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Increasing Realiblity of Spark Plug Using FMEA Tool

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Abstract: A failure modes and effects analysis (FMEA) is a process by which the identification and the evaluation of potential failure modes for a system, product, component or a process is done for classification by the severity and likelihood of the failures. A successful FMEA helps to identify potential failure mode, its causes, identifying the impact of these potential failures and then prioritizing actions to reduce or eliminate these failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs. This paper provides the use of FMEA for improving the reliability of spark plugs in order to ensure the engine efficiency which in turn improves the bottom line of automotive industries. Thus the various possible causes and their effects along with the prevention are discussed in this work. Severity rating, Occurrence rating, Detection rating and Risk Priority Number (RPN) are some parameters, which are to be determined.

Keywords: Spark plug; FMEA; Severity, Occurrence rating, Risk Priority Number (RPN), Detection rating

I. INTRODUCTION

Day by day need of consumer increased they want high quality and more reliable product, its challenge to manufacturing industry to developed defect free, high quality and more reliable product so that life of the product increase. All of these needs of consumer can be satisfied by using some latest techniques and strategies implemented in both the product design and manufacturing. Failure Mode and Effect Analysis (FMEA) is one of the technique by which potential failures of a product or process design are identified, analyzed and documented. The Failure Modes and Effects Analysis (FMEA), also known as Failure Modes, Effects, and Criticality Analysis (FMECA) [1], [2]. This paper is about the increasing reliability of spark plug it's an automotive component by using FMEA tool which identifies failure modes of product or process and how to eliminate or reduce risk of failure.

A. Failure Mode & Effect Analysis

FMEA was first described in US Armed Forces Military Procedures in 1949. Later, various groups and departments of NASA used FMEA principles under variety of names in mid 1950s and 1960s. Ford Motor Company published instruction manuals for FMEA in the 1980s and the automotive industry collectively developed standards in the 1990s. Engineers in a variety of industries have adopted and adapted the tool over the years. [1]

FMEA is an indispensable tool for industries such as aerospace, automobile industries and Government agencies (Army, Navy, Air Force, etc) because of the following reason

1) Improves design by discovering unanticipated failures
2) Highlights the impact of the failures
3) Provides a method to characterize product safety
4) It records and documents the logic of the engineers and related design and process considerations
5) It is an indispensable resource for new engineers and future design and process decisions. [11]

B. Need of fmea in spark plug

A spark plug is an electrical device that fits into the cylinder head of some internal combustion engines and ignites compressed aerosol gasoline by means of an electric spark. By using FMEA technique, the Reliability of spark plug increased which improves the overall efficiency of engine. . Reliability of a spark plug can be achieved through eliminating its failure modes. Failure modes are eliminated by proper maintenance & servicing of system & spark plug. All possible failure modes due to which spark plug fails need to be identified

II. LITERATURE REVIEW

A lot of research has been undertaken for increasing the reliability of product process & system in manufacturing industry. Investigators have attempted FMEA Tool to increase reliability of product by identifying failure modes of product, system & process

Tejaskumar S. Parsana used A Process FMEA Tool to Enhance Quality and Efficiency of Manufacturing Industry. study is conducted and FMEA technique is applied to the cylinder head manufacturing process industry. There are various operation and processes carried out by various machine for manufacturing cylinder head. Facing, drilling and tapping are the main manufacturing operations of the cylinder head. Criteria for ranking of severity occurrence and detection are selected suitably by analysing the past failure records of the machine

George Mathew used FMEA Analysis for Reducing Breakdowns of a Sub System in the Life Care Product Manufacturing Industry. Study is conducted and FMEA technique is applied to the automatic plastic welding machine in a life care product industry. Automatic plastic welding machine is used for the production of blood bags. Automatic plastic welding machine is manufactured by Colpitt which is a ten station fully automatic machine consisting of two robotic arms. Capacity of the machine is 12000 bags per shift. For the analysis, the machine breakdown details for the past three years are taken. Criteria for ranking of severity occurrence and detection are selected suitably by analyzing the past failure records of the machine.

III. PROCEDURE FOR CONDUCTING FMEA

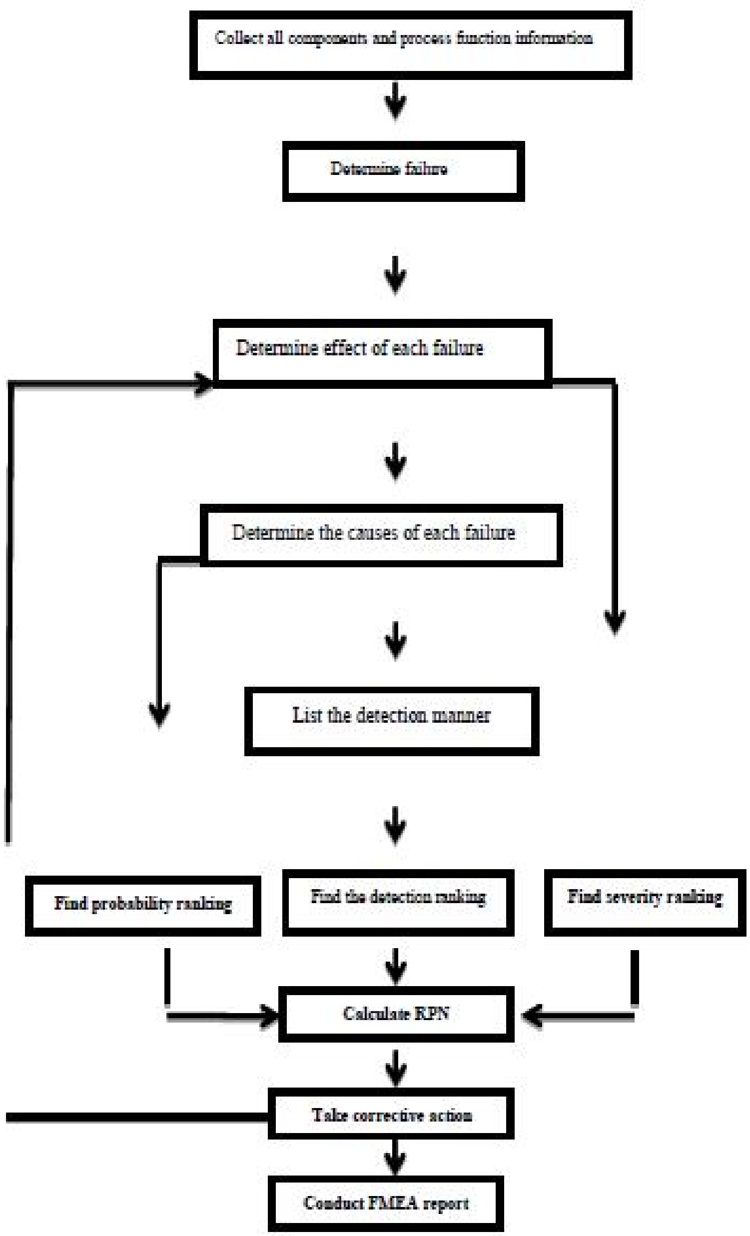

Fig. 1 FMEA Procedure

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The above Fig. 1 shows the procedure of FMEA

A.Potential Failure Mode

Identify failure modes for each component/system. Typically there will be several ways in which a component can fail. Potential Failure Mode comes from things that have gone wrong in the past, concerns of designers, and brainstorming. A potential failure mode represents any manner in which the component or process step could fail to perform its intended function or functions. Brainstorm the potential failure modes for each function for each of the components identified.

B. Potential Effects of Failure

Determine the effects (both locally and globally) associated with each failure mode on the system. The effect is related directly to the ability of that specific component to perform its intended function. An effect is the impact a failure could make if it occurred.

C. Severity

Assign a severity ranking to each effect that has been identified. The severity ranking is an estimate of how serious an effect would be should it occur. To determine the severity, consider the impact the effect would have on the customer, on downstream operations, or on the employees operating the process. The severity ranking is based on a relative scale ranging from 1 to 10. Depicts relative severity and corresponding rankings. An example Table.1 of severity is given below. [7]

Table. 1 Severity Rating

Rank	Effect	Rank	Effect
1	None	6	Severe
2	Very Slight	7	High Severity
3	Slight	8	Very High Severity
4	Minor	9	Extreme Severity
5	Moderate	10	Maximum Severity

D. Occurrence

Determine the failure's probability of occurrence. Assign an occurrence ranking to each of those causes or failure mechanisms. The occurrence ranking is based on the likelihood or frequency, that the cause (or mechanism of failure) will occur. The occurrence ranking scale, like the severity ranking, is on a relative scale from 1 to 10 as shown in Table 2. [8]

Table 2 Occurrence Rating

Rank	Occurrence	Rank	Occurrence
1	Extremely Unlikely	6	Medium Likelihood
2	Remote Likelihood	7	Moderately High Likelihood
3	Very Low Likelihood	8	Very High Severity
4	Low Likelihood	9	Extreme Severity
5	Moderately Low Likelihood	10	Maximum Severity

E. Detection rating

To assign detection rankings, identify the process or products related controls in place for each failure mode and then assign a detection ranking to each control. Detection rankings evaluate the current process controls in place. The Detection ranking scale, like the Severity and Occurrence scales, is on a relative scale from 1 to 10 as shown in Table. 3 [8], [7] Table. 3 Detection rating

Rank	Occurrence	Rank	Occurrence
1	Extremely Likely	6	Moderately Low Likelihood
2	Very High Likelihood	7	Low Likelihood
3	High Likelihood	8	Very Low Likelihood
4	Moderately High Likelihood	9	Remote Likelihood
5	Medium Likelihood	10	Extremely Unlikely

F. Calculate RPN

The RPN is the Risk Priority Number. The RPN gives us a relative risk ranking. The RPN is calculated by multiplying the three rankings together. Multiply the Severity ranking times the Occurrence ranking times the Detection ranking. For example Risk Priority Number (RPN) = (Severity) X (Occurrence) X (Detection).Calculate the RPN for each failure mode and the corresponding effect. RPN will always be between 1 and 1000. The higher the RPN, the higher will be the relative risk. The RPN gives us an excellent way to prioritize focused improvement efforts.[9]

G. Develop an action plan to address high RPN's

Develop an action plan by which reduction in the RPN. The RPN can be reduced by lowering any of the three rankings (severity, occurrence, or detection) individually or in combination with one another.

H. Take action

The action plan outlines what steps are needed to implement the solution, who will do them, and when they will be completed. Responsibilities and target completion dates for specific actions to be taken are identified. All recommended actions must have a person assigned responsibility for completion of the action. There must be a completion date accompanying each recommended action. Unless the failure mode has been eliminated, severity should not change. Occurrence may or may not be lowered based upon the results of actions. Detection may or may not be lowered based upon the results of actions. If severity, occurrence or detection ratings are not improved, additional recommended actions must to be defined.[11]

IV. SPARK PLUG

A spark plug is an electrical device that fits into the cylinder head of some internal combustion engines and ignites compressed aerosol gasoline by means of an electric spark. The first reliable spark plug was invented in 1903 by Oliver Lodge. They're aptly named as well; spark plugs are simply insulated plugs that are screwed into an internal combustion engine's **cylinder head** to deliver the spark that ignites the mixture of air and fuel in the combustion chamber. Spark plugs also transfer heat away from the combustion chamber. Spark plugs have an insulated center electrode which is connected by a heavily insulated wire to an ignition coil or magneto circuit on the outside, forming, with a grounded terminal on the base of the plug, a spark gap inside the cylinder.[6]
Internal combustion engines can be divided into spark-ignition engines, which require spark plugs to begin combustion, and compression-ignition engines. which compress the air and then inject diesel fuel into the heated compressed air mixture where it auto ignites. Compression-ignition engines may use glow plugs to improve cold start characteristics. The spark plug has two primary functions viz., to ignite the air/fuel mixture and to remove heat from the combustion chamber. The spark plug works as a heat exchanger by pulling unwanted thermal energy from the combustion chamber and transferring heat to the engines cooling system.[4]

A. Spark Plugs Principle

The spark plug plays an important role in petrol engines. It is responsible for ignition of the fuel-air mixture. The quality of this ignition influences several factors which are of great importance for both the driving operation and the environment. This includes smooth running, performance and efficiency of the engine as well as the harmful emissions.

B. Spark plug components

Fig.2 shows the components or parts of spark plug

1) *Connection:* The connection is designed as an SAE connection or a 4 mm thread. The ignition cable or a rod coil is plugged into the connection. In both cases a high voltage coupled here must be transported to the other end of the spark plug
2) *Insulator:* The ceramic insulator has two tasks. It serves primarily for insulation, whereby it prevents a flashover of the high voltage to the vehicle mass and conducts combustion heat to the cylinder head.
3) *Creepage current barriers:* The wave-shaped creepage current barriers on the outside of the insulator prevent the leakage of voltage to the vehicle mass. So that path to be travelled and increase the electrical resistance. Therefore it is guaranteed that the energy takes the path of least resistance - the path through the middle electrode
4) *Interference suppression:* In order to ensure the electromagnetic compatibility (EMC) and thus the fault-free operation of the on board electronics, a glass melt is used inside the spark plug as interference suppression.

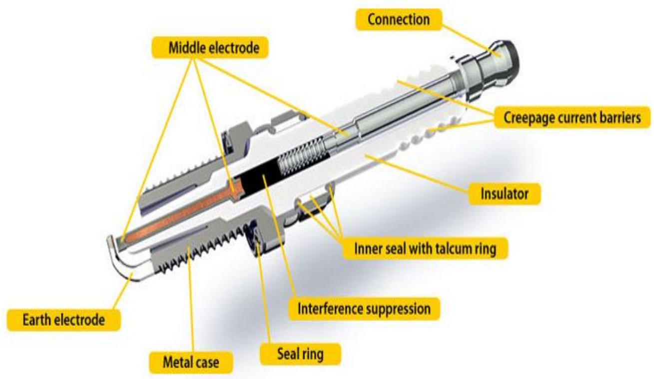

Fig. 2 Components of Spark Plug

5) *Middle electrode with copper core:* The middle electrode of a standard spark plug is comprised mostly of a nickel alloy. From the end of this electrode the spark must jump over to the earth electrode.
6) *Metal housing with thread:* The metal housing plays an important role in the heat dissipation of the spark plug. Its thread is always rolled for spark plugs. As opposed to cut threads, this has the advantage of no sharp edges which can damage the threaded bore in the cylinder head.
7) *Seal ring:* The seal ring prevents combustion gas from emerging past the spark plug through high combustion pressures. In the process, it prevents pressure losses. Moreover, it conducts heat to the cylinder head and evens out the different expansion properties of the cylinder head and spark plug housing
8) *Inner seals:* The inner seals create a gas-tight connection between insulator and metal housing. For this purpose, a talcum ring is enclosed between two additional seal rings. During the production of the spark plug it breaks down, ensuring an optimal seal

V. OBSERVATION

After Observing & analyzing the used spark plug tell us operating conditions of the engine, the plug and some problems are also understood, which ultimately causes the failure of plug & reducing performance of engine. That problems & effects are mentioned below.

A. Carbon Fouling

Carbon fouling is the most common spark plug related failure, but is not a spark plug fault. Carbon deposits are conductive, and as they accumulate along the insulator nose they reduce the insulation resistance of the spark plug shown in Fig.3. As electricity always takes the path of least resistance a misfire may occur if a significant amount of carbon deposits accumulate. A spark will not form as electricity can track along the conductive carbon deposits to the metal shell rather than forming a spark across the electrode gap which has a very high resistance. As mentioned the optimal operating temperature range for a spark plug is 450 – 870°C, 450°C is the spark plug self cleaning temperature at which point carbon deposits will burn off. However, if too cold a spark plug is used and this temperature is not achieved carbon fouling will occur. This is the most common reason for carbon fouling.[3]

Fig. 3 Photographic view of Carbon Fouled spark plug

B. Oil fouled

Center electrode, ground electrode and/or ceramic insulator tip are coated with a black, oily substance shown in Fig.4. This is caused by the presence of oil in the combustion chamber. Check for worn rings, valve guides and/or valve seals. In two-stroke engines, this could be the result of high oil content in the fuel mixture.[3]

Fig. 4 Photographic view of Oil Fouled spark plug

C. Flash-Over

Dark vertical lines and deterioration of the spark plug in the ribbed area of the insulator from a short between the metal spark plug shell and the terminal nut shown in Fig.5. Likely misfires. Can be caused by a variety of factors, including old/cracked spark plug boots, dirt or residue on the insulator, incorrect spark plug gap (too large) or even highly ionized air from an electrical storm. When the spark gap has widened due to wear of the electrodes, a higher voltage is required.

The flash-over occurs when the required voltage between the plug electrodes is higher than the voltage flying between the terminal and metal shell.The plug cable material hardens as time elapses, which in turn reduces the tightness of the cover and insulator, lowering the preventive power for flash-over.[5]

Fig. 5 Photographic view of Flash over occurred in spark plug

D. Over heating

When the firing end of the plug has overheated, the ceramics may break or the electrodes may melt. Overheated spark plugs have a white insulator surface at the firing shown in Fig.6 Under usual engine condition, the plug does not overheat. Note, however, that it gets extremely hot in the case of abnormal combustion (ex. high - speed knocking, pre - ignition).When the A - F setting is lean due to a faulty fuel system, the combustion temperature may rise, resulting in abnormal combustion. The engines cooling system may be faulty. When the spark timing is too early, the combustion temperature may rise, resulting in abnormal combustion. When deposits (generating from combustion) are accumulated in the combustion chamber, the combustion temperature may rise, resulting in abnormal combustion. When deposits have accumulated on the firing end of the plug, deposits may overheat, causing abnormal combustion. Especially in a two - cycle engine, oil gets burned and remains in the combustion chamber as deposits, accumulating on the plug as well. It is necessary to remove these deposits periodically.[3]

Fig. 6 Photographic view of Overheated spark plug

E. Spark plug deformation

Center electrode and ground electrode are bent out of position shown in Fig.7. Ceramic tip is broken and missing. This is a serious condition caused by a possible foreign object inside the cylinder. Also check for the improper spark plug thread due to the use of the wrong spark plug for this application.[5]

Fig. 7 Photographic view of bend of center electrode of spark plug

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Table. 4 FMEA analysis of Spark Plug

Failure Mode and Effect Analysis		
Part/Product No- REM38E	Key Contact Person : ****	Doc. No : X/FMEA/**
Part/Product Description : Spark Plug	Key Contact No : *****	Rev. No :123
Customer Name(if Any) : ****	Case Team : *****	Revision Data:
Customer drawing No : --1234		

Sr. No.	Potential failure modes of Spark plug	• Potential effects of failure	Severity Rating	Occurrence Rating	Detection Rating	Potential causes for failure	Solutions	RPN
1	Fouling - Carbon Fouling and Oil Fouling	Misfiring	7	3	5	Faulty injector	Check the condition of injector	105
		Weak ignition system voltage		5	5	Clogging of air cleaner element	Clean the air filter	175
		Poor cylinder compression		3	7	Delay in ignition timing	Check ignition system and oxygen sensor	147
		Hard starting		2	6	Plug heat range too high	Make sure the plug has correct heat range / thermal rating	84
				5	6	High oil consumption	Check the valves for proper seating	210
							Check and or replace oil seal	
							Make sure gasket ring is leak proof	
				8	5	Rich air/fuel Mixture	Maintain correct air/fuel ratio	280
				5	4	Too cold a spark plug is used	Use a hotter spark plug in the specified range	140
2	Flashover	Wear of terminal electrodes		2	5	High compression pressure	Maintain optimal compression pressure	80
		Misfiring and hard starting		4	3	Contamination in the ignition leads	Avoid contamination by replacing/cleaning dirty spark plugs	84
							Check O-rings at the bottom of the lead	

		Deterioration of plug cap	7	3	5	Worn out insulator boots	Check the insulator boots for proper fit	105
				7	3	Widened spark gap	Adjust the gap precisely	147
				2	6	Torn rubber gasket	Replace the rubber gasket	84
				3	5	Plug cable material hardens	Replace plug cable periodically	105
				2	3	High ignition voltage	Check the ignition coil	42
3	Spark Plug overheating	Abnormal combustion	9	3	5	Ignition timing too far advanced	Adjustment of ignition timing is required	135
		Melting of spark plug electrodes		4	2	Air/fuel mixture(A/F) too lean	Adjustment of air fuel ratio (A/f) is required	72
		Possible damage of piston		3	4	Insufficient cooling water and lubricants	Top up cooling water and lubricants	108
		Difficulty in staring		3	3	Applied turbo boost pressure too high in the case of a turbo engine	Adjustment of turbo boost pressure control is required	81
				4	3	Insufficient tightening of spark plug	Tighten to specified torque	108
				1	2	Use of too hot a spark plug	Use colder spark plug in the given range	18
				5	4	Block or leak in intake manifold	Clean or replace the intake manifold	180
4	Spark plug deformation / damage	Damage Of Thread	8	2	2	Spark plug inserted at an improper angle	Tightening the plug by hand first instead of using a wrench from the start	32
		Damage of Metal shell		3	6	Excessive tightening	Tighten to the specified tightening torque	144
		breakage of Insulator		1	4	Spark plug wrench used at an angle or it slipped	Use hexagon socket wrench that does not slip easily	32
							Avoid spherical or loose wrench	

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				3	6	Gasket too loose/too tight	Make sure gasket is tightened to the recommended Tension	144
5	Electrode wear	Hard starting of Engine	7	4	4	Plugs have been left in the engine too long	Change the spark plugs Follow the recommended maintenance schedule	112
		Misfiring during running		1	6	Incorrect spark plug selection	Replace with spark plugs of the required heat range	48
		Maximum power cannot be obtained from the engine		5	5	Inadequate engine servicing	Follow the service chart periodically	175

VI. RESULT AND DISCUSSION

Different parts and Potential failure modes of spark plug are analyzed. After study and observation of spark plug FMEA table is plotted. From the FMEA Table it is observed that spark plug is get fail due to fouling and overheating. Fouling is of two types carbon fouling and oil fouling. In carbon fouling carbon deposition can be reduced by periodically checking the spark plug and maintaining the constant air/fuel mixture. When the spark plug is get overheated, which causes the melting of electrode and reduced efficiency of engine, so temperature of spark plug should be maintain by cleaning the air filter periodically and doing a periodical check for any blocks in the fuel passage and the intake manifold. Other defects such as spark plug deformation and the electrode wear have very less chances to occur if above defects which are mentioned are avoided. Flashover which can be eliminated during design level. The life or running time of spark plug can be increased if we follow above remedies. Following graph Fig.8 shows causes that have higher RPN.

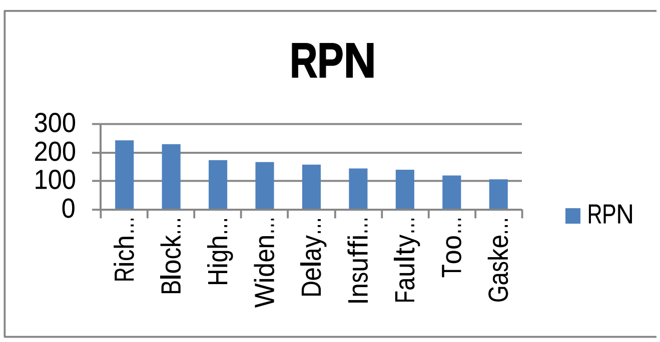

Fig. 8 Causes having higher RPN

VII. CONCLUSION

Spark plug is an automotive component, which is analyzed and the expected failure modes have been observed and tabulated. By giving the detection rating to failure modes risk priority number is calculated. From the analysis failure modes which having higher risk priority numbers are selected.

The potential causes, effects and alternative solutions are given along with the ratings which decrease the risk of failure. Thus this process analysis is a helpful tool to detect the occurring of failure modes and also assures in the effective functioning of the spark plugs. It is a well-documented method. As a result of this FMEA analysis, the down time of the vehicle is reduced by improving the reliability of spark plug

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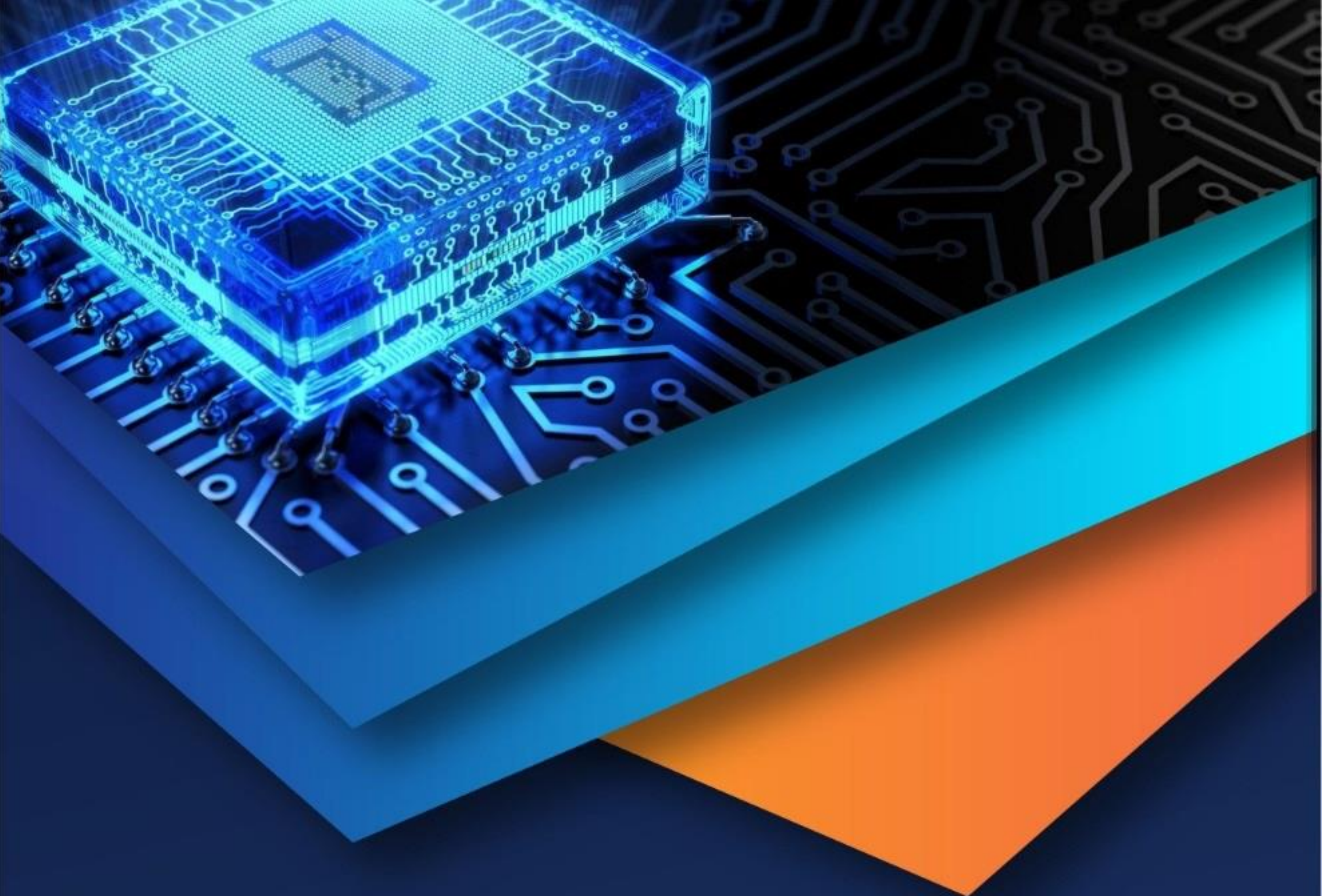

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