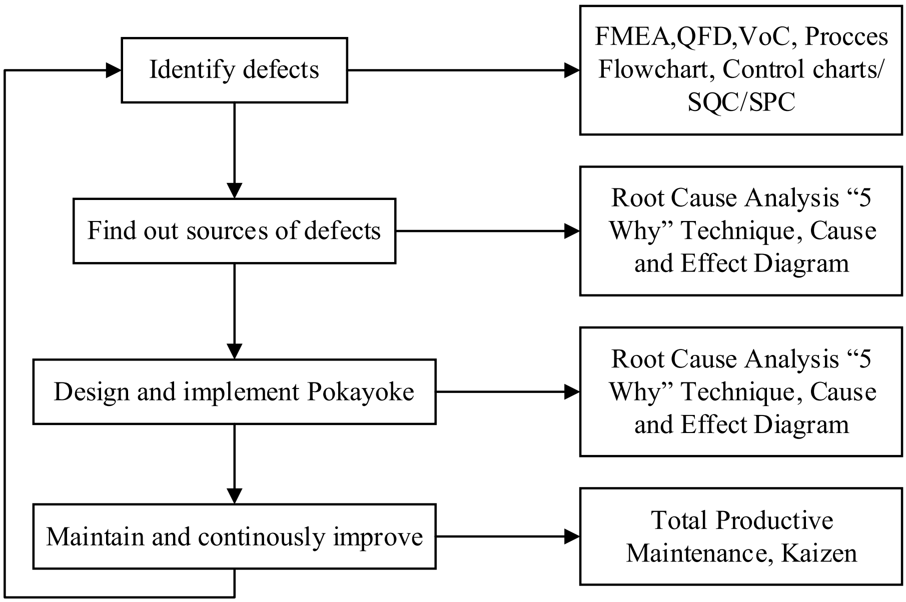


Fig. 1. Stages of using the Pokayoke method

3 Results and Discussions

The data collection carried out in this research on the 901 line uses a Pareto diagram which is one of the quality control tools. A Pareto diagram is a bar graph. The length of the bar represents frequency or cost (time or money) and is organized with the longest bar on the left and the shortest on the right. In this way, the graph visually illustrates which situations are more significant. This cause analysis tool is considered one of the seven basic quality tools. One of the data collected is secondary data that has been processed by the production department.

The following breakdown data has been collected in the form of Pareto diagrams that occur on line 901 in the October-December 2022 timeframe. The data is shown in Fig. 2 below

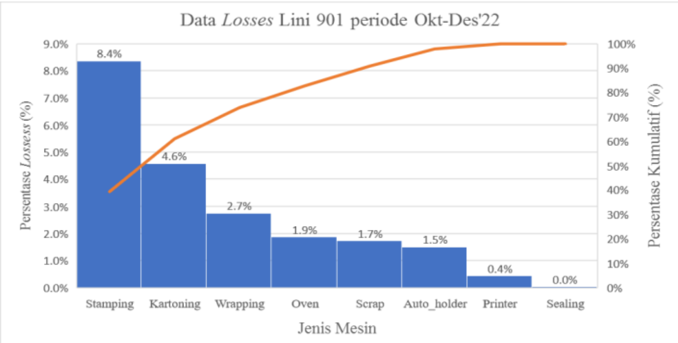


Fig. 2. Pareto diagram of breakdowns that occurred on line 901 for the period Oct-Dec'22

Fig. 2. above shows that the seven types of defects by area each affect the OEE of the 901 lines by 21.2%. The three most significant types of defects include stamping (8.4%), cartoning (4.6%), and wrapping (2.7%), each responsible for a decrease in OEE.

At this stage of the FTA method, the risks that play a role in failures that occur in mold breakdown are identified. Top events can be defined by answering the questions what, where and when. While events at the lowest level are called basic events. Based on observations and analysis in the field, it can be determined about the top event, intermediate event and basic event risks that play a role in mold breakdown as shown in Fig. 3 FTA diagram below:

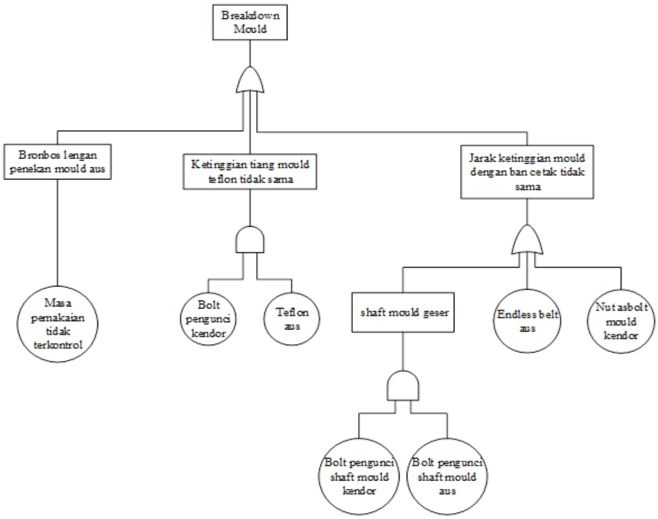


Fig. 3. Fault Tree Analysis Diagram of Mold Damage

Fig. 4 above is a Fault Tree Analysis diagram of the failure of the breakdown mold process (Top Event). The failure of the brekadown mold process can be caused by one of the components failing, so the relationship between the top event and the intermediate event is depicted with the "or" symbol. Then the basic events that cause the failure of the mold breakdown process include:

1. Uncontrolled bronbos usage period
2. Bolt locking the Teflon mold pole is loose
3. Teflon mold wear
4. Bolt locking mold shaft loose
5. Bolt locking shaft mold worn
6. Endless belt worn
7. Nut asbolt mold loose

To ensure that the factors responsible for failures that have been determined through FTA cannot be left unchecked. In this study, the Failure Mode and Effect Analysis (FMEA) method is still used to analyze the seven basic events. The purpose of this method is to determine which failure causes are most important in reducing mold damage.

From the results of the FTA method research, the 7 points are entered into the FMEA table into a failure mode so that this research will continue. The following is Table 3 of the FMEA breakdown mold worksheet.

Table 3 FMEA Worksheet

No	Component	Failure mode	Impact of failure	Cause of failure	Current control	S	O	D	RPN	Rank	Recommended action
1	Bronbros	Uncontrolled usage period	Engine damage due to non-optimal lubrication	No maintenance schedule	Routine maintenance not performed; visual inspection not performed	8	6	7	336	1	Create and stick to a regular maintenance schedule
2	Teflon mold pole locking bolt	bolt loosened	Unstable mold pole	Vibration, wear and tear	Periodic inspection is not carried out	7	5	6	210	3,4	Tighten bolts periodically
3	Teflon molds	Wear out	Imprecise molding results	Repeated pressure and friction	Visual inspection is not performed	8	4	5	160	6	Replace Teflon molds on schedule
4	Mold shaft locking bolt	Bolt loosening	Unstable mold shaft	Vibration, wear and tear	Periodic inspection is not carried out	7	5	6	210	3,4	Periodic tightening of bolts

5	Mold shaft locking bolt	Bolts wear out	Shaft mold is not locked properly	Repeated pressure and friction	Visual inspection is not performed	7	5	5	175	5	Replace worn bolts with new ones
6	Endless belt	Wear out	Inefficient use of endless belts	Repetitive stress	Inconsistent checks	8	6	5	240	2	Replace/reverse endless belts on a scheduled
7	Nut as-bolt mold	Slack	Unstable mold	Vibration, wear and tear	Periodic inspection is not carried out	7	4	5	140	7	Periodic tightening of bolts

Based on the results of the FMEA analysis above, it will be developed for the Pokayoke method. However, not all the results of the failure mode will be developed into the Pokayoke method. Researchers argue that those that have the potential to be developed into the next method are the 3rd and 5th points which have RPN values of 210 and 175 respectively. It is not without reason that researchers developed the 3rd and 5th points towards the Pokayoke method because these points are directly related to the main component of the mold, namely the mold itself. And the 3rd and 5th points have a high repair frequency so that it will have an impact on the high risk of scrap as well.

The 3rd and 5th priorities, which are loose or worn mold shaft locking bolts, can be proposed to be applied in the Pokayoke method. Because these priorities have a high frequency and are repeated, the impact on the stamping machine will be quite significant even though they are in the 3rd and 5th priorities. It is expected that the development of this failure mode will reduce the number of mold failures as well as errors caused by the layout design of the production environment, workplace, incorrect procedures, or possibly errors caused by human or employee factors.

The researcher was inspired by the ratchet key tool on the market, how it can quickly and easily unload and install various sizes of keys. This will be developed for loading and unloading the end of the mold shaft with the mold post.

The following is a picture of a mold that has not changed at the end of the mold shaft. At this time the installation of the mold when a replacement occurs takes -+ 10 minutes and still requires positioning so that the mold fits what is needed so that it will have an impact on the duration of repair time. This has not been added to the frequency of events during the production process. As shown in Fig. 4 below, the shape of the shaft mold before being developed to Pokayoke was a long round shape from the end of the mold to the base.

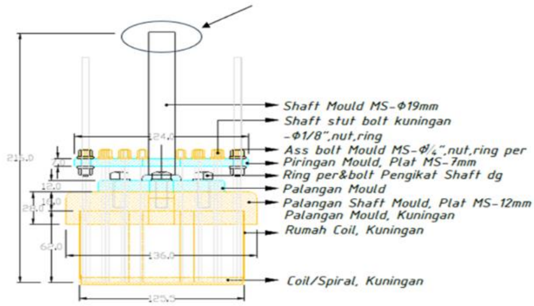


Fig. 4. Shaft mold before Pokayoke

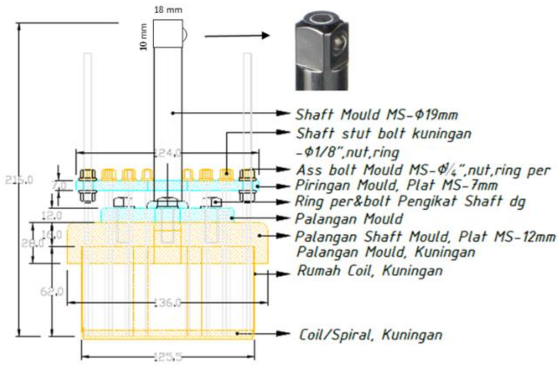


Fig. 5. Shaft mold after Pokayoke

In Fig. 5 above is a picture of a shaft mold that has undergone changes to the end of the shaft mold in the form of a box. With the size between the sides of the cross section of the box is 18 mm and the size of the box height is 10 mm. In developing the shape of the shaft, researchers were inspired by rachet key equipment commonly sold on the market. The function of the rachet key itself is basically to adjust the size of the mura or bolt quickly (Remove and install with "just 1 click"). This is one of the factors that the researcher believes can be used for the design of the end of the molded shaft and the base section of the molded pole. Fast removal and attachment of the shaft mold to the mold post can potentially reduce the duration of repair time.

Researchers not only designed a box-shaped shaft end, but this design is also symmetrical to the basic cross-section of the mold pole and the shape of the mold itself against the mold table and endless belt, so that when changing mold components technicians do not need to adjust the position of the mold. These two points, namely the box-shaped shaft end and the symmetrical design, are the capital for applying the Pokayoke method in this study.

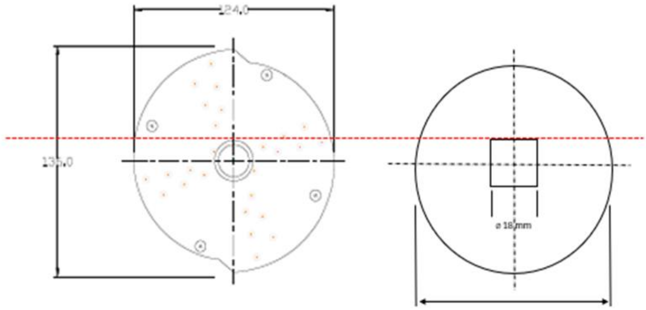


Fig.6. Symmetrical design between the design of the base cross-section of the mold post and the base cross-section of the mold component.

Fig. 6 above is a symmetrical design of the basic cross section of the mold pole with the basic cross section of the mold component. The symmetrical design is shown with a red dotted line that is parallel between the basic cross section of the mold pole which is round with a square shape. This symmetrical design is the basis of the Pokayoke method applied by researchers so that when replacing mold components, it is done without the need to adjust the position of the mold itself against the mold table and endless belt. this can also be called the "fool proof" concept which is the concept of the Pokayoke method.

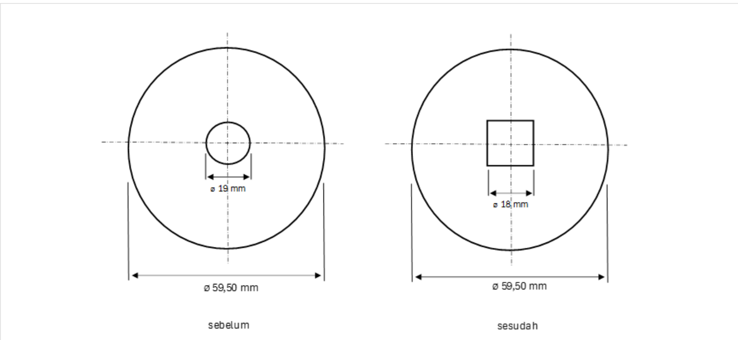


Fig. 7. Cross-section of the base of the mold post for the insert shaft mold before and after Pokayoke.

Fig. 7 above is a cross-sectional view of the base of the molded shaft before and after the Pokayoke method. The design is related to the design of the end of the mold shaft and the symmetrical position of the mold components. From this design, researchers argue that there are two main points of the concept of the Pokayoke method, namely fool proof and fast.

From the results of design development using the Pokayoke concept, several benefits are obtained, among others

1. Increase efficiency, which can reduce installation time because there is no need to rotate or adjust the position of the mold. Can reduce the possibility of installation errors that can cause product defects or damage to the tool.
2. Reduces errors i.e. the square end design ensures only one correct orientation for installation, thus eliminating the possibility of incorrect installation.
3. Improves safety i.e. it can reduce the risk of injury due to incorrect or improper mounting attempts.

4 Conclusions

Based on the results of the analysis and discussion that has been carried out, the following conclusions are obtained:

- Sources of causes of mold breakdown with the FTA method includes uncontrolled bronbos usage period, bolt locking pole mold Teflon loose, teflon mold worn, bolt locking shaft mold loose, bolt locking shaft mold worn, endless belt worn, nut asbolt mold loose.
- Risk analysis that can be concluded using the FMEA method includes machine damage due to not optimal lubrication, unstable mold poles, imprecise mold results, unstable mold shafts, mold shafts not locked properly, inefficient use of endless belts, unstable molds.
- Based on the results of the FMEA method, points number 3 and 5, namely the bolt locking the shaft mold is loose or worn out by tightening the bolt regularly and replacing the worn bolt with a new one. The proposal can be carried out with the development of using the Pokayoke method, namely changing the shape of the shaft end from round to square according to the Pokayoke principle to prevent installation errors. This can improve efficiency and safety in the manufacturing process by reducing the possibility of incorrect installation. Effective implementation will require design adjustments and thorough testing to ensure that these changes provide the desired benefits without creating new problems.

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Disclosure of Interests. It is now necessary to declare any competing interests or to specifically state that the authors have no competing interests. Please place the statement with a third level heading in 9-point font size beneath the (optional) acknowledgments[1], for example: The authors have no competing interests to declare that are relevant to the content of this article. Or: Author A has received research grants from Company W. Author B has received a speaker honorarium from Company X and owns stock in Company Y. Author C is a member of committee Z.

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