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Optimization and Modelling of End Milling Process Parameters by Using Taguchi Method

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Abstract—Surface roughness is an index which determines the quality of machined products and is influenced by the cutting parameters. The aim is prediction of surface roughness by using artificial neural systems. The neural network model can be efficiently find the best cutting parameters value for a specific cutting condition in milling operation and achieve minimum surface roughness. In machining operations, achieving desired surface quality features of the machined invention, is really a exciting job. Because, these quality structures are highly correlated and are expected to be influenced directly or indirectly by the direct effect of process parameters or their interactive effects (i.e. on process environment). However, the amounts of major influence of the process parameters are different for different reactions. Therefore, optimization of surface roughness is a multi-factor, multi-objective optimization difficulty. Thus, to solve such a multi-objective optimization problem, it is sensed necessary to classify optimal parametric combination, following which all purposes could be optimized instantaneously. In this context, it is important to convert all objective functions into an equivalent single objective function or overall representative function to meet desired multi-quality features of the machined surface. The mandatory multi-quality features may or may not be contradictory in nature. The representative single objective function, thus designed, would be optimized finally. In the present work, Design of Experimentation (DOE) with Taguchi L9 Orthogonal Array (OA) has been explored. Finally, Taguchi method has been adopted for searching optimal process condition to yield desired surface quality. In the present work an experimental investigation of the end milling of AISI D2 steel with carbide tool by varying feed, speed and depth of cut and the surface roughness was measured using Surface Roughness Tester. The neural network design and development was done using MATLAB. The training data set has been used to train ANN model for data prediction.

Keywords- Taguchi Method, Surface Roughness, Artificial Neural networks, Orthogonal Array.

I. INTRODUCTION

Milling is the process of machining smooth, curved, or uneven surfaces by feeding the work piece against a rotating cutter containing a number of cutting edges. Milling machine is one of the important machining processes. In this operation, work piece is fed against a rotating cylindrical tool. The rotating apparatus consists of many cutting edges (multipoint cutting tool). Normally axis of rotation of feed is given to work piece. Milling operation is illustrious from other machining operations on the basis of orientation between the tool axis and the feed track; however, in other processes like drilling, turning, etc. the tool is fed in direction parallel to axis of rotation.

The milling machine consists basically of a motor driven spindle, which supports and revolves milling cutter, and an interchanging adjustable worktable, which mounts and feeds work piece. Milling is normally used to produce parts that are not axially symmetric and have many features, such as hovels, slots, pockets, and even three dimensional surface curves. Parts that are fabricated completely through milling often include components that are used in partial quantities, maybe for prototypes such as custom designed clasps or brackets. Due to high tolerances and surface finishes that milling can deal, it is ideal for a adding precision features to a part whose basic shape has already been formed. Various types of milling processes are end milling, peripheral milling and face milling.

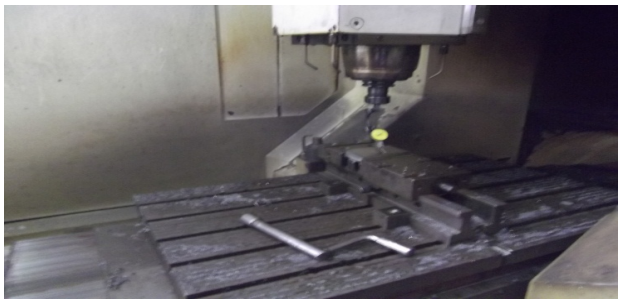


Figure 1: End Milling Operation on AISI D2 Steel

Among different types of milling procedures, end milling is one of most vital and common metal cutting operations used for machining parts because of its capability to remove materials at faster rate with a reasonably good surface quality (see figure 1). Also, it is capable of producing a variety of configurations using milling cutter. In end milling, the cutter, called end mill, has a diameter less than the work piece width. The end mill has helical cutting edges passed over onto the cylindrical cutter surface. End mills with smooth ends are used to produce pockets, closed or end key slots, etc. In end milling an end mill makes either peripheral or slot scratches, determined by the step-over distance, across work piece in order to machine a specified feature such as a profile, slot, pocket, or even a composite surface contour. The penetration of the feature may be machined in a single pass or may be reached by machining at a smaller axial depth of cut and making multiple passes.

End milling operation produces flat upright surfaces, flat horizontal surfaces and other flat surfaces making an angle from table surface using milling cutter named as end mill. This operation is preferably carried out on vertical milling mechanism. This operation is illustrated in Figure 2.

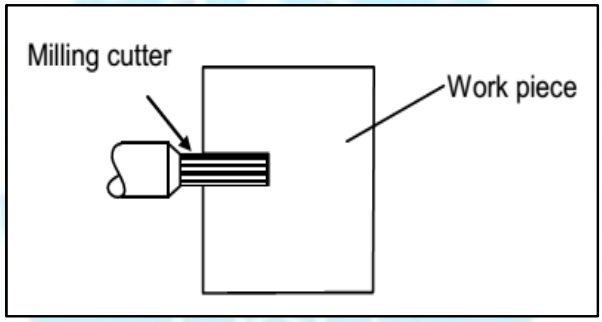


Figure 2: End Milling Operation

The paper is well-organized as follows. In section II, we discuss correlated work with end milling process. In Section III, It defines the complete experimental work and setup. After this, it designates the main results of this system.Finally, conclusion is explained in Section V.

II. RELATED WORK

In literature, authors studied the performance of multilayer coated carbide insert in the machining of hardened AISI D2 steel (53 HRC) using Taguchi design of experimentation. The experiment was calculated based on Taguchi L27 orthogonal array to predict surface roughness. The S/N ratio and optimal parametric situation are analysed. The examination of variance had also been passed out to predict the significant factors affecting surface roughness. Based on Taguchi S/N value and ANOVA, feed was the most manipulating parameter for surface roughness followed by cutting speed whereas depth of cut has least significant from the experiments. In regression model, the value of R2 being 0.98 indicates that 98 % of the total deviations were explained by the model [5].

Some Authors proposed that Optimum machining parameters are of great concern in manufacturing surroundings, where economy of machining operation plays a key role in competitiveness in market. So the present research was aimed at finding the optimal process parameters for End milling process. The End milling process was a widely used machining process in aerospace industries and many other industries ranging from large manufacturers to a small tool and die shops, because of its versatility and efficiency. The reason for being widely used was that it may be used for the rough and finish machining of such features as slots, pockets, peripheries and faces of components[6].

Some proposed that the determination of optimal cutting parameters have significant importance for economic machining in minimizing of particular operating mistakes like tool fraction, wear, and chatter. The evolutionary algorithm GA was used to

improve many solutions of optimization complex problems in many applications. This paper studiedideal selection of cutting parameters in turning operation using GA and its variants. This study deals with GA procedure in different machining aspects in turning operation like surface roughness, production amount , tool lifetime, production cost, machining time and cutting temperature [7].

Authors proposed that CNC End milling is a unique adaption of the conventional milling process which uses an end mill tool for the machining process. CNC Vertical End Milling Machining is a widely accepted material removal process used to manufacture components with complicated shapes and profiles. During end milling process, material is removed by the end mill cutter. The effects of several parameters of end milling process like spindle speed, depth of cut, feed rate have been examined to reveal their Impact on surface finish using Taguchi Methodology. Experimental plan is achieved by a Standard Orthogonal Array. The results of investigation of variance (ANOVA) indicate that the feed Rate is most influencing factor for modelling surface finish [9].

III. EXPERIMENTAL WORK

Experiments are performed by investigators in almost all fields of inquiry, usually to discover something about a particular process or system.

A. Material Used

In this work hardened AISI D2 steel (hardness 50-70 HRC) will be used as the work piece material and Tungsten carbide preferably coated will be used as the tool material. The chemical arrangement of AISI D2 tool steel is given in below Table 1.

Table 1: Chemical Composition of Steel

Carbon	1.55 %
Silicon	0.30 %
Manganese	0.35 %
Chromium	12 %
Molybdenum	0.75 %
Vanadium	0.90

AISI D2is recommended for tools requiring very high wear resistance, combined with moderate toughness (shock-resistance).AISI D2can be supplied in various finishes, including the hot-rolled, pre-machined and fine machined condition creating Dies, Punches, Forming Rolls, Knives, Slitters, Shear edges.

B. Machine Used

Machining was carried out in CNC machine at CTR, Ludhiana.



Figure 3: CNC Machine

Table 2: Specification of Vertical CNC Milling Machine

Table Size	915 * 356 mm
Table Load	341 KG
Power	3 phase, 60 Hz
Control	GE FANUC 211
X Axis Travel	560 mm
Y Axis Travel	406 mm
Z Axis Travel	508 mm
Spindle Speed	100 RPM Direct Drive
Spindle Diameter	65 mm
Spindle Taper	ISO-40
Tool Taper	BT-40
Magazine Capacity	22 Tools
Maximum Weight of Tool Holder	50 KG
Maximum Tool Length	254 mm

C. Proposed Steps

- Use D2 steel as work piece.
- Experiments were conducted according to L9 orthogonal array
- Independently controllable cutting parameters were (1) cutting speed, (2) feed rate, and (3) depth of cut.
- Apply machining operations with the help of CNC machine.
- Calculate roughness parameters by machining operations.
- Average surface roughness (Ra) of the turned surface was measured using a surface roughness measuring tester.
- Apply taguchi technique for optimization and calculating mean and S/N ratio of parameters using MINITAB.

D. Experimental Procedures

- Checking and preparing the Centre Lathe ready for performing the machining operation.
- Firstly, the work-piece was cut according to above mentioned dimension i.e. 100*100*25 mm by cutter.
- For developing models on the basis of experimental data three main machining parameters are considered to predict surface roughness of D2 material using carbide tool. Among the range of spindle speediness, feed, and depth of cut accessible possible in the machine the following three levels are considered as shown in Table 3.
- The machining was carried out on end milling machine, the material work piece is clamped on vice mounted on the table of the machine. The machining procedure and work tool motion of end milling process respectively.
- The machining is carried out by selecting proper spindle speed and feed rate during each experimentation. Experiment was carried out by varying the depth of cut.

Table 3: Levels of Input Control Parameters

Factors	Levels	Factor Level values
Speed (RPM)	3	796,995,1194
Depth of Cut (mm)	3	0.75,0.50,0.25
Feed (mm/min.)	3	500,800,1100

Orthogonal Array is a statistical method of defining parameters that converts test areas into factors and levels. Test strategy using orthogonal array generates an efficient and concise test suite with fewer test cases without compromising test coverage. An orthogonal array is a "table" (array) whose entries come from a fixed finite set of symbols (typically, {1,2,..., n}), arranged in such a way that there is an integer t so that for every selection of t columns of table, all ordered t-tuples of symbols, formed by taking the entries in each row restricted to these columns, appear same number of times. The number t is called strength of orthogonal array. The Table 4 shows the design matrix used in this work.

Table 4: Orthogonal Array L_9

Sample No.	Spindle Speed (rpm)	Feed Rate (mm/min)	Drilling Depth (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Taguchi's designs aimed to allow greater understanding of variation than did many of the traditional designs. Taguchi contended that conventional sampling is inadequate here as there is no way of obtaining a random sample of future conditions. Taguchi projected extending experimentation with an "outer array" or orthogonal array should simulate the random atmosphere. Here we use L9 orthogonal array with 3 stages. In this work, L_9 Orthogonal Array design matrix is used to set the control parameters to evaluate the process performance. Taguchi orthogonal array is designed with three levels of turning parameters with the help of software Minitab. Orthogonal Array design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table 5.

Table 5: Process Parameter Design

Pieces	Speed (rpm)	Depth of Cut (mm)	Feed (mm/min)
1	796	0.75	500
2	796	0.50	800
3	796	0.25	1100
4	995	0.75	800
5	995	0.50	1100
6	995	0.25	500
7	1194	0.75	1100
8	1194	0.50	500
9	1194	0.25	800

IV. RESULTS

A. Surface Roughness by End Milling

End milling is one of the most fundamental and commonly encountered chip removal operations occurring in a real manufacturing environment. In this machining process, the surface finish is a key factor in evaluating and determining excellence of a part. In practice, a chosen surface roughness value is usually designated, and suitable cutting parameters are selected to achieve the desired quality of a specified part.

There are various surface roughness amplitude parameters such as roughness average (*Ra*), R_t, root-mean-square (rms) roughness R_q etc. which are used in industries as shown in Table 6. Surface roughness average parameter (*Ra*) is the most extended index of product quality and has been used in this study. The average roughness (*Ra*) can be defined as the area between the roughness profile and its mean line or integral of absolute value of the roughness profile height over the evaluation length.

Table 6: Measured Roughness Parameters

Pieces	R_a (µm)	R_t(µm)	R_z(µm)	R_c(µm)
1	0.18	1.6	1.19	0.44

2	0.38	2.41	2.06	0.66
3	0.37	3.69	2.46	0.93
4	0.61	3.41	2.69	1.64
5	0.31	1.74	1.61	0.79
6	0.36	1.91	1.74	0.9
7	0.83	4.47	3.62	2.88
8	0.4	2.02	1.71	1.16
9	0.25	2.09	1.57	0.56

The main objective of the paper is to optimize the milling parameters (spindle speed, feed rate, depth of cut and cutting tool grade) to achieve low value of the surface roughness. The experimental data for the surface roughness values is shown in table 7.

Table 7: Measured Surface Roughness

Pieces	Speed (rpm)	Depth of Cut (mm)	Feed (mm/min)	Surface Roughness
1	796	0.75	500	0.18
2	796	0.50	800	0.38
3	796	0.25	1100	0.37
4	995	0.75	800	0.61
5	995	0.50	1100	0.31
6	995	0.25	500	0.36
7	1194	0.75	1100	0.83
8	1194	0.50	500	0.4
9	1194	0.25	800	0.25

B. Optimization by Taguchi Method

Performance characteristics are first converted into the S/N ratio using the Taguchi method. Using S/N quantity, optimal performance and minimal variance can be designed. A longer tool life generally implies a higher metal removal rate and better cutting performance. Therefore, the wear rate should be at a minimum and the metal removal rate should be at a maximum. Table 8 lists the S/N ratio and means value. The S/N ratio can be used for performance analysis. Moreover, a higher S/N ratio should improve the performance characteristics. The result of S/N ratio analysis for the surface roughness values, which was calculated using taguchi process, is shown in Table 8.

Table 8: Measured SNR & Means by Taguchi Optimization

Pieces	Speed (m/rev.)	Depth of Cut (mm)	Feed (mm/min)	Surface Roughness	SNR	Means
1	796	0.75	500	0.18	14.89	0.18
2	796	0.50	800	0.38	8.40	0.38
3	796	0.25	1100	0.37	8.636	0.37
4	995	0.75	800	0.61	4.293	0.61

5	995	0.50	1100	0.31	10.172	0.31
6	995	0.25	500	0.36	8.873	0.36
7	1194	0.75	1100	0.83	1.618	0.83
8	1194	0.50	500	0.4	7.958	0.4
9	1194	0.25	800	0.25	12.041	0.25

Figure 4 & 5 shows graphs, each of which contains a curve representing the mean and a curve representing S/N ratio. The S/N ratio indicates degree of predictable performance of a product or process in the presence of noise factors. Process parameter settings with maximum S/N ratio always yield the optimum quality with parameter on surface roughness are shown in Fig 4 & 5minimum variance. The level that has a higher value determines the optimum level of each factor. The main effects for each level of

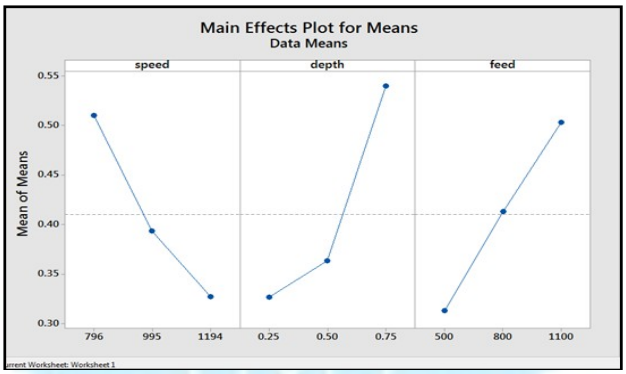


Figure 4: Effects Plot for Means

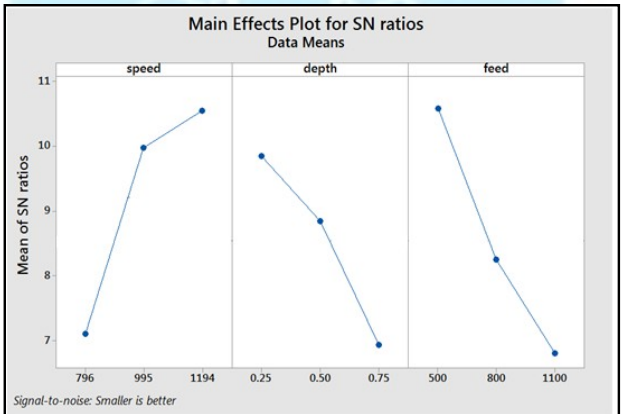


Figure 5: Effects Plot for SNR

The Taguchi method is a simple and effective solution for parameter design and experimental planning [15].In this method, signal-to-noise (S/N) ratio is used to signify a performance characteristic in which the largest value of the S/N ratio is required. The three S/N ratios are the lower-the-better, higher-the better, and the nominal-the-better.

V. CONCLUSION

The study proposes an integrated optimization approach using taguchi method. In this paper, the average value of surface roughness and S/N ratio were calculated and were found to be within the range. Taguchi parameter design can provide a systematic procedure that can effectively and efficiently identify the optimum surface roughness in the process control of individual end milling machines. It also allows industry to reduce process or product variability and minimize product defects by using a relatively small number of experimental runs and costs to achieve superior-quality products. This research only

demonstrates how to use Taguchi parameter design for optimizing machining performance with minimum cost.This approach can be recommended for continuous quality improvement and off-line quality of any production process. As speed increases surface roughness decreases and feed increases surface roughness also increases. For achieving good surface finish on the D2 work piece, higher cutting speed, lower feed and lower depth of cut are preferred.

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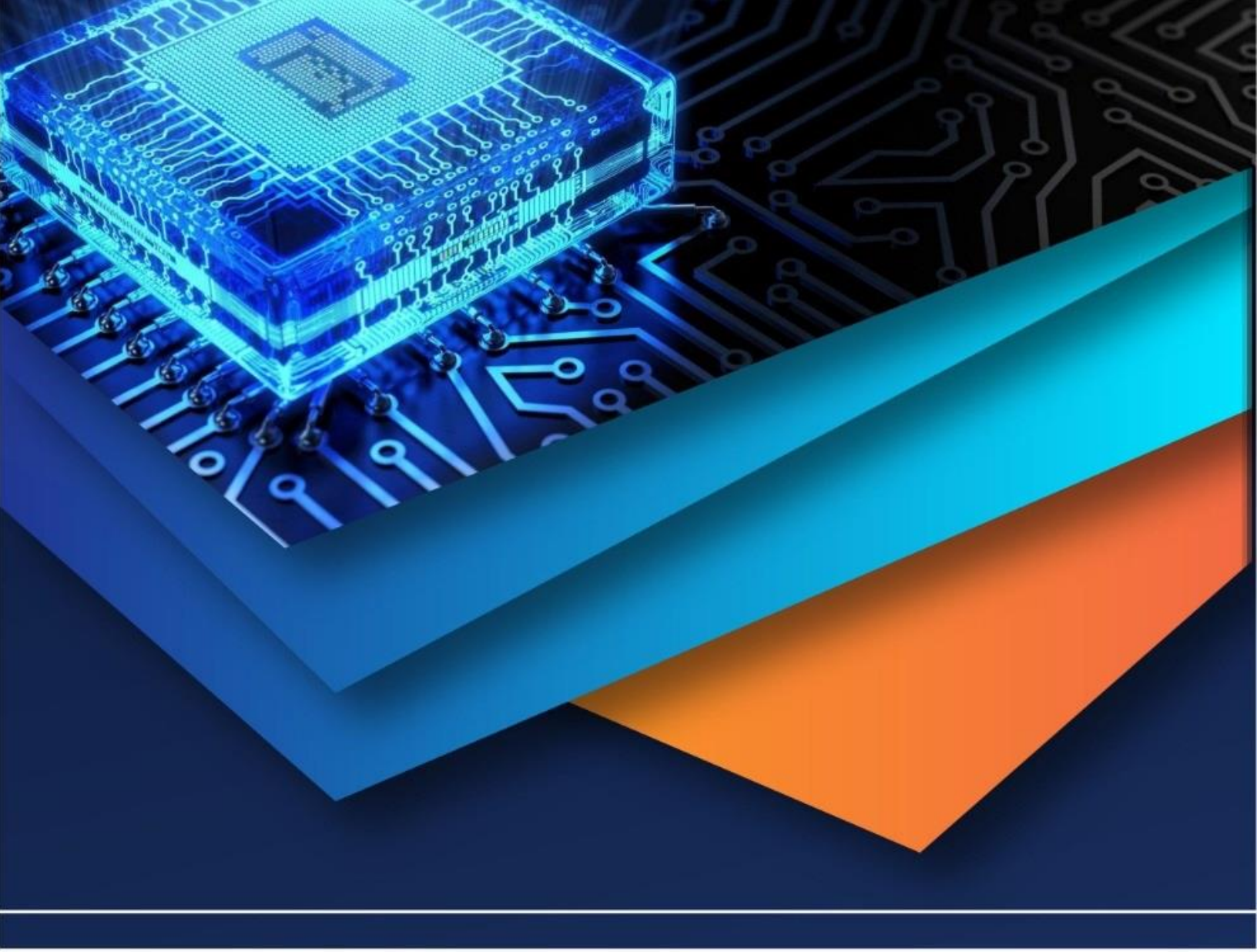
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