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Failure Mode Effect Analysis (FMEA) of Brake Pedal Lever of Automobile Light Motor Vehicle

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Abstract:

In a today's competitive word, many manufacturing industries are trying to decrease costs while maintaining quality value and reliability. In the manufacturing industry, correct processes & the well-maintained machineries are necessary because downtime can slowdown and stop production. Present work study explore the causes of production of faulty components in the manufacturing industry for enhanced productivity, reliability, and availability. Present work is focused on identifying potential failures modes, of brake pedal lever component of braking system of automobile light motor vehicle using Failure Mode and Effects Analysis (Process- FMEA), Risk Priority Number (RPN). To analyze and identify critical processes in the manufacturing of brake pedal levers by evaluating failure modes and their causes, assessing their impact on reliability, safety, availability, and maintainability, and implementing strategies for process optimization and risk mitigation.

This work contains the Process- FMEA of brake pedal lever of automobile considering the manufacturing aspects. In this work, the manufacturing process of brake pedal lever was assessed critically. Causes of manufacturing defects were identified & corrective actions were taken to prevent these defects. Using FMEA tool the process had been corrected.

FMEA is a great tool for failure analysis, as it helps to prevent failures or reduce their impact. FMEA has provided the opportunity for the manufacturing of correct component & it ensures the detection of causes of faulty/rejected component. As a result, the quality, reliability and safety of a system or product are improved. This can result in improved customer satisfaction and loyalty, as well as reduced costs and risks associated with failures.

This tool provides an analysis of critical part of braking system. The FMEA analysis of brake pedal lever right from in ward of raw material to final inspection has been done. The Cross Functional Team - CFT (having knowledge and understanding of the product or process, its components, functions, interactions, and potential failure modes and effects) of FMEA make brainstorming on the process. Potential causes/modes, effects & corrective actions are identified. The corrective actions have been implemented. After the proper implementation of corrective actions the Risk Priority Number – RPN is calculated. After making the calculation, it was observed that there is significant reduction in RPN No.

From this paper focus on a systematic methodology for applying Failure Mode and Effects Analysis (FMEA) to the manufacturing process of the brake pedal lever in an automobile braking system, focusing exclusively on identifying, analyzing, and mitigating potential failure modes to enhance process reliability and efficiency.

***Keywords*-**Braking system, brake pedal lever, FMEA, RPN, reliability, safety, potential causes

1. INTRODUCTION

Industrial activity has grown to an infinite size during this globalization period. Technological progress have been made in mechanical engineering field. Which brought out more intricate and new designs of mechanical engineering systems. It is necessary to maintain such intricate designs. It requires a systematic model & framework in order to keep industrial facilities up to date & serves the need of the system.

Failure mode & effect analysis is a tool is used to ensure correctness in manufacturing process. It is used to reduce the production of faulty of component in industries. This work contains the Process- FMEA of brake pedal lever of automobile considering the manufacturing aspects. The present work has been conducted at Rucha Engineers Pvt. Ltd. Plant- VII MIDC Waluj, Aurangabad (Chhatrapati Sambhajinagar). The pedal or lever, is the part used to activate the braking function. The vital function of brake lever is to activate the brake mechanism, which allows people to stop or decrease speed while they are riding a vehicle. This component is generally located at the bottom of the steering wheel or beside the accelerator pedal. The mechanical brake that is activated by a pedal or lever in most vehicles is called the power brake. The brake pedal lever identified for the study is used in braking system of Volkswagen car.

However, in reality, every process would contain unwanted faultiness. This results in the inefficiency of the system and components. When such things are happen it ultimately results in unwanted output and unhappy customers and leads to higher maintenance cost. The brake pedal lever, is the part used to activate the braking function which is an essential part in braking system of automobile. Failure of it will adversely affect on braking operations, production rate & safety of drivers. Process-Failure Mode and Effect Analysis (FMEA), is the valuable tool which is used to predict problems that might arise during the manufacturing of brake pedal lever.

2. PROBLEM IDENTIFICATION

Customer feedback on brake pedal lever manufacturing indicates challenges in assessing its reliability, which poses difficulties in ensuring optimal operational performance. Without a clear understanding of potential failure points, maintaining consistent quality and durability becomes complex. One effective approach to address this issue is conducting a Process Failure Mode and Effects Analysis (Process-FMEA). This tool systematically identifies failure modes, their causes, and potential effects on the manufacturing methods. By analyzing each stage of production, it becomes easier to pinpoint critical areas requiring improvement. Implementing FMEA allows manufacturers to proactively mitigate risks and enhance product reliability. It also helps in optimizing production efficiency by reducing defects and unplanned downtime. Moreover, this structured approach ensures compliance with industry standards and safety regulations. As a result, manufacturers can improve the overall quality and longevity of the brake pedal lever. Ultimately, FMEA serves as a valuable tool for achieving high performance and reliability in manufacturing.

3. EXPERIMENTAL ANALYSIS

It is necessary to identify process problems before they occur. In present work Failure Mode Effect Analysis (FMEA) tool is applied. This tool focuses on when and how a system will stop working. In present work each failure mode is evaluated for Severity (S) Occurrence (O) & Detection (D). A grouping of the three ratings generates a risk priority number (RPN). The generated RPN is then gives a ranking system to prioritize which problem must requires more attention first. This Process - Failure Mode and Effects Analysis must be done in a step-wise manner as mentioned below:

Overview of Manufacturing Process of Component- Brake pedal lever:

The present study was conducted at Rucha Engineers Pvt. Ltd, MIDC Waluj, Aurangabad. The overview of the manufacturing processes involved had been taken in this article. The process flow of brake pedal lever manufacturing is as mentioned below:

Table: 1 Sequence of the process

Sr. No.	Name of Manufacturing Process
1	Raw material Receipt & Inspection
2	Blanking
3	Forming
4	Piercing
5	Re strike
6	Inspection (Visual + Panel checker)

Details of material used for the component:

- The material of the brake pedal lever is S355 MC, EN (European Standard) 10140:
- Hot rolled steel strip
- S 355 MC means- minimum yield (Average) for S355 steel is 355 N/mm²

Mathematical Model

The equation of Risk Priority Number (RPN) is as mentioned below: The rankings for Occurrence, Detection and Severity are as stated in respectively. Based on the requirement of customer appropriate ranking for Severity (S) Occurrence (O) and Detection (D) were assigned.

RPN=Occurrence (O) x Detection (D)x Severity(S)

Procedure:

Use of Failure Mode Effect Analysis:

Step 1: Recognition of Manufacturing Process of Brake Pedal Lever

Table 2: Sequence of Manufacturing Process

Sr. No.	Manufacturing Process
1	Raw material Receipt & Inspection
2	Blanking
3	Forming
4	Piercing
5	Re strike
6	Inspection (Visual + Panel checker)
7	WIP Storage

Step 2: Identifying Manufacturing Process/product Requirement

Sr. No.	Process	Product Requirement
1	Raw Material Receipt & Inspection S355 MC, EN 10140, (**Hot rolled steel strip):** Thickness 6 mm	Chemical Composition OK & Accepted as per S355MC, EN 10140, Thickness 6 mm
		Mechanical properties OK & Accepted as per S355MC, EN 10140, Thickness 6mm
		Material Thickness 6mm OK & Accepted
		No Damages
2	Blanking	No Damage, Dent mark
		Burr / edge finish as per VW 01088 +0.2mm
		No Blank cut
		No Blank OS / US
3	Forming	No Crack on part
		Wrinkles & tearing on part
		Thinning not more than 20% of part Thickness
		No Damage, No Dent mark
		No Scoring mark
		Forming Height as per specified
4	Piercing	Burr / edge finish as per Customer standard +0.2 mm
		No hole US
		No Hole Missing
		No Hole Shift
		No In complete hole piercing
5	Re strike	No Crack on part
		Wrinkles & tearing on part
		Thinning not more than 20% of part thickness
		No Damage, No Dent mark
		No Scoring mark
6	Inspection (Visual + Panel checker)	No NC part Mix with OK part
		100 % Inspection
7	W.I. P. Storage	No Dust, dirt, handling damage

Table 3: Identifying Manufacturing Process/Product Requirement

Sr. No.	Process	Product Requirement
1	Raw Material Receipt & Inspection S355 MC, EN 10140, (**Hot rolled steel strip):** Thickness 6 mm	Chemical Composition OK & Accepted as per S355MC, EN 10140, Thickness 6 mm
		Mechanical properties OK& Accepted as per S355MC, EN 10140, Thickness 6mm
		Material Thickness 6mm OK & Accepted
		No Damages
2	Blanking	No Damage, Dent mark
		Burr / edge finish asper VW 01088 +0.2mm
		No Blank cut
		No Blank OS / US
3	Forming	No Crack on part
		Wrinkles &tearing on part
		Thinning not more than 20% of part Thickness
		No Damage, No Dent mark
		No Scoring mark
		Forming Height as per specified
4	Piercing	Burr / edge finish as per Customer standard +0.2 mm
		No hole US
		No Hole Missing
		No Hole Shift
		No In complete hole piercing
5	Re strike	No Crack on part
		Wrinkles &tearing on part
		Thinning not more than 20% of part thickness
		No Damage, No Dent mark
		No Scoring mark
6	Inspection (Visual + Panel checker)	No NC part Mix with OK part
		100 % Inspection
7	W.I. P. Storage	No Dust, dirt, handling damage

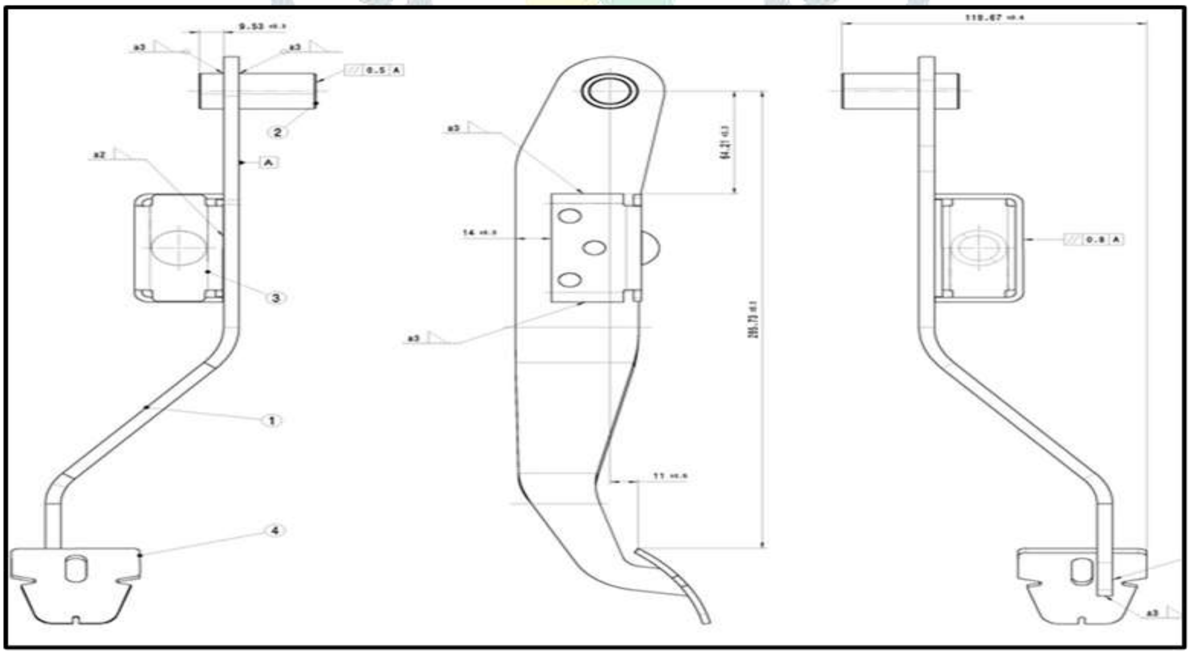

Figure 3.1 Part Drawing- Brake Pedal Assembly

Figure 3.2 Image of Actual Part: Brake Pedal Lever

The **brake pedal lever** is a vital part of the **braking system** in an automobile. Brake pedal lever is the mechanical link between the driver's foot and the brake mechanism, ensuring efficient braking operation. The lever is typically made of **high-strength steel (S355 MC, EN 10140)** to withstand repeated stress and ensure durability. In the **manufacturing process**, the lever undergoes multiple stages such as **blanking, forming, piercing, re-striking, and inspection** to ensure dimensional accuracy and defect-free production. Any failure in the brake pedal lever, such as cracks, improper forming, or material defects, can lead to reduced braking efficiency and potential safety hazards.

Step 3- Recognition of Failure Modes, its effects & potential causes:

From the customer feedback & literature study numerous potential failure modes, its effects & potential causes have been identified as per Table No.

Sr. No.	Process	Possible Failure Modes (Process Defects)	Possible Effects of Failure	Possible Causes of Failure
1	Raw material Receipt & Inspection S355MC, EN 10140, Thickness: 6 mm	Chemical Composition not OK & Accepted	NP (Next Procedure): - Nil SP (Subsequent Procedure): - Rejection CE (Customer End): - Rejection UE (User End): -Nil	1.Wrong material supplied 2. Inspection method not followed
		Mechanical properties Not OK & Accepted	NP: - Nil SP: - Rejection CE: -Rejection UE: -Nil	1.Wrong material supplied 2. Inspection method not followed
		Material Thickness is not OK & Accepted	NP: - Nil SP - Rejection may happen & Tool Breakdown CE - Rejection UE: -Nil	1. Wrong material supplied 2. Inspection method not followed
		Damages	NP - rework or rejection may happen. SP - rework or rejection may happen. CE: -Nil UE: -Nil	1. Transportation Damages 2. Material Handling System is poor.
2	Blanking	Damage, Dent mark	NP-Reject SP-Reject CE-Reject UE-Dissatisfaction	1. Unwanted dust & particles on die surface. 2. Strip properly not locked.
		Burr / Edge Finish more than +0.2mm	NP-Reject / Rework SP-Reject / Rework CE-Reject UE-Dissatisfaction	1. Improper Clearance between die & punch 2. Press Machine Alignment not ok 3. Raw material grade & thickness not ok 4. Operator Awareness 5. Un Skilled Operator 6. Improper part handling
		Blank cut	NP: - Reject SP: - Reject CE: - Customer Dissatisfaction UE: - May Cause the failures/ Reduce the level of performance / comfort	1. Strip stopper position not ok 2. Operator Awareness 3. Stopper pin wear 4. Locating pin alignment not ok 5. Coil feeder setting not ok
		1. Blank OS / US	NP: - Reject SP: - Reject CE: - Customer Dissatisfaction UE: - May Cause the failures/ Reduce the level of performance/comfort	1. Improper Location pin pper wear 3. Stopper position not ok
		Crack on part	NP: - Reject SP: - No effect CE: - No effect UE:- No effect	1. Excess die entry 2. Entry stopper height not ok 3. Lack of Lubrication at the sheet /punch interface 4. High Cushion pressure
		No Wrinkles& Tearing on part	NP:- Reject SP:- Reject CE:- Customer Dissatisfaction UE:- May Cause the failures/ Reduce the level of performance/comfort	1.Blank holding force not ok 2. Cushion pin height not ok 3. Low Cushion pressure
		Thinning more than 20% of part thickness	NP:- Reject SP:- Reject CE:- Customer Dissatisfaction UE:- May Cause the	1. Improper clearance between die & punch 2. Improper Oil application 3. Machine condition or parameter not ok

3	Forming		failures/ Reduce the level of performance/comfort	
		Damage, Dent mark on part	NP-Reject SP-Reject CE-Reject UE-Dissatisfaction	1. Unwanted dust & particles on die surface. 2. Part properly not locked.
		Scoring mark on part	NP-Reject / Rework SP-Reject CE-Dissatisfaction UE-Dissatisfaction	1. Improper clearance between die & punch. 2. Improper Oil application 3. Unwanted dust & particles on die surface. 4. Scratches or Rough surface of die bottom
		Less Formed Height	NP:- Rejection SP :- Nil CE :- Dissatisfaction & Rejection VF :- Rejection UE :- May reduce the level of performance / Comfort	1. Improper Shut Height 2. Wrong machine Parameter Setting 3. Wrong Cushion Pressure Setting
4	Piercing	Burr / edge finish more than (+0.2mm)	NP-Reject / Rework SP-Reject / Rework CE-Reject UE-Dissatisfaction	1. Improper Clearance between die & punch 2. Press Machine Alignment not ok Raw material grade & thickness not ok: 5. Operator Awareness 6. Un Skilled Operator 7. Improper part handling
		Hole US	NP:- Reject SP:- Reject CE:- Reject UE:- Nil	Piercing punch wear
		Hole Missing		Piercing punch Break
		Hole Shift		Improper Location
		Incomplete hole piercing		Improper die setting
5	Re strike	Crack on part	NP :- Reject SP:- No effect CE: - No effect UE :- No effect	1. Excess die entry 2. Entry stopper height not ok 3. High Cushion pressure
		No Wrinkles& Tearing on part	NP:- Reject SP:- Reject CE:- Customer Dissatisfaction UE:- May Cause the failures/ Reduce the level of performance/comfort	1. Cushion pin height not ok 2. Low Cushion pressure
		Thinning more than 20% of part thickness	NP: - Reject SP: - Reject CE: - Customer Dissatisfaction UE: - May Cause the failures/ Reduce the level of performance/comfort	1. Improper clearance between die & punch 1. Machine condition or parameter not ok
		Damage, Dent mark on part	NP-Reject SP-Reject CE-Reject UE-Dissatisfaction	1. Unwanted dust & particles on die surface. 2. Part properly not locked.
		Scoring mark on part	NP-Reject / Rework SP-Reject CE-Dissatisfaction UE-Dissatisfaction	1. Improper clearance between die & punch. 4. Rough die bottom surface 3. Unwanted dust & particles on die surface.
6	Inspection (Visual + Panel checker)	Mix up of NC parts with ok parts.	NP- Rejection may happen VF- may Not be OK UE- May Cause Failures OR Reduced level of Performance, So Customer Dissatisfaction	1. Un identified area / bin for NC parts
		Material dispatch without	NP- Rejection may happen	1. Inspection not carried

		inspection	VF- may Not be OK UE- May Cause Failures OR Reduced level of Performance, So Customer Dissatisfaction	out 2. Inspector Negligence
7	W.I. P. Storage	Dust, dirt, handling damage	NP - Nil SP - Nil CE: - Customer Dissatisfaction UE - Nil	1. Improper Material Handling System

Step 5: Assigning Severity (S) No. to Failure mode & Occurrence (O) No Failure Causes. & Detection No. (D) to Causes & Developing RPN No.

Risk priority number (RPN) is a function of the three factors as discussed in above, viz, the severity of the effect of failure, the probability of occurrence, and the simplicity of detection for each failure mode. The Risk Priority Number No. is applied to *prioritize high-risk matters*. In this segment, RPN numbers are developed by using Equation based on the grouping of occurrence (O), detection (D) and severity (S) ranks in Tables. Risk Priority Number -RPN is calculated for each failure recorded. RPN is calculated by using the following formula:

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

Specifically,

S refers to the severity

O is the occurrence

D refers to the detection o

In this study, as per the guidelines of Automotive Industry Action Group (AIAG) which currently compiles the FMEA standards, the ranking/rating of SOD are decided & assigned & according RPN is calculated.

Developing RPN Number:

Based on Severity, Occurrence & Detection ranking Risk Priority Number (RPN) was calculated. RPN will help in representing the areas of greatest attentiveness. A failure mode with a high Risk Priority *N*umber should be given the highest priority in the analysis and corrective measures taken.

The RPN value for each failure varies between 1 and 100. Threshold RPN is the maximum Risk Priority Number (RPN) below which the risk is considered as acceptable or inevitable. As per customer requirement, RPN value should be below 100. After making calculation for each Failure mode it was observed that RPN value for the failure **mode CRACK ON PART was 112 which** is not acceptable to the customer. That RPN No has to be brought below 100 by taking corrective actions on the potential causes of the failure. Corrective measures were taken on failure mode -Crack on Part having RPN 112. After taking corrective actions SOD ranks were reassigned & RPN No. was again calculated.
The details of assigning SOD value are as discussed below:

A. On Assigning Severity Rank: Failure mode: Crack on Part:

1. The effect of this mode is Loss or degradation of Primary function

Criteria: Severity of effect on Product (Customer Effect) is

Degradation of Primary function (Vehicle operable but at reduced level of performance)

2. The effect of this mode is significant disturbance

Criteria: Severity of effect on Product (Manufacturing /Assembly effect) is

A portion of the production may have to be scrapped. Deviation from primary process including decreased line speed or added manpower.

Severity rank of this effect on product is 7

B. On Assigning Occurrence Rank:

Failure Cause:

1. *Excess die entry:*
2. *Criteria: Occurrence of Cause PFMEA (Incidents per items/vehicles) is 1 ppm (1 in 10,00000)*

Likelihood of failure is LOW with rank 2

C. On Assigning Detection Rank:

From the detection rating table Likelihood of Detection by Process control is:

Failure Mode detection post processing by the operator through use of variable gauging or in station by operator through use of attribute gauging.

Opportunity of Detection is

Problem Detection post Processing

Failure Mode was detected by use of pressure sensor which was used to warn about increase or decrease in value of cushion pressure. Hence it was detection in process by the operator through use of Pressure sensor to detect the mode of failure.

The likelihood of this detection was LOW with ranking 6.

Developing RPN Number:

Based on Severity, Occurrence & Detection ranking Risk Priority Number was calculated again. The RPN value for each failure varies between 1 and 100. Threshold RPN is the maximum Risk Priority Number (RPN) below which the risk is considered as inevitable or acceptable. As per customer requirement RPN value should be below 100. After making Calculation for each Failure mode, it was observed that RPN value for the failure mode CRACK ON PART was 84which was acceptable to the customer.

Table 4: RPN Calculation after Taking Corrective Actions

Failure Mode	Potential Cause	Corrective actions taken	Responsibility	S	O	D	RPN
Crack on Part	1. Excess die entry	Recommended that Die Setting will be Through Skilled die setter	FMEA CFT	7	2	6	**84**
	2. Entry stopper height not ok	It is recommended to prepare the Tool PM schedule & insist for implementation	FMEA CFT		2	6	**84**
	3. Lack of Lubrication at the sheet /punch interface	To apply Lubrication, draw oil on punch & the sheet interface so that complete forming operation is carried out without crack.	FMEA CFT		2	6	**84**
	4. High Cushion pressure	Identify the standard value of cushion Pressure & pressure Sensor is to be used to warn about increase or decrease in pressure value.	FMEA CFT		2	6	**84**

As per customer requirements, the Risk Priority Number (RPN) should be below 100. After calculating the RPN values for different failure modes in the manufacturing process of the brake pedal lever, it was observed that the failure mode **"Crack on Part"** had an RPN value of **112**, which was not acceptable to the customer.

To bring the RPN below the acceptable limit, corrective actions were taken to address the root causes of failure. These corrective actions included:

- Ensuring that **die setting** is done by skilled die setters.
- Implementing a **Tool Preventive Maintenance (PM) schedule** to prevent tool-related defects.

- Applying **lubrication** on the punch and sheet interface to avoid cracks in the forming operation.
- Using a **pressure sensor** to monitor cushion pressure variations and prevent excess pressure application.

After implementing these corrective actions, the **RPN value for "Crack on Part" was reduced from 112 to 84**, making it acceptable to the customer. This indicates that the **Failure Mode and Effects Analysis (FMEA)** approach was successful in recognizing and mitigating high-risk failures in the manufacturing process.

However, challenges remain in applying FMEA effectively in real-world conditions. The analysis requires **significant time and meticulous data collection**, making it resource-intensive. Additionally, FMEA focuses on **individual components rather than system-wide failures**, which may limit its ability to address **common mode or systemic failures** affecting multiple components.

4. RESULT AND DISCUSSION:

As per customer requirements, the Risk Priority Number (RPN) should be below 100. After calculating the RPN values for different failure modes in the manufacturing process of the brake pedal lever, it was observed that the failure mode **"Crack on Part"** had an RPN value of **112**, which was not acceptable to the customer. To bring the RPN below the acceptable limit, corrective actions were taken to address the root causes of failure. These corrective actions included:

- Ensuring that die setting is done by skilled die setters.
- Implementing a Tool Preventive Maintenance (PM) schedule to prevent tool-related defects.
- Applying lubrication on the punch and sheet interface to avoid cracks in the forming operation.
- Using a pressure sensor to monitor cushion pressure variations and prevent excess pressure application. After implementing these corrective actions, the RPN value for "Crack on Part" was reduced from 112 to 84, making it acceptable to the customer. This indicates that the Failure Mode and Effects Analysis (FMEA) approach was successful in recognizing and mitigating high-risk failures in the manufacturing process. However, challenges remain in applying FMEA effectively in real-world conditions. The analysis requires significant time and meticulous data collection, making it resource-intensive. Additionally, FMEA focuses on individual components rather than system-wide failures, which may limit its ability to address common mode or systemic failures affecting multiple components.

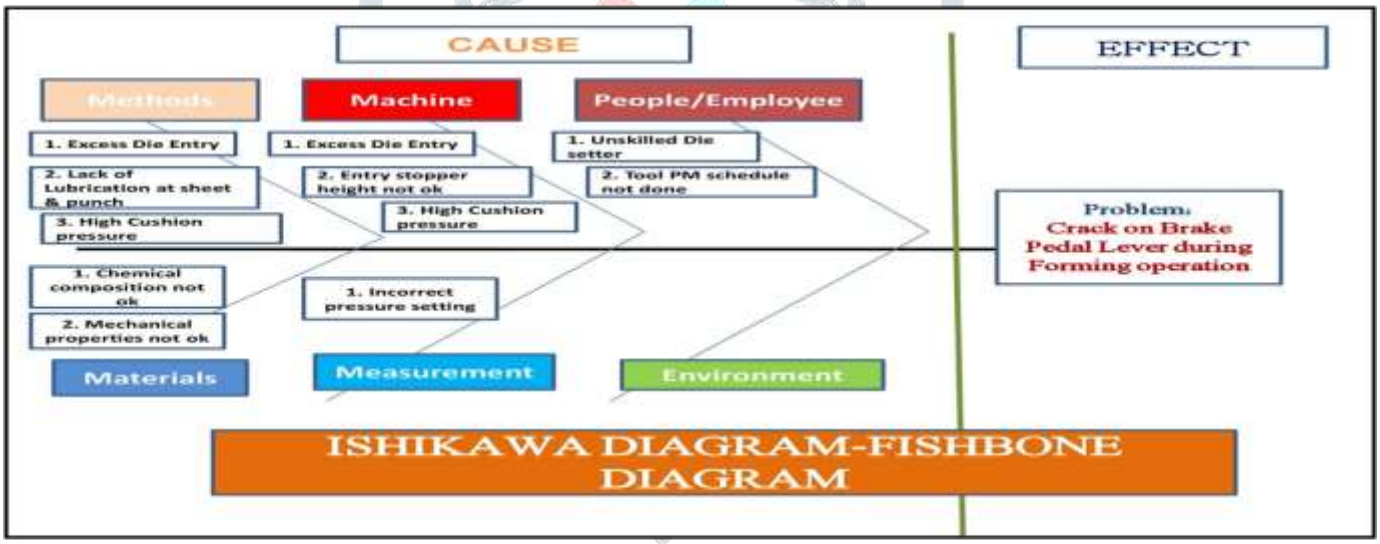

Figure: 4.1 Ishikawa Diagram of the Present Case

5. CONCLUSION:

Failure Mode Effect Analysis (FMEA) gives a systematic model and framework to conduct an experimentation regarding potential failures that may occur in Manufacturing process of Brake Pedal Lever. Analysis was conducted on each manufacturing stage of Brake pedal lever such as blanking, Piercing, Forming, re striking. Each of the sub process was identified having several failures associated with it. FMEA on Manufacturing process of Brake Pedal Lever, a complete view of an entire process and sub process of interest can be conducted. This provide directions to the manufacturing & maintenance team who are engaged in reduction & prevention of failures that may occur during production. By identifying and recognizing potential failures that might occur at various area of the Manufacturing process of Brake Pedal Lever, appropriate scheduled maintenance programme for the parts of interest and prevent critical failures by focusing on the most critical process, which is the equipment with the highest RPN value. In this study, the critical process identified was the forming having highest RPN value of 112.
After initiating corrective action RPN Value changes from 112 to 84 which was acceptable to the customer.
Apart from FMEA benefits, it could prove to be somewhat hard to practice in real working atmosphere because it requires a lot of time to complete the investigation due to the careful nature of the analysis.

- The drawback of this investigation of FMEA is that it focuses on a single component at a time. It does not deal with the effects of common mode or common cause of failures, which arise between parts that are similar or identical in design or can otherwise be affected by a shared cause resulting in multiple simultaneous failures. FMEA analysis is team work or activity. To identify failure modes is CFT - team requires through knowledge of the process. The team also needs time to go thoroughly into the process or design.

- At this stage, if CFT- team doesn't do a detailed work, an important failure mode could be left alone, waiting to occur.

6. SCOPE OF FRUTURE WORK

The current study on Failure Mode and Effects Analysis (FMEA) of Brake Pedal Lever Manufacturing has successfully identified and mitigated critical failure modes. However, there are several areas for future research and improvement:

- Integration of Advanced Technologies
- Implementation of Artificial Intelligence and Machine Learning for practical failure prediction.
- Use of IoT sensors to continuously monitor critical parameters such as cushion pressure, lubrication levels, and tool wear for predictive maintenance.
- Expansion of FMEA Application
- Extending FMEA beyond individual components to a system-level analysis for identifying common cause failures across multiple parts
- Application of Design FMEA (DFMEA) alongside Process FMEA (PFMEA) to optimize both product design and manufacturing processes simultaneously.
- Optimization of Manufacturing Processes
- Investigation of alternative materials that enhance durability while maintaining cost efficiency.
- Exploration of additive manufacturing (3D printing) techniques to reduce defects in production.
- Automation in Quality Control
- Adoption of computer vision and automated inspection systems to minimize human errors in quality checks.
- Implementation of robotic process automation (RPA) in material handling and assembly processes.
- Development of a Risk-Based Decision Model
- Enhancing the Risk Priority Number (RPN) model by integrating fuzzy logic or Analytic Hierarchy Process (AHP) to improve risk assessment accuracy
- Considering the cost impact of failures in the FMEA framework for better decision-making in process improvements.
- Real-World Implementation and Case Studies
- Conducting studies on different automobile manufacturers to compare FMEA effectiveness across multiple production setups.
- Implementing long-term tracking of failure modes to analyze how corrective actions improve component reliability over time.
- By addressing these areas, future research can significantly improve brake pedal lever manufacturing efficiency, reliability, and safety, ultimately benefiting the automobile industry and end users.

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