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RISK PRIORITIZATION USING PFMEA APPROACH: A CASE STUDY OF CAMSHAFT SUB ASSEMBLY

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ABSTRACT:

The objective of the study is to reduce the process potential failures and to prioritize the risk of failure of sub assembly of camshaft. A Process Failure Mode and Effects Analysis (PFMEA) methodology is used for risk investigative technique for potential process failure before it happens. PFMEAs focus on preventing failures, enhancing reliability and increasing customer satisfaction. It established a ranked list of potential failure modes, thus rating a priority system for corrective action considerations. Various possible causes of failure and their effects on sub systems have been evaluated for minimizing the failure of the manufacturing or assembly process. Generally, risk prioritization in PFMEA is carried out by using risk priority numbers (RPNs) which can be determined by evaluating three factors: occurrence (O), severity (S) and detection (D). Based on this parameters, some suggestion are proposed to avoid potential failure risks and, ultimately, to reduce the loss of time, quality and productivity.

KEYWORDS: PFMEA, Severity, Occurrence, Detection, RPN, Sub-assembly of camshaft

1. INTRODUCTION

In the highly competitive environments, manufacturing is considered as the backbone of any industrialized nation. Today, manufacturing industries are phasing challenges in quality, time and cost in competitive market. This challenge encountered by process, design, or maintenance failures. This failure creates a major impact on the product quality and productivity. The effects of a failure are focused on manufacturing operations, processes and impact on customer. There are several techniques developed to perform to risk assessment or prioritization. PFMEA is one of the most widely used risk assessment tool for identifying and prioritizing risk of potential failure modes of process or manufacturing operation (Stamatis, 1995). PFMEA is a type of FMEA which is looks at each process step to identify risks and possible failure from many different sources. A Process Failure Modes and Effects Analysis provide a structured, qualitative, analytical method which define and analyze to brainstorm answers to such questions as:

1. How can this process, function, facility, or tooling fail?
2. What effect will process, function, facility, or tooling failures have on the end product (or customer)?
3. How can potential failures be eliminated or controlled?

This FMEA was first proposed by National Aeronautics and Space Administration (NASA, U.S.A.) in 1960. Then, it was adopted and promoted by Ford Motor in 1977. Today, FMEA has been used in world wide spectrum in the areas of Chemical, Aerospace, Military, Automobile, and Electrical, Mechanical andSemiconductor industries. The risk computation of different potential failure modes using PFMEA has been done by developing risk priority number (RPN). RPN is the value obtained by the product of three components, i.e. the occurrence probability of a failure mode (O), the severity of the failure mode (S) and the delectability of the failure mode (D). Higher the value of the RPN higher is the risk associated with the corresponding failure mode. The purpose of RPN is to prioritize the failure modes of a process, so that the available resources can be effectively allocated. More risky failure modes will be tackled with more resources in terms of effort, time and cost. Mathematically the RPN can is represented as:

$$RPN = S \times O \times D \qquad (1)$$

2. LITERATURE REVIEW

During the beginning stage of this work, it was realized that FMEA/PFMEA technique has been applied widely in certain parts of the world. Dale and Shaw (1990) investigated the reasons for the usage of FMEA and found that majority of the companies used PFMEA because

of the mandatory requirement of their customers. Sheng and Shin (1996) execute FMEA to build up a powerful quality framework and to enhance the better process for the better quality of products. Ioannis and Theodoros (2008) applied FMEA show in salmon packing and processing industry in joint with ISO 22000 and they got the significant outcome from execution. After that Segismundo et al (2008) utilized FMEA to enhance the decision making process in new product development in automotive industry. Hoseynabadi et al (2010) FMEA can possibly enhance the unwavering quality of Wind turbine systems particularly for the offshore condition and reduced cost. Yang et al (2010) described a new fuzzy FMEA approach integrated with fuzzy linguistic scale method for the analysis of a CNC lathe. The model proposed a risk-space diagram to show the relationship of S, O, and D where the Risk Priority Number (RPN) is represented by weighted Euclidean distance formula and centroid defuzzification based on α-level set is calculated. Wu et al (2016) also directed an investigation on Computer Numerical Control (CNC) machine's failure utilizing is Multi-Criteria Decision Making (MCDM) system in view of the Fuzzy VIKOR technique. Shi et al (2016) Used Fuzzy FMEA and FAHP for crankshaft failure prediction. Zhou & Thai (2016) Indicated that Fuzzy FMEA and Grey theories has used for tanker failure prediction. Wang et al. (2016) proposed impact and criticality analysis in failure mode (FMECA) does not take into account the opinions of different team members when considering the allocation of criticality. In this paper, the improved criticality values were calculated and prioritized by FMECA based on the failure data. It is seen in the outcomes that vibration or motions, movement of parts, and output failures have more negative effects on the system. Salvi & Jindal (2017) conducted study on CNC machine failures based on the machine FMEA and result also verified by Grey relational analysis (GRA). Different maintenance strategies for each failure mode of functionally significant item of conventional milling machine are described by Gupta and Mishra (2016). The focus of this study in this paper aims to identify and prioritize the risk of failure in sub- assembly of camshaft.

3. CONCEPT OF PFMEA

Process failure mode and effect analysis (PFMEA) has three main objectives, identifying failure modes, analyze causes and their effect on customer end and determine the possible action to eliminate or reduce the impact of each failure mode. The degree of seriousness of each failure mode is determined by calculating risk priority number (RPN). Generally, the RPN is an index number ranges from 1 to 1,000, calculated as the product of the severity (S), occurrence (O), and detection (D) of a failure mode. Thus, higher the RPN means that more critical or higher risk of failure and lower RPN means that low chance of failure.

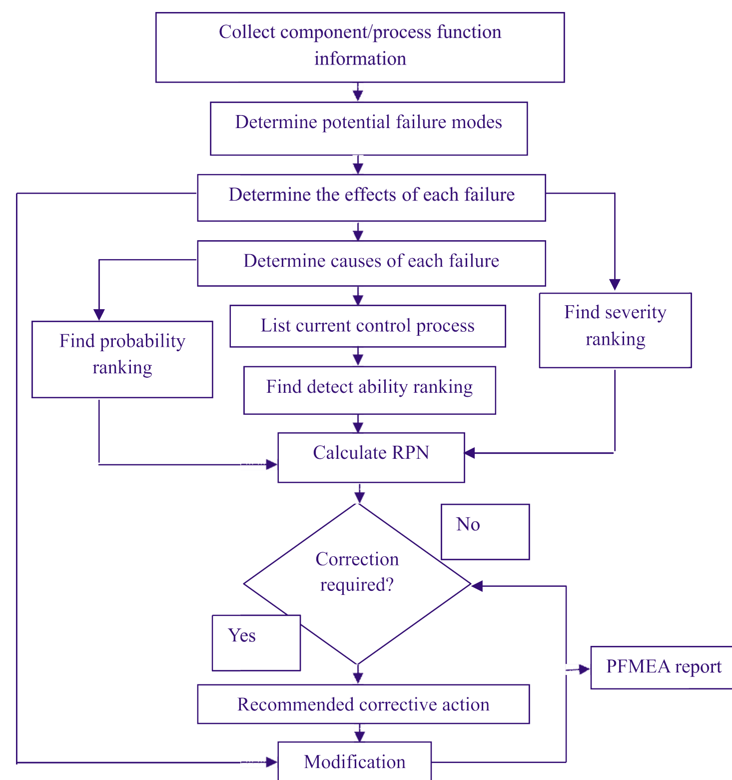

Figure 1: Flowchart of PFMEA

4. PROCEDURE OF PFMEA

Step 1: Review the process.

Use a process flowchart to identify each process component. List each process component in the PFMEA table.

Step 2: Brainstorm potential failure modes.

Review existing documentation and data for clues about all of the ways each component cans failure in assembly process.

Step 3: List potential effects of each failure.

The effect is the impact the failure has on the end product or on subsequent steps in the process. There will likely be more than one effect for each failure.

Step 4: Assign Severity ranking.

Severity is the assessment of the criticality of the effect of the potential failure mode. In this we have to determine all failure modes based on the functional requirements and their effects. The severity of the failure was estimated using an evaluation scales from 1-10 for process failure as shown in Table1.

Table 1: Criteria for severity ranking (S)
(Source: SAE J-1739, 2009)

Classification	Effect	Ranking
Hazardous Without Warning	Very High Ranking – Affecting safe operation.	10
Hazardous With Warning	Regulatory non compliance	9
Very High	Product becomes inoperable, with loss of function – Customer Very Much Dissatisfied	8
High	Product remain operable but loss of performance – Customer Dissatisfied	7
Moderate	Product remain operable but loss of comfort/convenience - Customer Discomfort	6
Low	Product remain operable but loss of comfort/convenience- Customer Slightly Dissatisfied	5
Very Low	Nonconformance by certain items – Noticed by most customers	4
Minor	Nonconformance by certain items – Noticed by average customers	3
Very Minor	Nonconformance by certain items – Noticed by selective customers	2
None	No Effect	1

Step 5: Assign Occurrence ranking.

Occurrence is the rating that one of the specific causes will occur. In this step, we look at the cause and how many times it occurs. The evaluations scale from 1-10 for process Failure as shown in Table 2. The scale 1 indicates a low probability of occurrence whereas scale 10 indicates very high probability to the occurrence of failure.

Step 6: Assign Detection rankings.

Detection is the rating that the failure will be detected before the impact of the failure done to the system or process being estimated. The detectability scale shown in table 3.

Table 2: Criteria for Occurrence ranking (O)
(Source: SAE J-1739, 2009)

Probability	Possible Failure Rates	Ranking
Very High: Failure is almost inevitable.	≥1 in 2	**10**
	1 in 3	**9**
High: Generally associated with processes that have often failed.	1 in 8	**8**
	1 in 20	**7**
Moderate: Generally associated with processes similar to previous processes which have experienced occasional failures, but not in major proportions.	1 in 80	**6**
	1 in 400	**5**
	1 in 2000	**4**

Low: Isolated failures associated with similar processes.	1 in 15000	**3**
Very low: Only isolated failures associated with almost identical processes.	1 in 150000	**2**
Remote: Failure is unlikely.	≤ 1in 1500000	**1**

Table 3: Criteria for detection ranking (D)
(Source: SAE J-1739, 2009)

Detection	Criteria	Ranking
Absolutely impossible	No known control(s) available to detect to failure mode.	10
Very remote	Very remote to detect failure mode	9
Remote	Remote to detect failure mode	8
Very Low	Very low to detect failure mode	7
Low	Low chance to detect failure mode	6
Moderate	Moderate chance to detect failure mode	5
Moderately high	Moderately High chance to detect failure mode	4
High	High chance to detect failure mode	3
Very High	Very high chance to detect failure mode	2
Almost certain	Current control(s) almost certain to detect the failure mode.	1

Step 7: Calculate the Risk Priority Number (RPN).

After deciding the Severity, Occurrence and Detection numbers, the RPN is calculated by equation no- 1.

Step 8: Develop the action plan.

Decide which failures will be worked on based on the Risk Priority Numbers. Focus on the highest RPNs. Define who will do what by when.

Step 9: Take action.

Implement the improvements identified by your Process Failure Mode and Effects Analysis team.

Step 10: Calculate the resulting RPN.

Re-evaluate each of the potential failures once improvements have been made and determine the impact of the improvements.

5. CASE STUDY

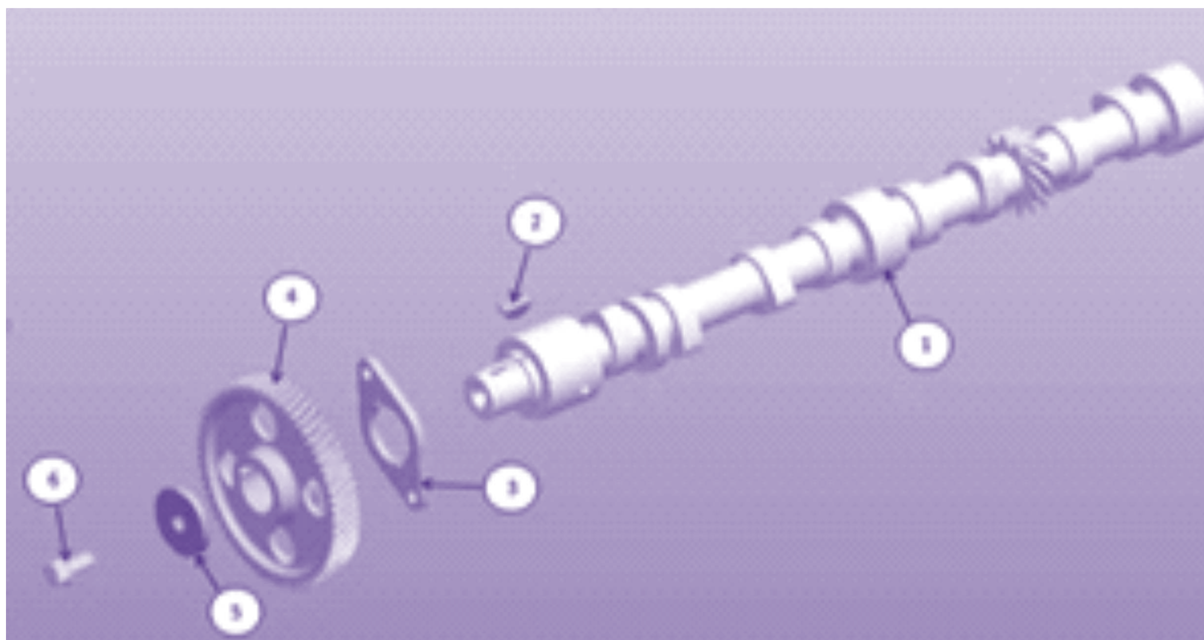

Figure 2: Parts of camshaft

A Case study is conducted and PFMEA technique is applied to the sub assembly of camshaft. There are total six operation and 17 risk factors identified in process. After obtained failure data PFMEA table has prepared. Finally, S, O and D values are calculated using table 1, 2 and 3 respectively and PFMEA worksheet has developed which is shown in Appendix-I. The RPN value for the failure modes was calculated by using equation no-1.

6. RESULT & DISCUSSIONS

Appendix-I shows the result of PFMEA of sub-assembly of camshaft. All operations marked with the operation no. 10 to 60. From first to last operation there are seventeen risks factor were identified in sub assembly of camshaft. Operation no. 10 has two risks of failures (i.e., risk no. 1 and 2) which is related to the key fitment in camshaft, when operator misses the key. This results in abnormal noise during engine testing. The severity ranking for this potential failure mode was decided as 8 and the ranking for occurrence was fixed as 2. The detection ranking was fixed as 8 and the RPN value obtained was 128. This is highest in all failures RPN. When operator fit the key in inclined direction in camshaft, the resultant problem occurs in gear fitment. This problem happens due to operator unaware of correct assembly process. The severity ranking for this potential failure mode was fixed as 3 and the occurrence ranking was fixed as 4. The current method to control this failure mode is following SOP. The detection ranking fixed was 6 and the RPN value obtained was 72. Next operation (Operation no. 20) is fitment of thrust plate in camshaft. Thrust plate is important part of the camshaft. It supports the axial load of camshaft. When operator forget to fitting thrust plate in camshaft happening major issues in fitment of camshaft in engine and without thrust plate camshaft recognized as a defect piece. The resultant RPN is 40. Similarly next operation related to fitment of Cam gear in camshaft. Cam gear is the important part of the camshaft it provides rotation of camshaft. Fitment of cam gear shows two risk factors of failure (Risk no. 4 and 5). The cam gear orientation wrong failure mode has severity is 5because low effect on product and easily rework able, total no failure during year was calculated 0 sooccurrence is 1 and failure moderately high detect, may be required so ranking was 4. The calculated RPN value is 20. This value is very lower value of the all failure. Washer fitment missing occurs due to the operator missing failure. Washer is very small part of the camshaft but it plays the important role in fitment. It main function is distribution of pressure evenly on cam gear. The severity and occurrence rankings were fixed as 3 and 5 respectively. The detection ranking was fixed as 8 and the RPN value obtained was 120. This is the second highest ranking of failure because of highest no failure during year.

Next operation is tightening of bolt on cam gear after the fitment of washer on camshaft. This operation shows with the operation no. 50. In this operation there are total eight risk factors from risk no 7 to 14. The risk no 7 and 8 is same as the key fitment. Risk no. 9 to 12 related to less torquing power. If bolt torque is less T.G case damage due to cam gear came out during testing and required rework of defective engine. The main **RPN**cause is low Gun setting value. The severity ranking and the occurrence rating were fixed as 6 and 2 respectively. The current method to control is calibration of gun once in month and 100% torquing with feedback limiter used. The detection ranking was fixed as 8 and the RPN value obtained was 96. This value is less than 130 it means that no recommended action required. Same RPN 96 also in risk no. 11 because their severity, occurrence and detection are 6, 2 and 8 respectively.

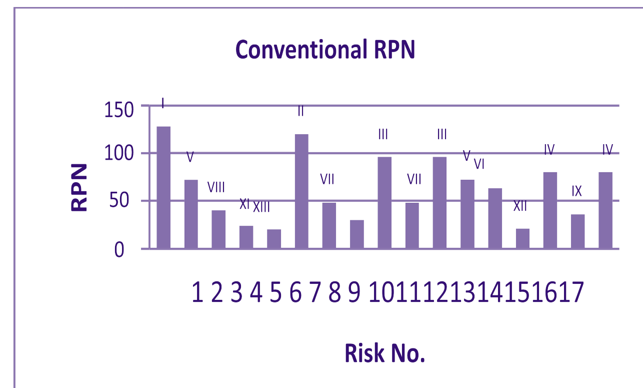

Figure 3: Bar graph (RPN Vs Risk No.)

Next operation (OPN. 60) related to unloading and storage of camshaft. It has total three risk factors 15, 16 and 17. Risk no. 15 is related to the dent on gear, if dents found on cam gear due to storage and unloading it creating problem in engine. So their RPN is 80. Similarly Risk no, 16 related to the dent on camshaft journal, their RPN is 36 and Risk no. 17 related to the dent on camshaft lobes, their RPN is 80. It can be seen that the failures related to key and washer fitment are prominent and must be given highest priority because of highest RPN. Similarly, in risk no 4, 9 and 11 the lower priority because of lowest RPN.

7. CONCLUSION

PFMEA provides a document for the analysis of future use and continuous process improvement. It is a systematic approach to the analysis, definition, estimation and evaluation of risk of failure. Following a standard configuration procedure will reduce the assembling time and improve the accuracy of the parts, thus increasing the quality and productivity of the process. Many measures, such as standard operating procedures (SOP), the correct depth of the master piece provide configuration, in-process inspection, process design and Minspection of the first part. The PF EA analysis can easily help improve the efficiency of the production process and the quality of the product, thus reducing the number of defective products and saving time and reprocessing costs.

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Appendix-I, Process Failure Mode Effect & Analysis (PFMEA)

Part no. & Name : *******/ Sub-assembly of camshaft | Team member: | Doc. No. xxxx

Customer name: xxxxxx ltd. | Revision date :

OPN. No.	Process function	Requirement	Risk No.	Potential Failure Mode	Potential Effect (s) of Failure	Severity (S)	Potential Cause	Occurrence (O)	Current process control: Preventive	Current process control: Detective	Detection (D)	RPN
10	Load camshaft on woodruff key fitment fixture & Woodruff key fitment on camshaft.	Key fitment	**1**	Key missing	Abnormal Noise during testing & required rework of defective engine	8	Operator missed the operation of woodruff key fitment on cam shaft	2	SOP	Engine Testing	8	128
		Inclined fitment of key	**2**	Key not fitted inclined	Gear fitment difficult & gear gets incompletely fitted resulting in rectification of defective assembly	3	Operator unaware of correct assembly procedure	4	SOP	During press fitment of cam gear on cam shaft	6	72
20	Loading on cam gear pressing machine & Thrust plate mounting.	Thrust plate	**3**	Thrust plate missing	Fitment of cam shaft on engine not possible & no bearing effect for cam shaft & required rectification of defective	5	Operator missed the operation of thrust plate fitment on cam shaft	2	SOP	During assembly of cam shaft on engine	4	40
30	Fitment of cam gear on camshaft by pressing machine	Cam gear fitment	**4**	Cam gear miss	Fitment of cam shaft on engine not possible & required rectification of defective assembly	3	Operator missed the operation of cam gear fitment on cam shaft	2	SOP	During assembly of cam shaft on engine	4	24
			5	Cam gear orientation wrong	Gear timing setting not possible & required rework of defective assembly	5	Operator mistakenly assembled gear in wrong orientation / unaware of correct assembly procedure	1	SOP & Poka-yoke for detecting correct orientation of gear before assembly	While gear timing	4	20
40	Fitment of washer on cam gear	Washer fitment	**6**	Washer miss	Distribution of pressure not evenly on cam gear	3	Operator missed the operation of washer fitment	5	SOP	Visually	8	120
50	Tightening the bolt with washer on cam gear	Tightening of bolt to 4~6 kgf-m	**7**	Bolt miss	T.G.Case damage due to cam gear came out during testing & required rework of defective engine	6	Operator missed the operation of mounting nut fitment on cam gear	1	SOP & Poka-yoke for declamping the cam shaft after torquing of mounting bolt on cam gear	Engine Testing	8	48

			8	Inclined fitment of bolt in mounting thread of cam shaft	Mounting thread of cam shaft damage & required part to be reworked	5	Operator didn't hand tightened 2~3 of mounting bolts in the mounting threads of cam shaft	2	SOP	During fitment of bolt on cam gear	3	30
			9	Bolt torque less	T.G.Case damage due to cam gear came out during testing & required rework of defective engine	6	Gun setting to low value	2	Calibration of gun once in month & 100% torquing with feedback limiter	Engine Testing Torque Audit	8	96
			10			6	Operator tightened the bolt but did not torqued it.	1	SOP & 100% torquing with feedback limiter	Engine Testing Torque Audit	8	48
			11			6	Operator missed the operation of tightening the bolt	2	SOP	Engine Testing Torque Audit	8	96
			12			6	Torque wrench torque less	2	Lock type limiter provided on station	Engine Testing Torque Audit	6	72
			13	Bolt torque more	Mounting bolt break inside the mounting thread of cam shaft & part required to be scrapped	7	Gun setting to higher value	3	NIL	During fitment of bolt on cam shaft	3	63
			14			7	Torque wrench torque more	1	SOP & 100% torquing with feedback limiter	During fitment of bolt on cam shaft	3	21
60	Unloading of camshaft on storage trolley.	No dent on gears	**15**	Dent on gears	Abnormal Noise during testing & required rework of defective engine	5	Improper storage	2	Proper storage trolley to be provided to avoid contact of gears with each other after assembly.	Engine Testing	8	80
		No dent on cam shaft journals	**16**	Dent on cam shaft journals	Fitment of cam shaft in its mounting hole in block not possible / cam shaft rotation jam after fitment & required part to be scrapped	3	Improper storage	4	Storage trolley with separation	During insertion / after fitment of cam shaft in block	3	36
		No dent on cam shaft lobes	**17**	Dent on cam shaft lobes	Abnormal Noise during testing & required rework of defective engine	5	Improper storage	2	Storage trolley with separation	Engine Testing	8	80