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Root Cause Analysis of Collapseable Aluminium Tube Failure on Lj-60 Type Impact Extrusion Press Machine Using The Fault Tree Analysis (Fta) Method

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Abstract--*The impact extrusion press machine is a machine that supports the manufacture of folded aluminium tubes. There are supporting components, namely dies and punches. These dies and punches have a lifespan and valuable life. Checking and replacing are necessary to be done regularly, as they have a significant impact on the quality of the tube. This research aims to analyze product failure resulting from the impact of extrusion press machines on the interaction between parts and dies and punches. Folding aluminium tubes are often used for glues, ointments, cosmetics, and other purposes. During the production process, leaks and defects were found in the tube. Tube quality that does not meet standards will cause various problems. The influence of settings on dies, punches, and skewed stamps results in the shape of the tube becoming ugly and unusable. The impact of the extrusion press machine and operator, apart from the dies and punch, also has a big influence on the results of collapsible aluminium tubes. Apart from these factors, continuous tilting pressure causes the mold to become chipped, scratched, and damaged. The method used to analyze failure is the Fault Tree Analysis (FTA) method. Leak testing on collapsible aluminum tubes was also carried out. Total tube production for the 6 months from October 2023 to March 2024 is 29.758.430. The amount of production varies; January 2024 is the month with the highest production (5,180,872), and December 2023 is the month with the lowest production (4,791,760). From the results of data processing, the total defects in collapsible aluminum tubes for 6 months were 1.386.809. The number of defects varies, November 2024 is the month with the most defects (256.765) and December 2023 is the month with the lowest defects (196.901). The highest percentage of defects occurred in January 2024 (5.12%) and the lowest in December 2023 (4.11%)..*

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1. INTRODUCTION

Production is defined as the fabrication and assembly process and all functions and activities that contribute directly to the creation of goods [1]. PT.XYZ is a manufacturing company that produces collapsible aluminum tubes. Collapsible aluminum tubes are made from an aluminum slug as a base material. Aluminum tube collapsible packaging has properties that are more flexible and easier to use; this is why packaging made from collapsible aluminum tubes is very suitable for use in the pharmaceutical sector. Certain types of medicines are packaged in collapsible aluminum tubes because they are more hygienic, not easily contaminated, and airtight; for example, skin ointment and eye ointment packaging. Collapsible aluminum tubes are also widely used in power glue, epoxy (iron glue) gasket glue, PVC glue, and sealants. One of the machines that plays a crucial role in the production of collapsible aluminum tubes is the impact extrusion press, which is used in the extrusion process. The extrusion process involves forming an aluminum slug into collapsible aluminum tubes. In this extrusion process, a special mold is used to form the basic aluminum slug material into collapsible aluminum tubes, which are then formed using dies and punches.

This mold determines whether the collapsible aluminum tube is good or defective in terms of its shape.

If the mold is good or in accordance with established standards, the collapsible aluminum tube results will be perfect. On the other hand, if the mold is in poor condition or damaged, the collapsible aluminum tube produced will also be of poor quality due to damage or deformation. Machines installed at PT. XYZ is an Impact Extrusion Press engine of the LJ-60 type, featuring a compressive capacity of 60 tons. It has a total power of 4.3 kW and a productivity level of 60 counts per minute. Based on the manual book, the maximum extrusion process on the LJ-60 type impact extrusion press machine, in 1 minute, produces ≤ 60 tubes. In reality, the machine is only able to produce 56-57 tubes per minute in 1 minute, representing a 4% decrease. Ideally, the LJ-60 type impact extrusion press machine produces 59-60 tubes per minute.

The final results of research on impact extrusion press machines can be a reference for PT. XYZ. In the production process of collapsible aluminum tubes, many defects or Damage are found, such as leaks, long or short lengths, and tears in the walls. By addressing these issues, researchers aim to minimize tube damage and defects. This must be prevented by overcoming the failure of collapsible aluminum tubes in die and punch parts. A collapsible aluminum tube failure occurred during the initial tube manufacturing process on the LJ-60 type impact extrusion press machine.

The author researched the LJ-60 type impact extrusion press machine. The press machine that the author researched was made in China. The author conducted research and collected data at PT. XYZ. The aluminum collapsible tube failure that occurred was caused by defects in the die and punch components, including tears, damaged walls, and leaks. Failure will affect the continuation of the next process. The failure rate is 1.4%

.

Making collapsible aluminum tubes requires several machines. One machine that plays an important role is the impact extrusion press machine. The impact extrusion press machine that we use is the LJ-60 type. The LJ-60 type impact extrusion press machine is capable of producing extrusions with diameters ranging from Ø11.4 mm to Ø18.9 mm. Below is a picture of the LJ-60 type impact extrusion press machine.

Figure 1. LJ-60 impact extrusion press machine (3D)

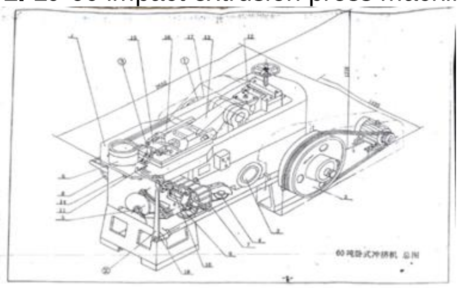


Figure 2. LJ-60 impact extrusion press machine (2D)

To overcome this problem, a Fault Tree Analysis method is necessary, which can help identify the root causes of a system's failure systematically and comprehensively. FTA is also used as a risk assessment method to eliminate risks in industrial processes [2].

2. METHODOLOGY

This research aims to identify events that cause failure of collapsible aluminum tubes in the LJ-60 type impact extrusion press machine. In this research, a flowchart was used. The form of the flowchart is as shown in the image below.

2.1. Flowchart

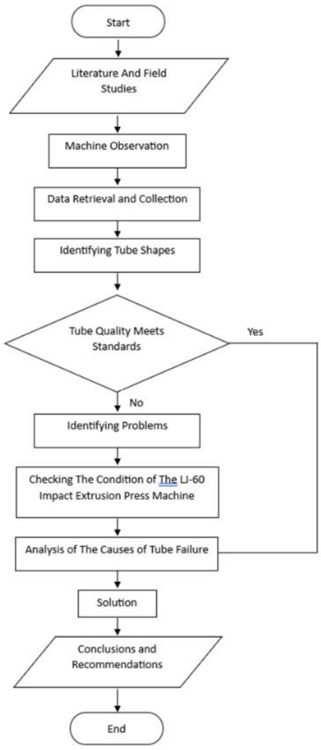


Figure 3. Tube failure analysis flowchart

The author collected data by observing the LJ-60 impact extrusion press machine directly in the production area at PT. XYZ. Apart from discussing the causes of tube failure, this research also provides solutions to overcome the failures that occur.

2.2 Tube Leak Testing Flowchart

Next, in Figure 3, is a flow diagram of tube leak testing

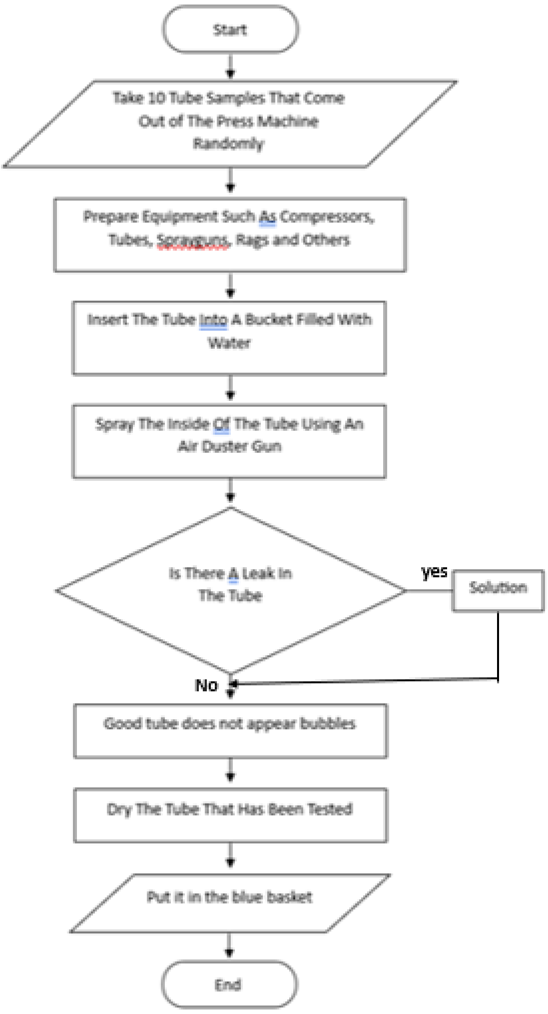


Figure 4. Tube Leak Testing Flowchart

Leak testing on collapsible aluminum tubes is conducted to ensure the tubes remain hygienic, maintain optimal tube quality and glue adhesion, and prevent contamination and leaks that can be detrimental to both consumers and the company. The following is a picture of leak testing on the tube.

Figure 5. Tube Leak Testing

There are several indicators that there is a leak in the aluminum collapsible tube. One of them is that bubbles or foam appear in the water. This process uses a pressure of 6 bar obtained from the compressor. There are seven steps for leak testing.

- Take 10 tube samples from the press machine at random.
- Cut the end of the tube so it is neater and doesn't stick out.
- After that, we spray it using a spray gun from inside, and put it in a bucket filled with water
- If a leak occurs, bubbles and water splashes will appear.
- A good tube will not leak.
- Then we separate the leaking tube and put it in a cardboard box.

- A good tube will be put in the box.

2.3 Failure

Failure can occur in both impact extrusion press machines and in dies and punches, as well as in vibratory feeder controllers and aluminum collapsible tubes. There are several causes of tube failure, one of which is due to the punch being off-center. This results in the aluminum slug not being able to be pressed properly, resulting in a defective tube. Failures can be overcome using the fault tree analysis method. Fault tree analysis (FTA) is a top-down approach to analyzing failures, starting with a potential event or accident called a top event and determining how the event could [3]. In Figure 6, the damaged tube is illustrated.

Figure 6. Extreme Damage to the tube

In Figure 7, there is a small leak in the collapsible aluminum tube

Figure 7. Leak in the tube

To reduce and avoid failures, changes and modifications to the system must be made, one of which is the installation of sensors.

2.4 Die Damage

Dies are molds found in impact extrusion press machines. Damage is often found on the dies. This part is made of tungsten, which is generally very hard. One of the damages to the dies occurred because the punch with the aluminum slug was not centered and tilted when extruded. As a result, the surface of the dies becomes lumpy, deformed, and uneven. In Figure 8. This is an example of Damage that occurred to the dies

Figure 8. Dies Damage

2.5 Stamp Damage

Stamps play an important role in forming a tube. When doing a replacement, the punch or stamp operator must reset the part.

(a) (b)

Figure 9. Figure (a) Stamp Damage, (b) Punch Damage

2.6 Fault Tree Diagram

In this research, the author uses the Fault Tree Analysis method. The following are the steps for creating a fault tree diagram, which include:

1. Set incident peak (Top Event)
   Top events are those located at the very top; it is usually very important to identify them. The top event in this case was that the press machine failed to produce tubes properly.

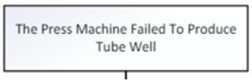


Figure 10. Top event

2. Determine Intermediate Event
   Intermediate events are those that occur in the middle, typically involving logic gates to describe the next event.

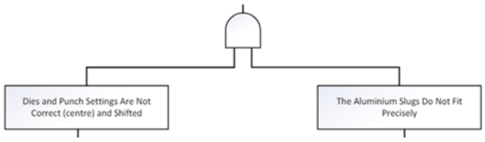


Figure 11. Intermediate event

3. Determining Cut Set
   A cut set is a series of system components that, if any one of them fails, can result in system failure.

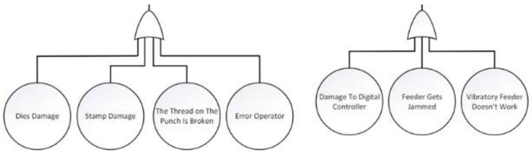
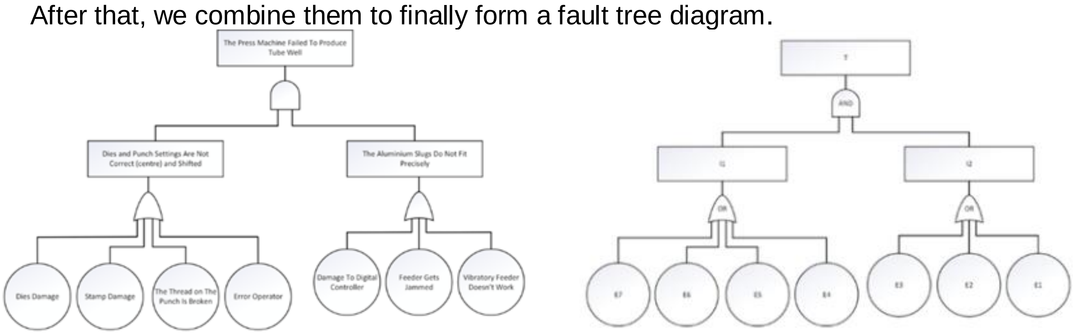


Figure 12. OR Gate and Basic Event

4. Make a Fault Tree Diagram
   After that, we combine them to finally form a fault tree diagram.



(a) (b)

Figure 13. Figure (a) Overall fault tree diagram, (b) Coding fault tree diagram

From Figure 13 (b). There is 1 AND gate and 2 OR gates. Fault tree diagram coding is divided into three codes, namely T, I, and E. For example:

- T is the top event
- I is an Intermediate event
- E is a basic event (primary event)
-

Apart from FTA, Boolean algebra is also very important. Boolean algebra is algebra related to binary values and logical operations [4].

2.7 Tools and Materials

In this research, the author used several tools, such as:

1. Sensor
   Sensors are tools that measure a physical or chemical property and convert it into a signal that can be processed by an electronic system [5]. The sensor is used to detect an aluminum slug on the feeder rail of the impact extrusion press machine. The sensor used in this research is the Autonics brand with type PRD12-8DN.
2. Power Supply

A power supply is a component that is used to supply or provide electrical power to one or many devices. Essentially, this power supply features a circuit construction that is nearly identical to that of a transformer, rectifier, and voltage stabilizer [6]. Here, the author uses a DC 24V power supply. Below is the shape of the power supply model S-120-24.

3. Relay
   A relay is an electronic device used to control the flow of electricity by using electrical signals from one source to control electrical signals at another source [7].
4. MCB
   MCB is a safety device used to limit the electric current and/or automatically break the circuit when a disturbance occurs [8]. Here, the author uses MCB 1P (Single Pole) from the Schneider Electric brand.
5. Pilot lamp
   A pilot lamp (pilot light) is also known as an indicator light. The pilot lamp is useful for monitoring the connection process [9]. Pilot lamps are available in various colors, including white, red, orange, yellow, green, and blue. The author uses a pilot lamp as an indicator of the presence or absence of aluminum slugs on the rail along the feeder.
6. Buzzer
   A buzzer is an electronic component that can produce sound vibrations in the form of sound waves [10]. The type of buzzer most commonly found and used is the piezoelectric buzzer. This buzzer requires a minimum voltage of 3V DC to operate, with a maximum voltage of 24V DC. In this case, the author uses a buzzer to indicate whether there are empty aluminum slugs on the rail along the feeder.

3. RESULT AND DISCUSSION

3.1 Failure Calculation

The author has carried out calculations using Boolean algebra. Meanwhile, the FTA calculation uses quantitative analysis. Then we get the Boolean Equation, namely:

$$\mathrm{T1} = \mathrm{I1} + \mathrm{I2}$$
$$\mathrm{I1} = \mathrm{E7} + \mathrm{E6} + \mathrm{E5} + \mathrm{E4}$$
$$\mathrm{I2} = \mathrm{E3} + \mathrm{E2} + \mathrm{E1}$$

Then we combine this Equation into a single equation, so that the Equation becomes:

$$\mathrm{T1} = \mathrm{E7} + \mathrm{E6} + \mathrm{E5} + \mathrm{E4} + \mathrm{E3} + \mathrm{E2} + \mathrm{E1} + \mathrm{I2}$$
$$\mathrm{T1} = (\mathrm{E7} + \mathrm{E6} + \mathrm{E5} + \mathrm{E4}) + (\mathrm{E3} + \mathrm{E2} + \mathrm{E1}) + \mathrm{I2}$$

For the sub-gate probability formula that the author uses, it can be seen in Equations (1) and (2):

$$P(I_1) = 1 - \{(1 - P(E_7))(1 - P(E_6))(1 - P(E_5))(1 - P(E_4))\} \quad (1)$$

$$P(I_2) = 1 - \{(1 - P(E_3))(1 - P(E_2))(1 - P(E_1))\} \quad (2)$$

Next, we calculate the total probability of the new system for each basic event.

A. Count probability (I_1):
   $P(I_1) = 1 - (1 - 0.12)(1 - 0.46)(1 - 0.048)(1 - 0.116)$
   $P(I_1) = 1 - (0.88)(0.54)(0.952)(0.844)$
   $P(I_1) = 1 - 0.381$
   $P(I_1) = 0.619$
B. Count probability (I_2):
   $P(I_2) = 1 - \{(1 - 0{,}02)(1 - 0.141)(1 - 0.015$
   $P(I_2) = 1 - (0.98)(0.859)(0.985)$
   $P(I_2) = 1 - (0.829)$
   $P(I_2) = 0{,}171$
C. Calculate the probability of total system failure:
   $P(T) = 1 - (1 - 0.619)(1 - 0.171)$
   $P(T) = 1 - \{(0.381)(0.829)\}$
   $P(T) = 1 - (0.315)$
   $P(T) = 0.685$

The probability of total system failure is 0.685 or 68.5%.
From these calculations, the probability of failure value is obtained.

Table 1. Probability of the cause of Damage

Number	Basic Events	Probability
1	Dies Damage	12%
2	Stample Damage	54%
3	The thread is broken	4.8%
4	Operator faults	11.6%
5	Digital controller failure	2%
6	The feeder gets stuck	14.1%
7	Vibratory feeder not working	1.5%

The primary failure is caused by stamp damage, accounting for 54%. Meanwhile, the smallest failure probability value is caused by the feeder not running properly, which is 1.5%. For more details, see the image below.

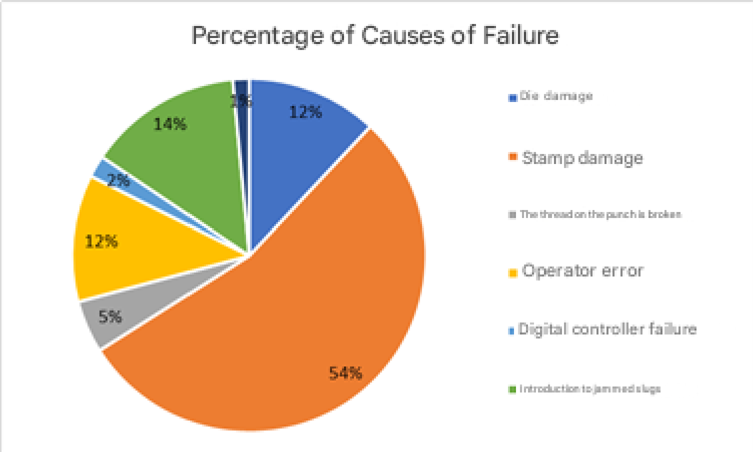


Figure 14. Circle diagram of causes of Damage

3.2 Tube Production

Data collected from November 2023 to April 2024.

Table 2. Collapsible aluminum tube failure data

Number	Collapsible Aluminum Tube Failure Data					
	Month	Production Amount	Number of Failures or Defects			
			Leaking Membrane	Leaking Wall	Tube Scratches	Short Tube
1	November	5.037.923	60.571	67.873	69.103	59.218
2	December	4.791.760	49.872	50.101	48.525	48.403
3	January	5.180.872	62.985	70.294	71.909	60.192
4	February	4.803.918	50.314	51.879	49.032	49.561
5	March	5.001.406	60.609	65.780	70.312	57.320
6	April	4.316.571	48.198	46.159	42.304	40.185
Total		29.132.450	332.549	352.086	351.185	314.879

From Table 2. The total production amount of collapsible aluminum tubes is 29.132.450. For membrane leakage, it is 332.549, while for wall leakage, it is 352.086. Meanwhile, the scratched body tube is 351.185. Then, for the short tube dimensions, it is 314.879.

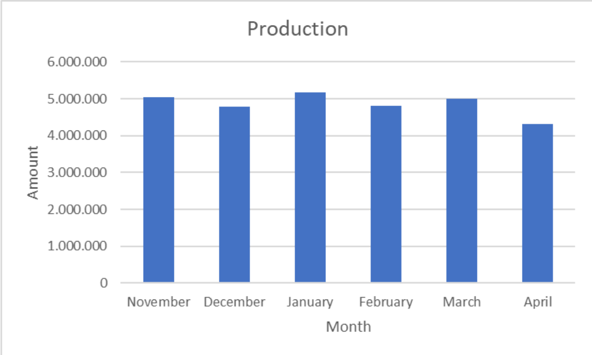
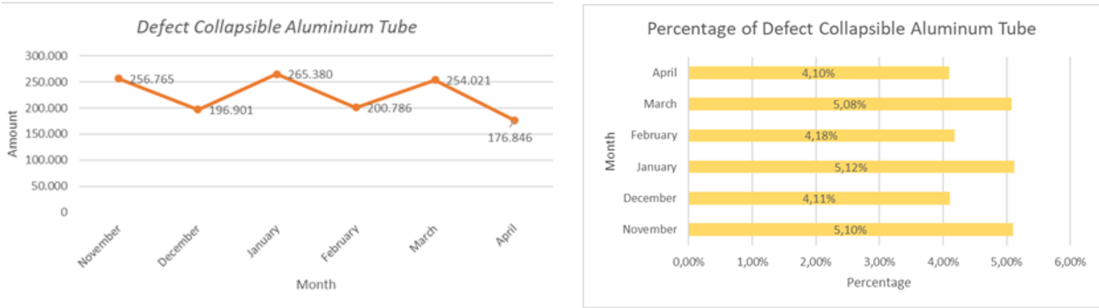


Figure 15. Production for 6 months

The picture above shows the number of tubes produced for 6 months from November 2023 to April 2024. In January, tube production was very high, namely 5.180.872. The lowest was in April, namely 4.316.571. From Table 2. Then we get the defects of the collapsible aluminum tube.



(a) (b)

Figure 13. Figure (a) Defect on the tube, (b) Percentage in a way whale

Based on Figure 4.2, the minimum number of defects in collapsible aluminum tubes is expected to occur in April 2024, specifically 176.846. Meanwhile, the highest number of defects occurred in January 2024, namely 265.380. Based on Figure 13(b), the smallest percentage is in April 2024, specifically 4.10%. Meanwhile, the largest percentage was in January 2024, namely 5.12%. The monthly variations indicate a fluctuation in the data.

3.3 Calculation

To ensure that the results are more accurate and presented in numerical form, the author calculated the compressive force on an LJ-60 type impact extrusion press machine. The calculated force can be formulated as shown in Equation (3).

$$F = m\ x\ g \quad (3)$$
$$F = 4275.738\ x\ 9.8$$
$$F = 41902.2324\ N$$

So the force acting on the machine is 41902.2324 N. Then, calculate the pressure generated on the die with a punch diameter of 5 mm. The pressure formula is shown in Equation (4).

$$P = \frac{F}{A} \quad (4)$$
$$P = \frac{F}{\pi r^2}$$
$$P = \frac{41902{,}2324}{3{,}14\ x\ 5^2}$$
$$P = 533.7864\ Mpa \approx\ 533.8\ Mpa$$

Thus, the pressure of the die and punch component is obtained at 533.8 MPa.Next is the timing calculation. Timing calculations on the feeder line and vibratory bowl are necessary to determine the time required for the aluminum slug to fall or move downward towards the die ring housing correctly. The following are the results of the feeder timing calculations.

$$t = \frac{s}{v 2\pi cos\alpha}$$

$$t = \frac{23}{10\ x\ 2\ x\ \pi\ x\ cos 15^{\circ}}$$

$$t = 0.3789\ s \approx 0.38\ s$$

By doing so, we get the timing of the fall of the aluminium slugs, which is 0.38 s

3.4 Prototype

The aim of making this prototype is to test the accuracy and ability of the proximity sensor to detect aluminium slugs. The system is then assembled as shown in Figure 14.

Figure 14. Planning system detection of aluminium slugs

After that, we run the system as shown in Figure 15.

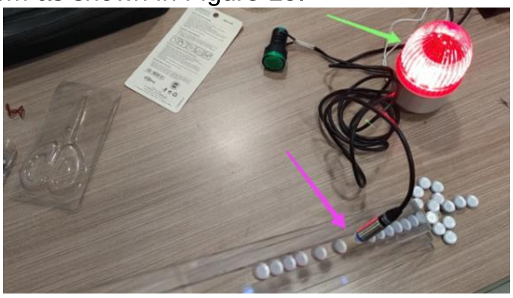


Figure 15. Running conditions

Testing of the prototype has been carried out. The test results indicate that this detection system functions properly, with the green indicator light in standby, the buzzer sounding loudly, and the flasher flashing normally. This type of proximity sensor is also very sensitive and is suitable for application on LJ-60 type impact extrusion press machines.

3.4 Simulink

Here, we utilize the MATLAB Simulink R2019a software to simulate the sensor, ensuring it operates properly. The following is a system capture created using MATLAB Simulink software.

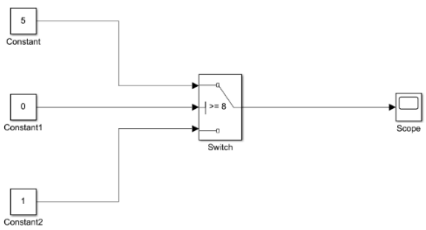


Figure 22. Sensor simulation with Simulink

The simulation results also run smoothly, as shown in the image below. A value of 1 indicates that the proximity sensor has detected an object.

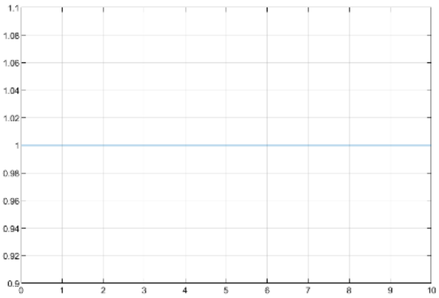


Figure 23. Scope output

4. CONCLUSION

Based on analysis using FTA, the failure of collapsible aluminum tubes is due to Damage to the die and punch components, Damage to the stamp, and also due to the influence of off-center punch settings. Apart from that, the main cause of Damage is caused by damaged stamp components. According to the fault tree diagram, the probability of stamp damage is 54%. This prototype system is specifically designed to reduce the failure of collapsible aluminum tubes. The sensing distance of the Autonics PRD12-8DN sensor is 8 mm. Through testing, it was found that the proximity sensor can effectively detect aluminum slugs.

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