iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 **Issue:** IV **Month of publication:** April 2018

DOI: http://doi.org/10.22214/ijraset.2018.4185

Implementation of Process FMEA during Assembling of a Connecting Rod

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Abstract: A failure modes and effective analysis procedure is used in connecting rod production and assembling operation development and operation management for analysis of potential failure modes within a system for classification by the severity of the failures. A successful FMEA activity helps a identify potential failure modes of connecting rod based on past experience with similar products or processes, enabling the team to design the failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and cost. The application of FMEA in automotive Industry is a trend nowadays. Both PFMEA and DFMEA have the same main purpose identification prevention and correction of failures during the production process of connecting rod but, PFMEA have many shortcomings. In many cases, the major reason behind or causing catastrophic engine failure is the occurrence of the connecting-rod failure. The major aim of the current work is to analyse the connecting rod failure.
Keywords: connecting rod, PFMEA, Potential failure

I. INTRODUCTION

A connecting rod is an engine component that transfers motion from piston to the crankshaft. Connecting rods are commonly made from cast aluminium alloy and are designed to withstand dynamic stresses from combustion and piston movement. The small end of the connecting rod connects to the piston with a piston pin. The piston pin or wrist pin, provides the pivot point between the system and connecting rod. Spring clips or piston pin locks, are used to hold the piston pin in place.

It is the main power transmitting medium from the crank shaft to the piston. Hence the review of sequence of operation for assembling a connecting rod with piston helps in forecasting its failure. the list of assembling sequence was given below.

A. Insert the smaller end of connecting rod into the piston
B. Insert the piston pin
C. Lock the circlip to hold the piston pin
D. Add the connecting rod bearing (half)
E. Connect the bigger end of the connecting rod with the crank shaft
F. Insert the bearing into crankshaft (next half)
G. Connect the c section & connecting rod bigger end
H. Assemble the bolts into bigger end
I. Tight the nuts

PARTS
1,2,3 - Piston Ring, Oil Ring, Compression Ring
4- Smaller End Bearing
5- Piston
6- I -Section
7- Smaller End Port
8- Circlip
9 - Piston Pin
10- Bigger End Bearings
11 - C Section
12- Fasteners

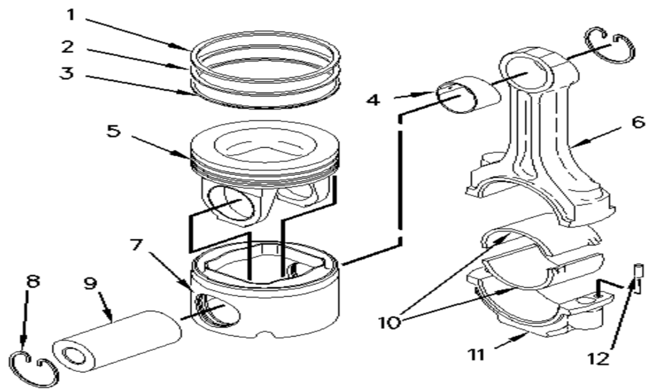

Fig. 1 assembling of various parts in connecting rod

II. LITRETURE SURVEY

A. Experimental investigation

1) *Janaki ram and Keats(1995) [1]* found that the FMEA was well-known useful tool in the design process but it is virtually ignored in most process quality improvement paradigms. Sheng and Shin (1996) discussed the implementation of FMEA for both product design and process control. They implemented the FMEA in two ways to ensure that the reliability requirements can be met for the production of an airbag inflator. They performed Design FMEA to generate a process control plan, visual aids, and a process verification list. They also integrated Design FMEA and Process FMEA through reliability prediction and supplier PPM reports. The supplier PPM reports contained the information that can be employed to update the probabilities used in design FMEA.
2) *Pantazopoulos and Tsinopoulos [2]* found that FMEA is one potential tool with extended use in reliability engineering for the electrical and electronic components production field as well as in complicated assemblies (aerospace and automotive industries). The main purpose for study was to reveal system weaknesses and thereby minimize the risk of failure occurrence. They used FMEA technique in the design stage of a system or product (DFMEA) as well as in the manufacturing process (PFMEA). They applied this technique in a critical process in the metal forming industry.
3) *Cassanelli* et al. [3] applied ordinary FMEA during the design phase of an electric motor control system for Heating/Ventilation/Air Conditioning (HVAC) vehicle. The analysis of the field data from the second year forced to review FMEA. They planned the corrective actions on the basis of the sole failure mode, as usual in FMEA, and experienced that taken actions are inadequate
4) *Carl S. Carlson* is a consultant and instructor in the areas of FMEA, reliability program planning and other reliability engineering disciplines, currently supporting clients of ReliaSoft Corporation. [4]
5) *S. M. Muzakkir,(* In the present research work the Failure Mode and Effect Analysis (FMEA) of a conventional radial journal bearing is presented. The FMEA process is applied to identify the various possible failures modes of a journal bearing and the corresponding effects of these failures on the bearing performance.[5]
6) *Pushpendrakumar Sharma et al. [6]* performed the static FEA of the connecting rod using the software and said optimization was performed to reduce weight. Weight can be reduced by changing the material of the current forged steel connecting rod to crack able forged steel (C70). And the software gives a view of stress distribution in the whole connecting rod which gives the information that which parts are to be hardened or given attention during manufacturing stage.
7) *K. Sudershn Kumar et al. [7]* analysed Two Wheeler Connecting Rod. In this project connecting rod was replaced by Aluminium reinforced with Boron carbide for Suzuki GS150R motorbike. A 2D drawing was drafted from the calculations. A parametric model of connecting rod was modelled using PRO-E 4.0 software. Analysis was carried out by using ANSYS software. Finite element analysis of connecting rod was done by considering two materials, viz... Aluminium Reinforced with Boron Carbide and Aluminium 360. The best combination of parameters like Von misses stress and strain, Deformation, Factor of safety and weight reduction for two wheeler piston were done in ANSYS software. Compared to carbon steel, aluminium boron carbide and aluminium 360, Aluminium boron carbide is found to have working factor of safety is nearer to theoretical factor of safety, 33.17% to reduce the weight, to increase the stiffness by 48.55% and to reduce the stress by10.35% and most stiffer.

From the literature survey it is evident that very less work has been reported on assembling failure for connecting rod by using process failure mode effective analysis. Hence the experimentation is done on above said combination of connecting rod assembling failures & PFMEA.

B. Objectives of the proposed work

1) To focus in on manufacturing related deficiency on connecting rod
2) Improving the manufacturing of the connecting rod.
3) Ensuring the connecting rod is built to design requirements in a safe manner, with minimal downtime, scrap and rework
4) The objectives to improve the design of the manufacturing process
5) Improve process control plans.

III. METHODOLOGY

The Continuous improvement of product and process is very important now days to have an edge over in the comparative manufacturing market and that is becoming more commanding in highly comparative industries like automotive. Failure Mode and Effects Analysis (FMEA) is one of the tools used for continuous quality improvement Failure Modes and Effects Analysis (FMEA) is one of the basic and the most used method for analysing the safety and reliability of technical systems.

Processes by eliminating many potential failure modes prior to operation of the process and by specifying the appropriate tests to prove the designed product. Process FMEA is used to identify potential process failure modes by ranking failures and helping to establish priorities according to the relative impact on the internal or external customer. Implementing process FMEA helps to identify potential manufacturing or assembly causes in order to establish controls for occurrence reduction and detection.

Furthermore, design and process FMEA document the results of the design and production processes respectively.

A. Stages of FMEA

The four stages of FMEA are given below:

1) Specifying possibilities
a) Functions
b) Possible failure modes
c) Root causes
d) Effects
e) Detection / Prevention
2) Quantifying Risk
a) Probability of Cause
b) Severity of Effect
c) Effectiveness of Control to Prevent Cause
d) Risk Priority Number
3) Correcting High Risk Causes
a) Prioritizing Work
b) Detailing Action
c) Assigning Action Responsibility
d) Check Points on Completion
4) Re-evaluation of Risk
a) Recalculation of Risk Priority Number

B. Process FMEA

The process FMEA is applied to improving the process in contrast with design in DFMEA. The purpose is to ensure that the potential failure modes and the associated causes / mechanisms are considered & addressed in the appropriate form. The process FMEA addresses production operations.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
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FAILURE MODE AND EFFECT ANALYSIS
(PROCESS FMEA)

FMEA Number ____________
Page ________ of ________
Item ____________ Process Responsibility ____________ Prepared By ____________
Model Number/Year ____________ Key Date ____________ FMEA Date (Orig.) ________ (Rev.) ________
Core Team ____________

Process Function Requirements	Potential Failure Mode	Potential Effect(s) of Failure	S	CLASS	Potential Cause(s)/ Mechanism(s) of Failure	O	Current Process Controls	D	RPN	Recommended Actions	Responsibility and Target Completion Dates	Action Results				
												Actions Taken	SEV	OCC	DET	RPN

Table 1 Process FMEA data char

C. *Components of Process FMEA data chart*

1) *FMEA Number:* On the top left corner of the document is the FMEA Number, which is only needed for tracking.
2) *Component:* The component space is used only to clarify which exact component or process is being analyzed. The appropriate level of analysis should be included here, along with the name and number of the system or sub-system being analyzed.
3) *Process Responsibility:* The team in charge of the design or process should be identified in the space designated Design Responsibility. The name and company of the person or group responsible for preparing the document should also be included.
4) *Prepared by:* The name, telephone number and address should be included in the Prepared By space for use when parts of the document need explanation.
5) *Model Number | Year:* Both the name and identification number of the system, sub-system, or component should be included in the Model Number | Year space to avoid confusion between similar components.
6) *Key Date:* The date the initial FMEA is due should be placed in the Key Date space.
7) *FMEA Date:* The date the original FMEA was compiled and the latest revision date should be placed in the FMEA Date space.
8) *Core Team:* In the space reserved for Core Team, the names of the responsible individuals and departments that have authority to perform tasks should be listed. If the different people or departments involve dare not familiar with each other, team members "names", departments, and phone numbers should be distributed.
9) *Part Function:* In this section, the name and number of the item being analysed is recorded. This information should be as precise as possible to avoid confusion involving similar items. Next, the function of the item is to be entered below the description of the item. No specifies should be left out in giving the function of the item.
10) *Process Function | Requirements:* Instead of entering the item being analysed and its functions, as in the design FMEA, A Description of the process being analysed is given here. Examples of this process in clued, but are not limited to, turning, drilling, tapping, welding, and assembling. The purpose of the process should be given as completely and concisely as possible
11) *Potential Failure Mode:* In process FMEA, one of the three types of failures should be listed here. The first and most prevalent is the manner in which the process could potentially fail to meet the process requirements It should for the most part be assumed that the incoming parts and |or material are correct according to the general definition of nonconformity. Each potential failure mode for the particular operation must be listed in terms of a component, sub-system, or process characteristic.
12) *Potential Effects of Failure:* Like design FMEA, the potential effects of failure are the effects as perceived by the customer, whether internal or external. The effects of failure must be described in terms of what the customer will notice or experience, so if conditions are given by the customer there will be no dispute as to which mode caused the particular failure effect. It must also be stated whether the failure will impact personal safety or break any product regulations

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue IV, April 2018- Available at www.ijraset.com

IV. RESULT AND DISCUSSION

Input for Preparation of PFMEA: To conduct the process FMEA the following inputs were gathered from design team or cross functional team to attain the experimentation of failures and its effects.

1) Process Flow Diagram
2) Drawing & DFMEA
3) AIAG FMEA manual & guideline standard for PFMEA preparation.
4) PFMEA check sheet for carrying out the PFMEA.
5) Historical data (Customer Return / Warranty Rejection, In-house Rejection, etc.)
6) Quality and Reliability History
7) Occurrence matrix and feedback ratio
8) CFT (cross functional team) approach for making PFMEA.
9) Identify the potential failure mode of each process and find out the effect of each
10) Potential failure mode at the current operation, next operation(s) and at customer end.
11) Lesson learned cards (LLCs)
12) List of M/C tools, Gauge

A. Process Flow Diagram

The process flow diagram was developed by using the basic steps in assembling of connecting rod. This helps in finding the steps and order and relationship between each components so that the list of failures can be generated easily.

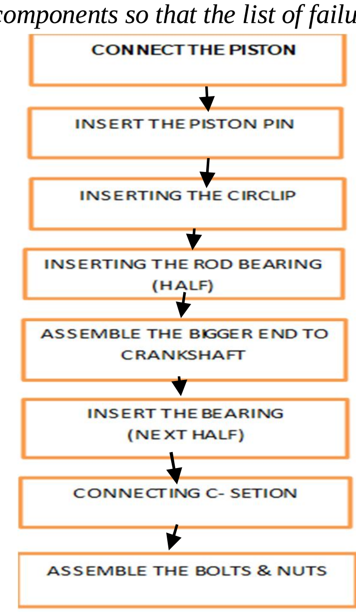

Fig No 2 Process Flow Diagram

B. Part drawing

It helps in understanding the list of parts given and their exact dimensions and tolerance for forecasting interrelationship failure modes

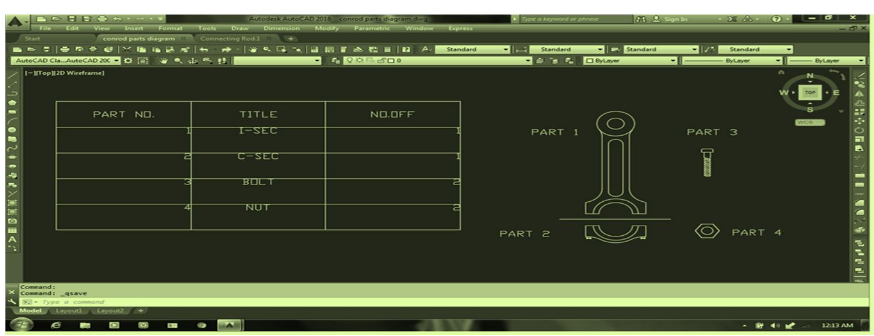

Fig no 3 Part Diagram

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C. Product Characteristic Matrix

This matrix is recommended as an aid in developing product-to process and product-to-product linkage. When compiling this matrix, identify all of the process steps that can "compromise" the part characteristics identified in the DFMEA. When completed or revised, attach the product characteristic matrix to the FMEA.

1) Operation 1 - Movement of piston
2) Operation 2 - Holding the piston
3) Operation 3 - Power transmission from crankshaft
4) Operation 4 - Connection between the smaller & bigger end
5) Operation 5 - Sealing
6) Operation 6 –Fastening

	Op1	Op2	Op3	Op4	Op5	Op6
Piston	X	X				
Piston pin	X	X				
Smaller end		X				
I section				X		
C section			X		X	
Bolt					X	X
Nut						X
Bearing					X	

Fig no :4 matrix function and characteristics

D. Identifying And Listing Potential Failures

Potential effects of failure are defined as the effects of the failure mode as perceived by the customer. Effects will be described by external, entrance customer and end user. It will be considered for next operation to end user. Each must be considered when assessing the potential effect of a failure. The product effects in the PFMEA should be consistent with those in the corresponding DFMEA.

If the failure mode could impact safety or cause noncompliance to regulations. This should be clearly identified in the PFEMA.

1) Engine down
2) Noise and power loss of engine
3) Overheating
4) More wear and tear
5) Piston pin failure
6) Fatigue Failure
7) Hydro lock

E. Risk Priority Number

RPN is an indicator for determining proper corrective action on the failure modes. The small RPN is always better than high RPN

RPN = S x O x D

were

S- SERVERITY

O- OCCURRENCE

D- DETECTION

1) *Severity (S):* Severity is the assessment of the seriousness 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. A failure effects is defined as the result of the failure mode on the function of the system as perceived by the user. In this is way it is convenient to right this effect down in teams of what the user might see or experience. A severity rating of 9 or 10 generally reserved from those effects which would cause injury to a user or otherwise result in litigation.
2) *Occurrence (O):* Occurrence is the changed that one of the specific cause/mechanism will occur. In this step, it is necessary to look at the cause of failure and how many times it occurs. Looking at similar product or processes and the failures that have been documented for them can do this. A failure cause is looked upon as a design weakness. If non safety issue happened less than 1% one can give 1 to it. It is based on our product and customer specifications.
3) *Detection (D):* Relative measures of the ability of design control to detect wither a potential cause/mechanism or the subsequent failure mode before production supported by physical tests, mathematical modelling, prototype testing, and feasibility the assigned detection number measures the risk that the failure will escape detection. A high detection number indicates that the chances are high that the failure will escape detection or in other word, that the chances of detection are low.

F. AIAG FMEA Manual

It helps in selection of the ranking for severity, detection & occurrence of the problem specified failure. It is the standard manual book for FMEA which is known as Automotive industrial action group manual followed in all leading production and manufacturing industries to ensure the ranking for the FMEA data table.

Table 2 Severity criteria

Effect	Customer Effect	Manufacturing/Assembly Effect	Ranking
Hazardous with warning	Very high severity when a potential failure mode affects safe operations and/or involves noncompliance with government regulation with warning.	Or may endanger operator with warning.	9
Very high	Item inoperable (loss of primary function).	Or 100% of product may have to be scrapped, or item repaired in repair department with a repair time greater than one hour.	8
High	Item inoperable but at a reduced level of performance. Customer very dissatisfied.	Or product may have to be sorted and a portion (less than 100%) scrapped, or item repaired in repair department with a repair time between a half-hour and an hour.	7
Moderate	Item operable but comfort/convenience item inoperable. Customer dissatisfied	Or a portion (less than 100%) of the product may have to be scrapped with no sorting, or item repaired in repair department with a repair time less than a half-hour	6
Very Low	Item does not conform. Defect noticed by greater than 75% of customers	Or the product may have to be sorted, with no scrap, and a portion (less than 100%) reworked.	4
Minor	Item does not conform. Defect noticed by 50% of customers.	Or a portion (less than 100%) of the product may have to be reworked, with no scrap, on-line but out-of-station.	3
Very Minor	Item does not conform. Defect noticed by less than 25% of customers.	Or a portion (less than 100%) of the product may have to be reworked, with no scrap, on-line but in-station	2
None	No discernible effect.	Or slight inconvenience to operation or operator, or no effect	1

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Table 3 Occurrence criteria

Likelihood of Failure	Criteria: Occurrence of cause – PFMEA (Incidents per items/vehicles)	Rank
Very High	100 per thousand, 1 in 10	10
High	50 per thousand, 1 in 20	9
	20 per thousand, 1 in 50	8
	10 per thousand, 1 in 100	7
Moderate	2 per thousand, 1 in 500	6
	0.5 per thousand, 1 in 2000	5
	0.1 per thousand, 1 in 10,000	4
low	0.01 per thousand, 1 in 1,000,00	3
	H 0.01 per thousand, 1 in 1,000,000	2
Very low	Failure is eliminated through preventive control	1

Table 4 Detection criteria

Detection	Criteria	Suggestion Range of Detection Methods	Ranking
Almost impossible	Absolute certainty of no detection	Cannot detect or is not checked	10
Very remote	Controls will probably not detect	Control is achieved with indirect or random checks only	9
Remote	Controls have poor chance of detection	Control is achieved with visual inspection only	8
Very low	Controls have poor chance of detection	Control is achieved with double visual inspection only	7
low	Controls may detect	Control is achieved with charting methods, such as SPC (Statistical Process Control)	6
Moderate	Controls may detect.	Control is based on variable gauging after parts have left the station, or Go/No Go gauging performed on 100% of the parts after parts have left the station.	5
Moderately high	Controls have a good chance to detect.	Error detection in subsequent operations, OR gauging performed on setup and first-piece check (for setup causes only)	4
High	Controls have a good chance to detect.	Error detection in-station, or error detection in subsequent operations by multiple layers of acceptance: supply, select, install, verify. Cannot accept discrepant part.	3
Very high	Controls almost certain to detect.	Error detection in-station (automatic gauging with automatic stop feature). Cannot pass discrepant part	2
Very high	Controls certain to detect.	Discrepant parts cannot be made because item has been error-proofed by process/product design	1

G. Step By Step Procedure

1) *Step 1* Take the PFMEA format from latest FMEA manual of AIAG.
2) *Step 2* Refer to the connecting rod Part/Assembly Drawing for identifying special, critical characteristics, and connecting rod Drawing requirements given in General notes
3) *Step 3* Brain storm among CFT team to identify possible failure modes, causes / mechanism of failure Modes & their effects with severity, occurrence, detection respectively.
4) *Step 4* Refer DFMEA, List of Past Trouble Data Base, List of Technical Know How with corrective actions on problems for preparation of PFMEA
5) *Step 5* Define the current process control for prevention and detection.
6) *Step 6* For severity, Occurrence & Detection ranking refer to the latest PFMEA manual.
7) *Step 7* Calculate the RPN (S x O x D).
8) *Step 8* List out action plan on RPN as per below criteria.
9) *Step 9* Set target dates and implement action plan & re-establish the expected RPN.

Table 5 Failure table

Process FMEA(Function /Requirements)	Potential Failure Mode	Potential Effects Of Failure	SEVERITY	Potential Causes	OCCURENCE	Current Controls Detection	DETECTION	RPN
To transmit a power from piston to crankshaft	Do not transmitting proper range of power	Engine down	7	Damage of connecting rod physical properties	4	Almost impossible (detected by scanning and stress and fatigue analysis)	10	280
Working with noiseless and vibrations	Kinematics systems	Noise / power loss of engine	6	Bearing seizure Reduced accuracy of relative motion	3	Low (easy to identify by visual and hearing inspection)	6	108
Proper lubrication	Lubrication failure	Over heating	7	Trapped oil holes in bearing oiler hole	10	Moderate controls may detect (simultaneously temperature rising on engine run)	5	350
Withstand high wear	Break down	Wear and tear	10	Bearing damage	4	Easy to detect (engine won't run)	5	200
Power transmisson	Gudgeon pin or piston pin	Catastrophic engine failure	9	Wear on pin	7	Easy to detect (engine won't run)	6	378
Connecting rod shank	Hydro lock	Connecting rod will bend	7	Water gets in to piston chamber when the car driven	5	Moderate controls may detect (simultaneously temperature rising on engine run)	4	140

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Table 6 After prevention action table

Recommended Action	SEVERITY	OCCURENCE	DETECTION	RPN
Re check the physical properties of materials before installation and increase the hardness number of material	7	1	10	70
Use a proper SAE number of bearing/grinding journal surface with precise measurement	6	2	5	60
Install a magnetic plug and temperature sensor to monitor a performance of bearing	7	2	1	14
Change new one	10	1	1	10
Choose proper material	9	2	1	18
Design aspect will be modified	7	2	2	28

V. CONCLUSION

A. All the possible failures are forecasted and found earlier for the assembling of connecting rod.
B. For each and every potential failure the severity rating was calculated so the maximum severity was found for the failure of more friction between bearing and big end of rod
C. The maximum occurrence rating was found & it is distributed for lubrication failure
D. The function & characteristics matrix was developed for the connecting rod & it helps in understanding the function of each parts of connecting rod & its function.
E. Detection rating was found for the proposed work & plays higher detection rating in piston pin failure
F. The RPN number were calculated before applying prevention action & after applying prevention action and both are compared.
G. The RPN number helps in finding the risk of failure level & its significance.
H. The remedial action taken for the failure helps in preventing the reworks & rejections.
I. Reduction in occurrence & detection ranking helps in reducing the effect of appearance of failure
J. Hence after applying the remedial action the RPN is reduced to 18 from 378
K. PFMEA is continuous improvement process. Hence the period monitoring of failures is recommended.
L. Process FMEA is the best optimization process for reducing the failures before starting the production operation.
M. Table 7 Comparison of before & after FMEA prevention control action taken:

	BEFORE REMEDIAL ACTION TAKEN	AFTER REMEDIAL ACTION TAKEN
Severity	9	9
Occurrence	7	2
detection	6	1
RPN	378	18

VI. FUTURE DIRECTION OF WORK

A. The work can be expended for all FMEA for crank shaft and cam shaft
B. Further work may be directed towards applying the PROCESS FMEA for all engine component which was beyond the scope of the present work.
C. FMEA is a continuous improvement process. Hence periodic follow up for the present work is monitored and actions were improved.

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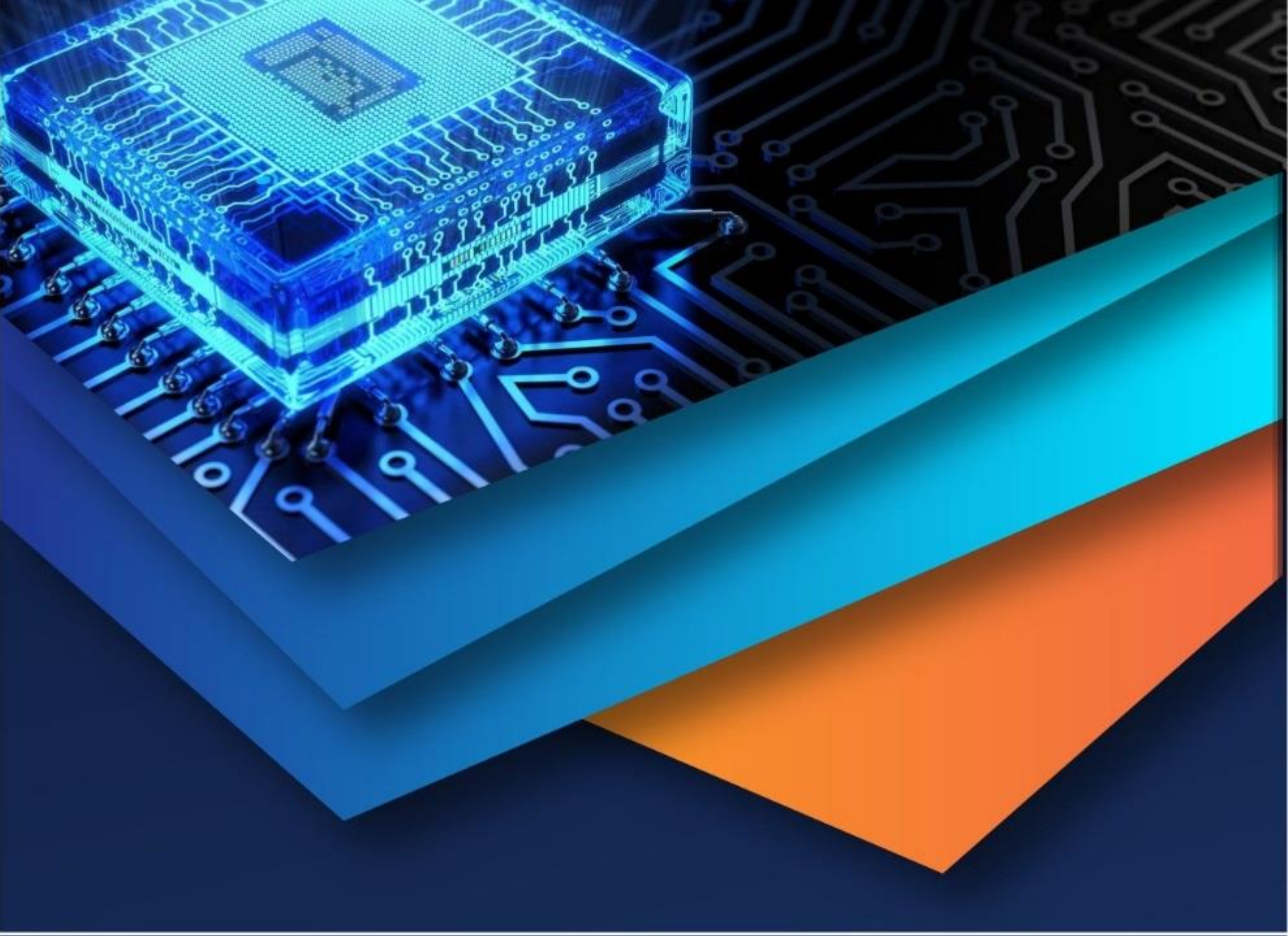

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