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An Investigation to Analyse MRR, TWR and Surface Roughness During Parametric Optimization of EDM of EN-31

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Abstract: Electric discharge machine is a non-conventional machining. In which there is no contact between tool and work piece. By EDM process machining of hard material components that are difficult to machine such as heat treated tool steels, ceramics, composites, carbides, heat resistance steel which are used in die and mould producing industries, aero space and nuclear industries. In the work, the machining parameters for thesis are current, pulse on time and pulse off time, which are optimized for minimum tool wear rate (TWR), maximum material removal rate (MRR) and minimum surface roughness during electro discharge machining of EN-31. Analysis of Variance is also used to find out variable affecting the various responses mentioned above.

Keywords: EDM, EN-31, MRR, TWR, Surface Roughness

I. INTRODUCTION

EDM or electric discharge machining is completed when a discharge take place between anode and cathode, due to discharge the intense heat energy is produced near the zone. That is sufficient to melt and evaporate the materials in the sparking zone. To improve the effectiveness of the process, a die electric fluid (hydrocarbon or mineral oils) is used in this work piece and the tool is submerged. It has been observed in the process that if both the electrodes are of same material, the electrode connected to positive terminal generally erodes at a faster rate than the other. Due to this, the work piece is normally made the anode. A suitable gap, known as spark gap, should be maintained between the tool and the work surfaces to complete the process. Since the spark occurs at the place where the tool and the work surface are the close enough and after each spark the spot changes (due to the material removal after each spark), the spark travels all over the surface. This is the reason of uniform material removal all over the surface, and finally work piece conforms to the tool surface.

A study conducted was by Subramanian Gopalakannan and Thiagarajan Senthilvelan [1] to observed the effect of pulsed current on material removal rate, electrode wear, surface roughness and diameter overcut in corrosion resistant stainless steels viz., 316 L and 17-4 PH. The materials used in the work were machined with different electrode materials such as graphite, , copper-tungsten & copper. It is observed that the output parameters such as material removal rate, electrode wear and surface roughness of EDM increases with increase in pulsed current. The final result obtained that the high material removal rate have been obtained with copper electrode whereas copper-tungsten yielded minimum electrode wear, smooth surface finish and good dimensional accuracy. The study of Pravin R. Kubade and V. S. Jadhav [2] investigated the effect of EDM parameters on EWR, MRR and ROC while machining of AISI D3 material with a copper electrode. The parameters considered were pulse-on time (Ton), peak current (Ip), duty factor (t) and gap voltage (Vg). It is found that the MRR is mainly influenced by peak current where as other the other factors used, have very less effect on material removal rate. Electrode wear rate is mainly influenced by peak current and pulse on time, duty cycle and gap voltage has very less effect on electrode wear rate. Peak current has the most influence on radial overcut then followed by duty cycle and pulse on time with almost very less influence by gap voltage.

To study the effected process parameters and electrode shape configuration on the machining parameter such as surface quality, electrode wear & material removal rate Shishir Mohan Shrivastava and A.K. Sarathe [3] conducted experiments and found better machining performance was obtained generally with the electrode as the cathode and the work-piece as an anode and it was observe that for high MRR main process parameters are peak current, pulse on time ,pulse off time, whereas for electrode wear were mainly influenced by peak current and pulse on time. Surface quality of the work was mainly influenced by peak current. The tool shape configuration concerned best tool shape for higher MRR and lower TWR is circular, followed by square, triangular, rectangular, and diamond cross sections. In a research, Abhishek Gaikwad, Amit Tiwari, Amit Kumar and Dhananjay Singh [4] studied the effect of control factors (i.e., current, pulse on time, pulse off time, fluid pressure) for maximum material removal rate (MRR) and minimum electrode wear rate (EWR) for EDM of hard material Stainless steel 316 with copper as cutting tool electrode. In this paper both the electrical factors and non electrical factors has been focused which governs MRR and EWR. Paper is based on Design of experiment and optimization of EDM process parameters. The technique used is Taguchi technique which is a statistical decision making tool helps in minimizing the number of experiments and the error associated with it. The research showed that the Pulse off time, Current has significant effect on material removal rate and electrode wear rate respectively.

In an investigation conducted by Y. H. Guu [5] of surface characteristics of Fe-Mn-Al alloy analyzed by means of the atomic force microscopy (AFM) technique and concluded that the higher discharge energy caused more frequent melting expulsions, leads to deep and large crater formation on surface of work, resulting in a poor surface finish. Another investigation conducted by George et al [6] optimized the machining parameters in the EDM machining of C-C composite using Taguchi method. The process variables affects electrode wear rate and MRR, according to their relative significance, are gap voltage, peak current and pulse on time respectively.

C.H. Cheron [7] machined XW42 tool steel and concluded that material removal rate with Cu electrode is greater than graphite electrode. He also concluded that Cu is suitable for roughing surface while graphite is suitable for finishing surface.

A similar study was conducted by Ahmet Hascalık and Ulas¸Caydas [8] using parameters such as pulse current and pulse duration and concluded that electrode material has an obvious effect on the white layer thickness, the material removal rate, surface roughness and electrode wear are increasing with process parameters. S. Ben Salem et al [9] conducted experiments by experimental design methodology and found that a fewer number of experiments are required to find optimum result and the surface roughness equation shows that the current intensity is the main influencing factor on roughness.

In a research carried out by V. Chandrasekaran et al [10] on WC/5ni Composites Using Response Surface Methodology concluded that the MRR is maximum for all compositions. As the percentage of nickel increases the thermal conductivity of the composition increases since the nickel material is easily removed from the surface of the parent material. So the MRR increases with percentage of nickel. The surface roughness increases with increase in current and flushing pressure irrespective of %Ni. The optimum Ra values decreased with increasing electrode rotation. Francesco Modica et al [11] aimed of investigation to shed a light on the relation and dependence between the material removal process, identified in the evaluation of tool wear ratio (TWR) and material removal rate (MRR), and some of the most important technological parameters (*i.e.*, open voltage, discharge current, pulse width and frequency), in order to experimentally quantify the material waste produced and optimize the technological process in order to decrease it. Kumar Sandeep [12] studied aspects related to surface quality and metal removal rate which are the most important parameters from the point of view of selecting the optimum condition of processes as well as economical aspects. It reported the research trends in EDM.

Lau et al [13] stated the feasibility of using Electrical Discharge Machining (EDM) as a means of machining carbon fiber composite materials. Machining was performed at various currents, pulse durations and with different tool materials and polarities and they concluded that it is entirely feasible machine carbon fiber composite materials by EDM process. Copper electrodes prove to be better than graphite electrodes in terms of tool wear and surface finish. Positive polarity should be used for machining carbon fiber composite materials in order to achieve a low tool wear ratio.

II. EXPERIMENTAL DETAILS

Work piece: The material used for the present work is EN-31 with 5mm thickness and 20mm diameter. The chemical composition of EN-31 is shown in table I below.

TABLE I: Composition Of En-31

Material	Fe	Mn	Cr	C	Si
% Composition	95.7	0.52	1.30	1.50	0.22

1) *Tool:* The tool material used is pure Copper of 5mm diameter and 25mm length.
2) *Machine:* ELECTRONICA ZNC EDM machine available at Dilawar Engineering Works, Lucknow.
3) *Process Parameters:* The process parameters selected for the present research are Current, Pulse on time and Voltage.
4) *Performance Measures:* The performance measures assessed I this research are material removal rate (MRR), tool wear rate (TWR) and surface roughness.

Fig. 1: Machining of EN-31 on ZNC EDM by copper tool

TABLE III: SHOWING PARAMETERS USED FOR EXPERIMENTATION ON MIG WELDING MACHINE

S.No.	Parameters	Units	Level 1	Level 2	Level 3
1	Current	A	1	5	9
2	Pulse-on-time	µsec	15	20	25
3	Gap Voltage	V	75	100	125

TABLE IIII: EXPERIMENTAL VALUES OF MRR, TWR AND SURFACE ROUGHNESS

Exp. No	Current	Pulse on time	Gap Voltage	MRR (mm3/min)	TWR (mm3/min)	Surface Roughness (µm)
1	1	15	75	0.254	0.221	3.06
2	1	20	100	0.298	0.065	4.4
3	1	25	125	0.229	0.100	5.72
4	5	15	100	0.652	0.852	3.97
5	5	20	125	1.317	0.764	4.25
6	5	25	75	1.182	0.514	6.12
7	9	15	125	1.952	1.133	3.11
8	9	20	75	3.734	1.084	6.78
9	9	25	100	1.972	1.717	7.03

III.RESULTS AND DISCUSSION

A. Influence of parameters on Material Removal Rate

The material removal rate is the rate at which the material is removed during machining. The weight loss is calculated by weighing the specimen before and after machining. Machining time is noted while machining each specimen. Following table III shows the response table for mean SN ratio for material removal rate. It shows that peak current has rank 1 and is the most influencing parameter for MRR followed by pulse on time and voltage.

TABLE IVII: RESPONSE TABLE FOR MEAN SN RATIO FOR MRR

Level	Peak Current	Pulse on Time	Voltage
1	-11.7408	-3.2696	0.3308
2	-0.0430	1.1065	-2.7775
3	7.7171	-1.8176	-1.5340
Delta	19.4578	4.3761	3.1084
Rank	1	2	3

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The following table IV shows ANOVA of MRR conducted on MINITAB 16.0. The result shows that the contribution of current is most and is 77.64%.

TABLE VV: ANOVA FOR MRR

Source	DOF	SS	Adj MS	F value	% Contribution
Peak Current	2	8.1359	4.0679	28.59	77.64%
Pulse on Time	2	1.1495	0.5748	4.04	10.97%
Voltage	2	0.9090	0.4545	3.19	8.67%
Error	2	0.2846	0.1423		2.72%
Total	8	10.4790			100%

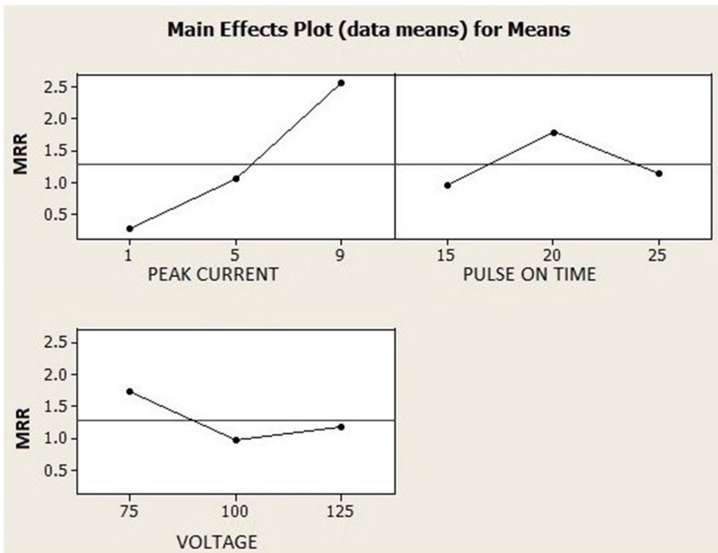

Fig. 2: Main effect plot for MRR

The above figure 2 shows the main effect plot for means. It shows that with increase in current, the MRR initially increases at slower rate but with increase in the level of current, MRR increases at a higher rate. Higher the current, intensity of spark is increased and thus metal removal rate increases. Current is the most significant factor for MRR with a contribution of 77.64%. In case of pulse on time, the MRR increase initially with increase in its level but with further increase in Ton it get decreased. Pulse on duration has a low contribution of 10.97%. The discharge energy is higher at higher levels of pulse on time and the debris of machined material did not get sufficient time to get removed from the spark gap, hence the MRR get reduced. In the case of voltage, the MRR tends to decrease initially with increase in voltage. When the voltage is increased to 125V, the MRR get increased. Voltage is the least influencing parameter for voltage and has a contribution of only 8.67%.

B. Influence of parameters on Tool Wear Rate

Tool wear rate is calculated by weighing the tools before and after machining and also noting the machining time for each specimen. Following table V shows the response table for mean SN ratio for tool wear rate. It shows that peak current has rank 1 and is the most influencing parameter for TWR followed by pulse on time and voltage.

TABLE V: RESPONSE TABLE FOR MEAN SN RATIO FOR TWR

Level	Peak Current	Pulse on Time	Voltage
1	18.951	4.473	6.064
2	3.170	8.460	6.813
3	-2.160	7.028	7.085
Delta	21.111	3.987	1.020
Rank	1	2	3

The following table VI shows ANOVA of TWR conducted on MINITAB 16.0. The result shows that the contribution of current is most and is 86.66%.

TABLE VI: ANOVA FOR MRR

Source	DOF	SS	Adj MS	F value	% Contribution
Peak Current	2	2.09825	1.04913	12.35	86.66%
Pulse on Time	2	0.03069	0.01534	0.18	1.27%
Voltage	2	0.12241	0.06120	0.72	5.05%
Error	2	0.16985	0.08492		7.02%
Total	8	2.42120			100%

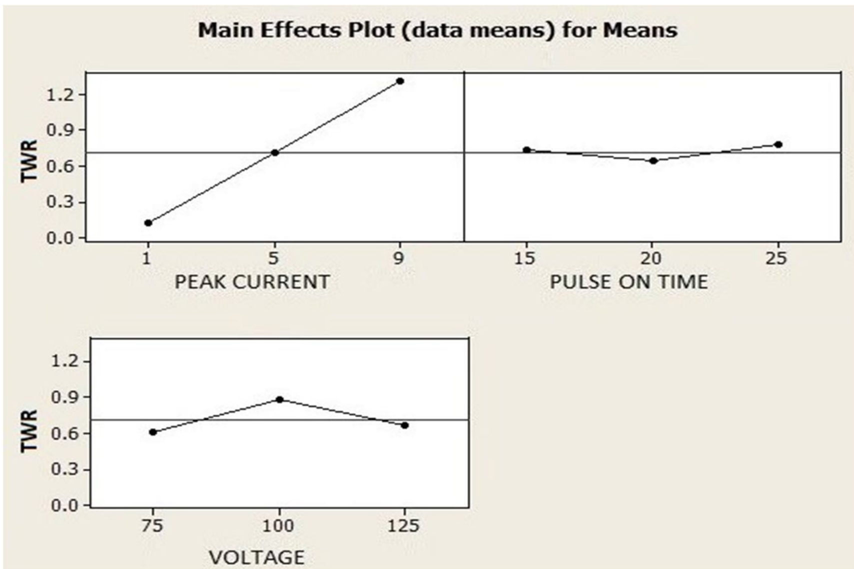

Fig. 3: Main effect plot for MRR

The above figure 3 shows the main effect of plot for tool wear rate shows a similar trend as it is for MRR. Peak current is the most dominating factor for TWR. There is an increase in TWR with increase in the value of current. This is because of the increased intensity of spark striking the tool. The minimum TWR is generated at 1 A. With pulse on time, TWR lies near the mean TWR and the graph obtained is almost flat. Pulse on time is the least influencing parameter for TWR and has a negligible contribution of only 1.27%. With voltage, initially the TWR increases with increase in its level. Voltage also being the least influencing factor, has a contribution of 5.05%.

C. Influence of parameters on Surface Roughness

The surface roughness is an important performance measure that is considered while electro discharge machining. TR-200 surface roughness tester was used to calculate the roughness of the machined hole. Following table VII shows the response table for mean SN ratio for surface roughness. It shows that pulse on time has rank 1 and is the most influencing parameter for surface roughness followed by peak current and voltage.

TABLE VII: RESPONSE TABLE FOR MEAN SN RATIO FOR TWR

Level	Peak Current	Pulse on Time	Voltage
1	-12.58	-10.52	-14.02
2	-13.43	-14.02	-13.93
3	-14.47	-15.94	-12.52
Delta	1.90	5.43	1.50
Rank	2	1	3

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The following table VIII shows ANOVA of Surface Roughness conducted on MINITAB 16.0. The result shows that the contribution of pulse on time is most and is 70.25%.

TABLE VIII: ANOVA FOR MRR

Source	DOF	SS	Adj MS	F value	% Contribution
Peak Current	2	2.443	1.221	1.68	13.32%
Pulse on Time	2	12.892	6.446	8.85	70.27%
Voltage	2	1.554	0.777	1.07	8.47%
Error	2	1.456	0.728		7.94%
Total	8	18.345			100%

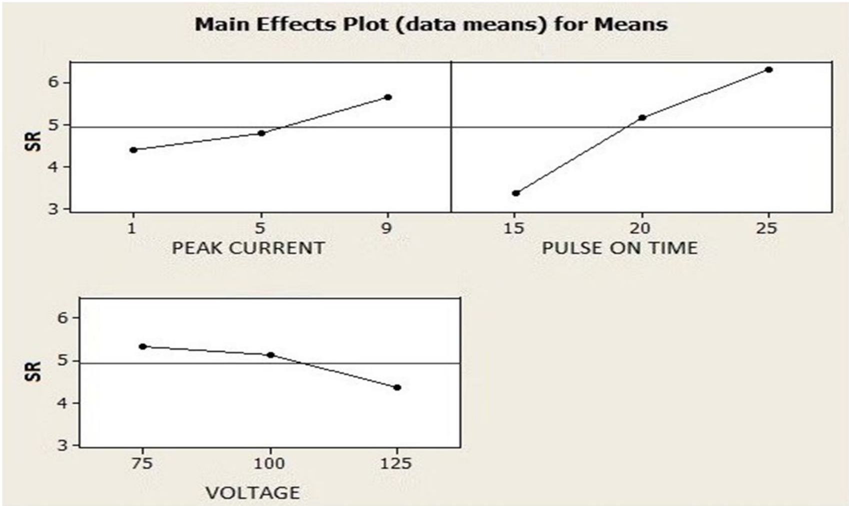

Fig. 4: Main effect plot for Surface Roughness

The above figure 4 shows the influence of input parameters on surface roughness of the machined surface. The surface roughness degrades as the current and pulse on time are increased. By increasing the current the surface roughness increases as more intense sparks strike the surface of the work piece. From the above graph it is observed that pulse on time is the most significant factor for surface roughness. In case of pulse on time, surface roughness increases at a higher rate as compared to peak current. Pulse on time has the highest contribution of 70.27%. With increase in voltage, surface roughness decreases and it is the least influencing parameter for surface roughness.

IV. CONCLUSIONS

This experimental investigation for optimization of input machining parameters in Electrical Discharge Machining of EN-31 using copper tools yield following conclusions:

A. With increase in current, the MRR initially increases at slower rate but with increase in the level of current, MRR increases at a higher rate. Higher the current, intensity of spark is increased and thus metal removal rate increases.

B. Current is the most significant factor for MRR with a contribution of 77.64%.

C. In case of pulse on time, the MRR increase initially with increase in its level but with further increase in Ton it get decreased. Pulse on duration has a low contribution of 10.97%. The discharge energy is higher at higher levels of pulse on time and the debris of machined material did not get sufficient time to get removed from the spark gap, hence the MRR get reduced.

D. In the case of voltage, the MRR tends to decrease initially with increase in voltage. When the voltage is incrased to 125V, the MRR get increased. Voltage is the least influencing parameter for voltage and has a contribution of only 8.67%.

E. Peak current is the most dominating factor for TWR. There is an increase in TWR with increase in the value of current. This is because of the increased intensity of spark striking the tool. The minimum TWR is generated at 1 A.

F. Pulse on time is the least influencing parameter for TWR and has a negligible contribution of only 1.27%.

G. With voltage, initially the TWR increases with increase in its level. Voltage also being the least influencing factor, has a contribution of 5.05%.

H. The surface roughness degrades as the current and pulse on time are increased. By increasing the current the surface roughness increases as more intense sparks strike the surface of the work piece. Pulse on time is the most significant factor for surface roughness. In case of pulse on time, surface roughness increases at a higher rate as compared to peak current. Pulse on time has the highest contribution of 70.27%.

I. With increase in voltage, surface roughness decreases and it is the least influencing parameter for surface roughness.

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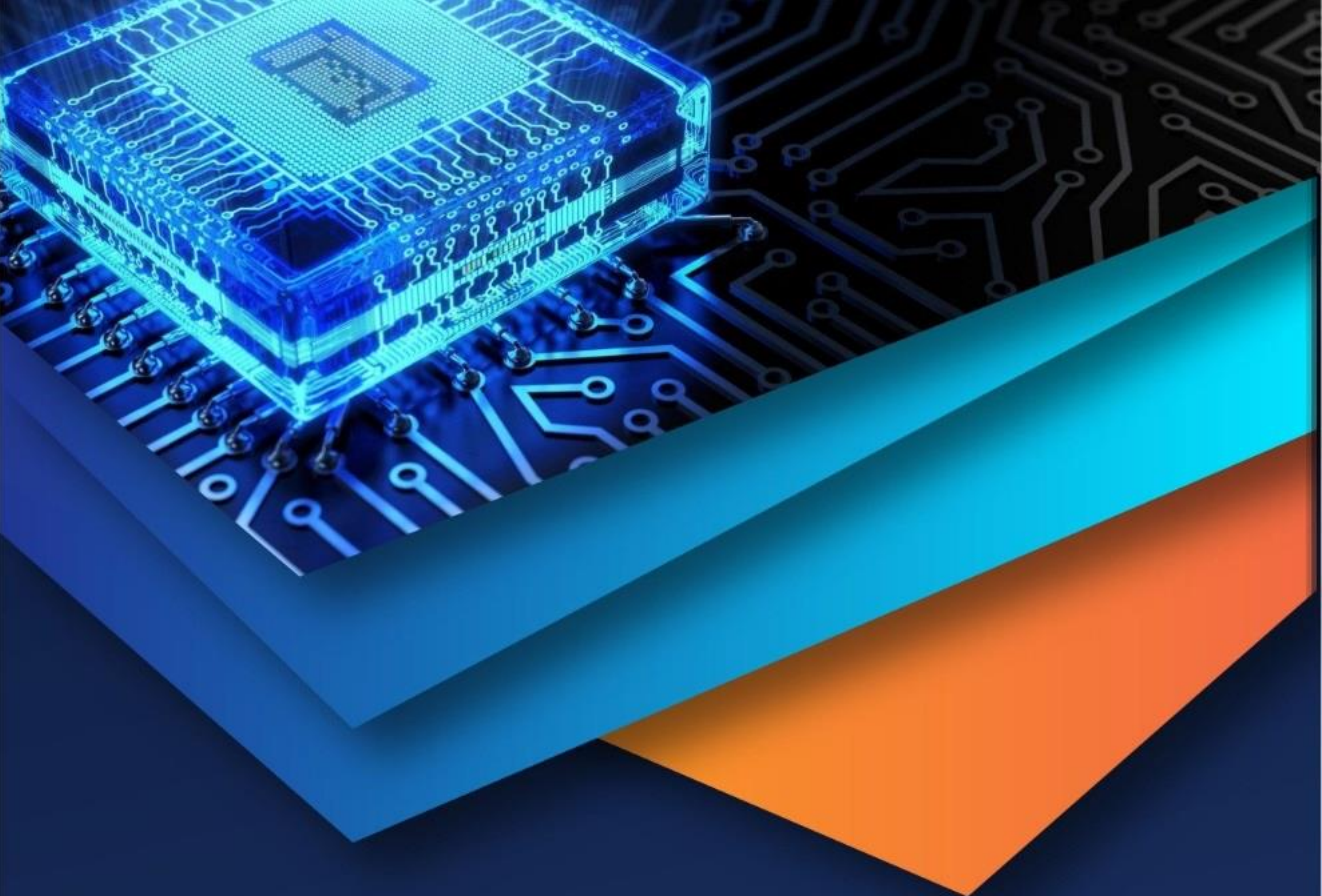

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