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Design, Modelling & Fabrication of Circle Cutting Machine

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Abstract: This paper details the design, modelling & fabrication a of a circle cutting machine engineered for efficient, precise, and cost-effective production of circular shapes. The machine employs a shearing operation to cut circles of varying diameters from metal sheets. Addressing the need for improved circular sheet cutting in industries, this solution offers a motorized, low-cost, and space-saving alternative. The integration of a servo motor enhances cutting accuracy and consistency. Its robust design and user-friendly interface contribute to the machine's durability and reliability, presenting an effective substitute for traditional cutting methods[3]. This research demonstrates the benefits of a locally manufactured circle cutting machine, providing small and medium-scale enterprises with an affordable and efficient cutting solution.

Keywords: Circle Cutting Machine, Shearing Operation, Servo Motor, Cost-Effective, Manufacturing

I. INTRODUCTION

The cutting of sheet metal into circular forms is an essential process across numerous industries, with the expanding automotive sector illustrating its growing importance. Sheet metal's adaptability allows it to be shaped through cutting and bending for use in a wide array of products, including automotive parts, aircraft components, medical devices, and building materials. Industries such as textile manufacturing, plastics processing, printing, packaging, and breweries also rely heavily on sheet metal to create frames and various components. In India, circular sheet metal cutting has traditionally been carried out using manual or semi-automated techniques, such as gas cutting and specialized circular cutting machines. These methods often face limitations in accuracy, efficiency, and the ability to produce complex or non-standard circular shapes. The reliance on skilled labour for manual operations introduces further challenges, as cut quality can be affected by the operator's skill and concentration.

In contrast, advanced manufacturing nations like China, Japan, and Korea have seen a revolution in circular sheet metal cutting through the adoption of Computer Numerical Control (CNC) machines. These machines provide exceptional precision, speed, and versatility, enabling the production of intricate circular shapes with high accuracy. However, the limited availability of advanced CNC machines in India necessitates imports, which significantly increases production costs. This cost burden can hinder the competitiveness of Indian manufacturers, especially in the price-sensitive domestic market.

Therefore, the development of a locally manufactured, fully automated, and cost-efficient circular sheet metal cutting machine is crucial for the Indian manufacturing sector. Such a machine would empower small and medium-scale enterprises to increase their production capabilities, produce high-quality circular profiles at lower costs, and effectively compete in the global market. This paper details the design and implementation of a cost-effective, automated circular sheet metal cutting machine tailored to address the current needs and challenges of the industry.

II. OBJECTIVES

The primary aims of this machinery are to achieve precise and consistent outcomes, while optimizing operational efficiency. This involves minimizing errors and waste, maximizing throughput, and ensuring reliable performance. Ultimately, the objective is to enhance productivity and quality while reducing operational costs

III. RESEARCH METHODOLOGY

The core goals of circular sheet metal cutting are to achieve accurate circular forms with tight tolerances, while simultaneously boosting operational efficiency. This involves streamlining production timelines and labour expenditures, maximizing output volume without compromising quality, and minimizing defects like burrs, irregular edges, and dimensional errors. Furthermore, this process seeks to broaden manufacturing potential by facilitating the creation of intricate circular designs that are challenging or impossible with conventional techniques, thereby diversifying product offerings.

A critical aspect is cost reduction, achieved through optimized material utilization to minimize waste and lowered operational expenses by reducing reliance on manual labor and costly imported machinery. Ultimately, proficient circular sheet metal cutting enhances market competitiveness by enabling manufacturers to produce superior products at competitive prices, effectively addressing the growing customer demands for precision and affordability.

A. Design Calculation

Circle Cutting Machine with two shafts, one gear pair and one hand grab.

1) Shaft 1

Step 1: Calculate torque (T)
Assuming power transmitted (P): 5 kW
Rotational speed (N): 1000 rpm
$T = (P * 60) / (2 * \pi * N)$
$= (5000\ W * 60) / (2 * \pi * 1000\ rpm)$
$T = 47.75$ Nm
Step 2: Calculate bending moment (M)
Assuming no external forces, M = 0.
Step 3: Calculate equivalent torque (Te)
$Te = \sqrt{(T^2 + M^2)}$
$= \sqrt{(47.75^2 + 0^2)}$
TE = 47.75 Nm
Step 4: Calculate shaft diameter (d) using torque
$d = \sqrt{(16 * Te / (\pi * \sigma y))}$
$= \sqrt{(16 * 47.75\ Nm / (\pi * 250\ MPa))}$
≈ 0.0219 m ≈ 21.9 mm
Since the calculated diameter (21.9 mm) is less than the given diameter (27 mm), the design is safe.
Step 5: Calculate critical speed (Nc)
L = Length of shaft (m) = 0.05 m
d = Diameter (m) = 0.03 m
E = Young's modulus (GPa) = 200 GPa (for steel)
ρ = Density (kg/m^3) = 7850 kg/m^3 (for steel)
I = Moment of inertia (m^4) = $(\pi * d^4) / 64$
$Nc = (\pi / L) * \sqrt{(E * I / (\rho * A))}$
$= (\pi / 0.05\ m) * \sqrt{(200\ GPa * (\pi * (0.03\ m)^4) / 64 / (7850 kg/m^3 * (\pi * (0.03\ m)^2 / 4))}$
≈ 2051 rpm
Safety factor (SF)
SF = Nc / N
= 2051 rpm / 1000 rpm
≈ 2.05

2) Shaft 2

Assuming power transmitted (P): 5 Kw
Rotational speed (N): 1000 rpm
Step 1: Calculate torque (T)
$T = (P * 60) / (2 * \pi * N)$
$= (5000\ W * 60) / (2 * \pi * 1000\ rpm)$
$T = 47.75$ Nm
Step 2: Calculate critical speed (Nc)
L = Length of shaft (m) = 0.552m
d = Diameter (m) = 0.027m pl
E = Young's modulus (GPa) = 200 GPa (for steel)

ρ = Density (kg/m³) = 7850 kg/m³ (for steel)
I = Moment of inertia (m⁴)
= (π * d^4) / 64
Nc = (π / L) * √(E * I / (ρ * A))
= (π / 0.06 m) * √(200 GPa * (π * (0.03 m)^4) / 64 / (7850 kg/m³ * (π * (0.03 m)^2 / 4))
≈ 1719 rpm
Safety factor (SF)
SF = Nc / N
= 1719 rpm / 1000 rpm
≈ 1.72

3) GEAR

Diameter of Gear 1(outer) (D1): 180mm
Diameter of Gear 1 (inner) (D2): 165mm
Gear type: Spur gear
Step 1: Calculate Pitch Circle Diameter (PCD)
PCD1 = D1 = 180mm
PCD2 = D2 = 165mm
Step 2: Calculate Module (m)
Module (m) = PCD1 / (Number of teeth (T1))
= PCD2 / (Number of teeth (T2))
Assuming T1 = 45
m = 180mm / 45
= 4 mm
Step 3: Calculate Number of Teeth (T)
T1 = PCD1 / m
= 180mm / 4 mm
=45
T2 = PCD2 / m
= 180 mm / 4 mm
=45
Step 4: Calculate Gear Ratio (i)
i = T2 / T1
= 45/45
=1
Step 5: Calculate Torque (T)
T = (P * 60) / (2 * π * N1)
= (5000W * 60) / (2 * π * 1000 rpm)
= 47.74 Nm
Step 6: Calculate Bending Stress (σ)
σ = (T * PCD1) / (m * T1 * y)
≈ (47.74 Nm * 180 mm) / (4 mm * 45 * 0.47)
≈ 101.57 MPa

4) Blade Design Parameters

- Blade thickness (t): 15 mm
- Blade diameter1 (D1): 170 mm
- Blade diameter 2 (D2):160 mm
- Material: High-carbon high cromium steel (HCHCR)
- Cutting edge geometry: Straight, sharp edge

5) Blade Geometry Calculations

Blade circumference (C1): π * D
= 3.14159 * 170 mm
≈ 533.8 mm
C2= 3.14*160
= 502.4 mm
Blade cutting edge length (L): π * D / 2
= 3.14159 * 170 mm / 2
=266.9 mm

6) Blade Strength Calculations

Bending stress (σ): assuming 1000 N force, 20 mm distance from centre
σ = (F * L) / (t^2 * π)
= (1000 N * 266.9 mm) / (15 mm^2 * 3.14159)
=377.7 MPa
Torsional stress (τ): assuming 1000 N force, 80 mm distance from centre
τ = (F * D/2) / (t * π * (D/2)^2)
= (1000 N * 80 mm) / (15 mm * 3.14159 * (80 mm) ^2)
= 265 MPa

7) Grabhand Design Parameters

Grabhand length (L): 150 mm
Grabhand width (W): 10 mm
Material: High-strength steel
Cutting tool mounting: Welded or bolted

8) Structural Calculations

Bending Moment (M): assuming 1000 N force at tip
M = F * L
= 1000 N * 150 mm
= 150 Nm
Bending Stress (σ)
σ = (M * t) / (W * t^2)
= (150 Nm * 10 mm) / (10 mm * 10 mm^2)
=1.5 Mpa
Torsional Moment (T): assuming 1000 N force at tip
T = F * L/2
= 1000 N * 150 mm
= 150 Nm
Torsional Stress (τ):
τ = (T * t) / (W * t^2)
= (150 Nm * 10 mm) / (10 mm * 10 mm^2)
= 1.5 Mpa
Deflection (δ):
assuming 1000 N force at tip
δ = (F * L^3) / (3 * E * I)
≈ (1000 N * 150 mm^3) / (3 * 200 GPa * 4167 mm^4)
=1.86 *10^-8 mm

B. CAD Model of Various Components

The components are design in CERO software. The different types components which are used in the circle cutting machine are given below:

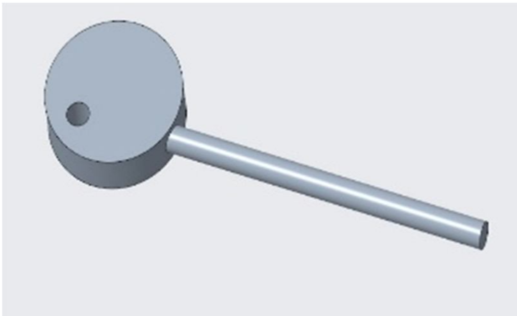

Fig.1. Grab Hand

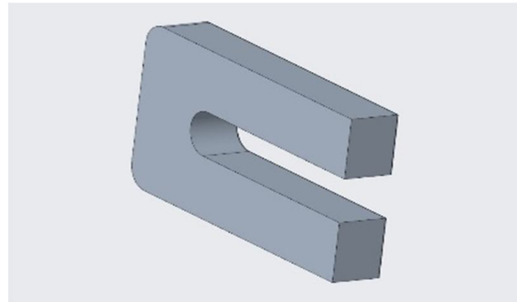

Fig.2 Left Hand

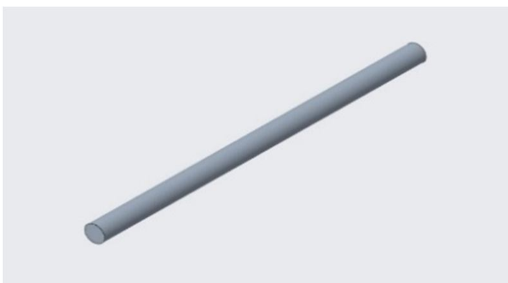

Fig.3 Shaft

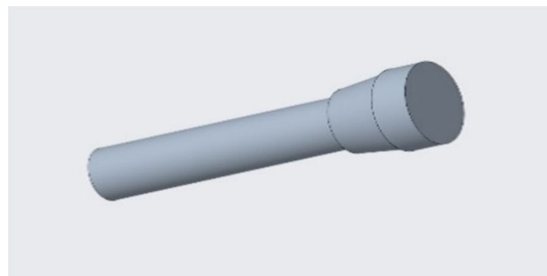

Fig.4 Sheet Holder

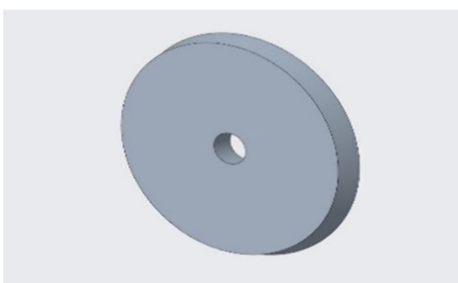

Fig.5 Cutter 1

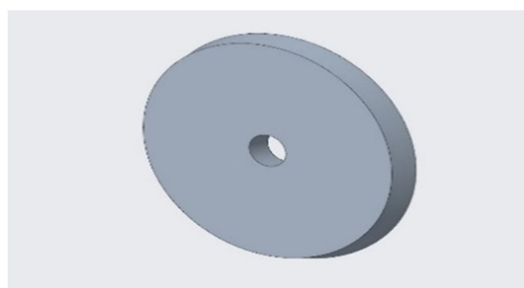

Fig.6 Cutter 2

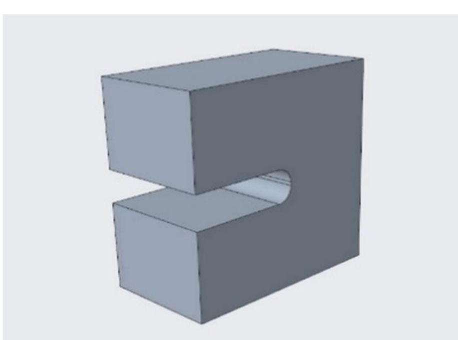

Fig.7 Right Hand

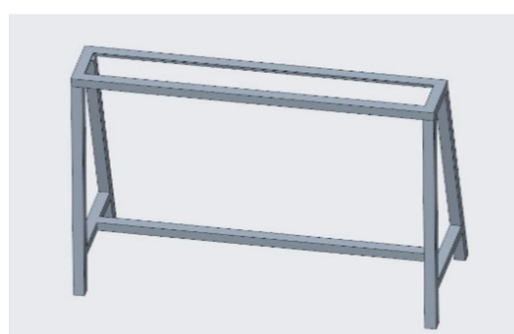

Fig.8 Stand of Machine

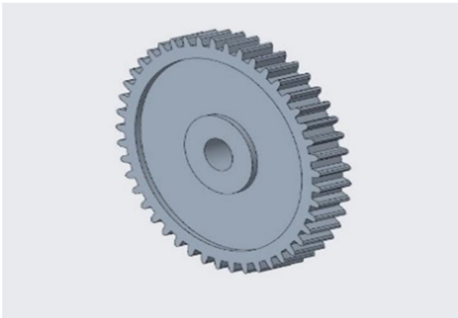

Fig.9 Gear 1

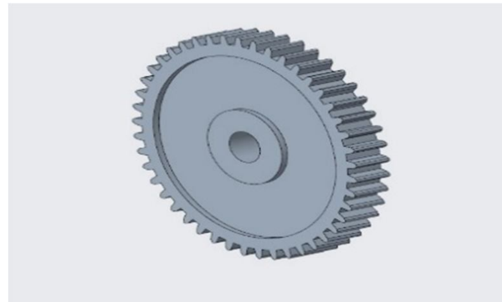

Fig.10 Gear 2

C. *Final CAD Design*

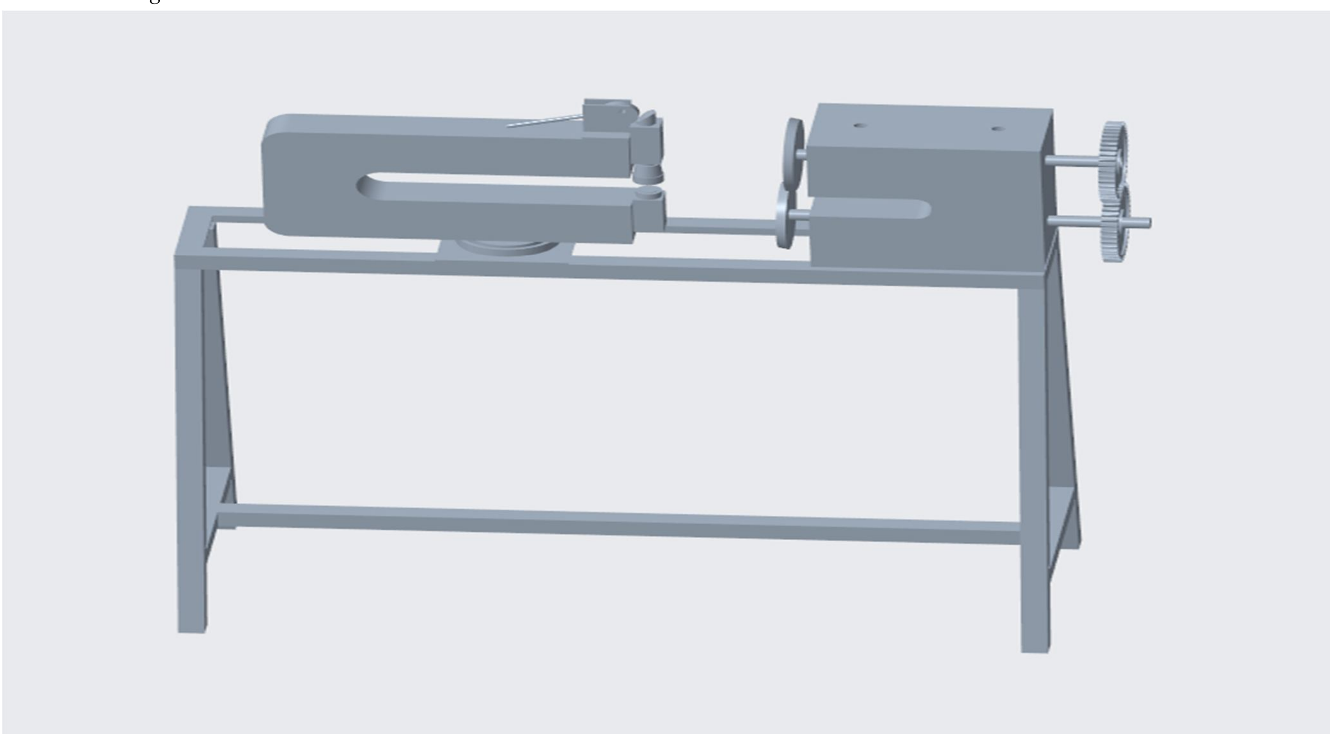

Fig.11 Final CAD Design

IV. RESULTS AND DISCUSSION

A. *Results*

The following data provides the design of circle cutting machine. The result are given below:

1) *Shaft 1*

- Torque (T): 47.75 Nm
- Equivalent Torque (Te): 47.75 Nm (since bending moment is 0)
- Shaft Diameter (d): 21.9 mm (calculated), compared to the given 27 mm. The design is considered safe as the calculated diameter is less than the actual diameter.
- Critical Speed (Nc): 2051 rpm
- Safety Factor (SF): 2.05 (Nc/N). This indicates a safe design against whirling.

2) Shaft 2
- Torque (T): 47.75 Nm
- Critical Speed (Nc): 1719 rpm
- Safety Factor (SF): 1.72 (Nc/N). This also indicates a safe design against whirling, although with a lower safety factor than shaft 1.

3) Gear
- Pitch Circle Diameter (PCD): 180 mm (Gear 1), 165 mm (Gear 2)
- Module (m): 4 mm
- Number of Teeth (T): 45 (for both gears)
- Gear Ratio (i): 1:1
- Torque (T): 47.74 Nm
- Bending Stress (σ): 101.57 MPa

4) Blade Design Parameters
- Blade thickness (t): 15 mm
- Blade diameter1 (D1): 170 mm
- Blade diameter 2 (D2): 160 mm
- Material: High-carbon high chromium steel (HCHCR)
- Cutting edge geometry: Straight, sharp edge

5) Blade Geometry Calculations
- Blade circumference (C1): 533.8 mm
- Blade circumference (C2): 502.4 mm
- Blade cutting edge length (L): 266.9 mm

6) Blade Strength Calculations
- Bending Stress (σ): 377.7 MPa
- Torsional Stress (τ): 265 MPa

7) Grab hand Design Parameters
- Grab hand length (L): 150 mm
- Grab hand width (W): 10 mm
- Material: High-strength steel
- Cutting tool mounting: Welded or bolted

8) Structural Calculations (Grab hand):
- Bending Moment (M): 150 Nm
- Bending Stress (σ): 1.5 MPa
- Torsional Moment (T): 150 Nm
- Torsional Stress (τ): 1.5 MPa

B. Discussion
The results and calculations provide valuable insights into the design and performance of the circle cutting machine. Below are a detailed discussion in simple language:
- Shafts: Safe design against whirling, but Shaft 2 has a lower safety margin.
- Gears: Acceptable bending stress, 1:1 gear ratio.
- Blade: High bending and torsional stresses, requiring strong materials.

- Grab hand: Low bending and torsional stresses, but deflection analysis is incomplete.
- Overall: Calculations indicate a generally safe design, but material selection and complete deflection analysis are critical.

V. CONCLUSION

Ultimately, the development and evaluation of this circular cutting apparatus confirm its practicality and utility within industrial settings. By drawing upon a comprehensive review of existing methodologies and a comparative study of current technologies, the device has been refined to maximize operational output while minimizing expenditures. The investigation underscores significant advancements, such as improved accuracy, decreased reliance on manual intervention, and reduced material consumption. By presenting a budget-friendly substitute for high-cost automated systems, this powered circular cutting machine empowers small and medium-sized businesses with a competitive edge. Subsequent enhancements could prioritize automation, expanded material processing capabilities, and further gains in operational efficiency to broaden its applicability across diverse industrial fields.

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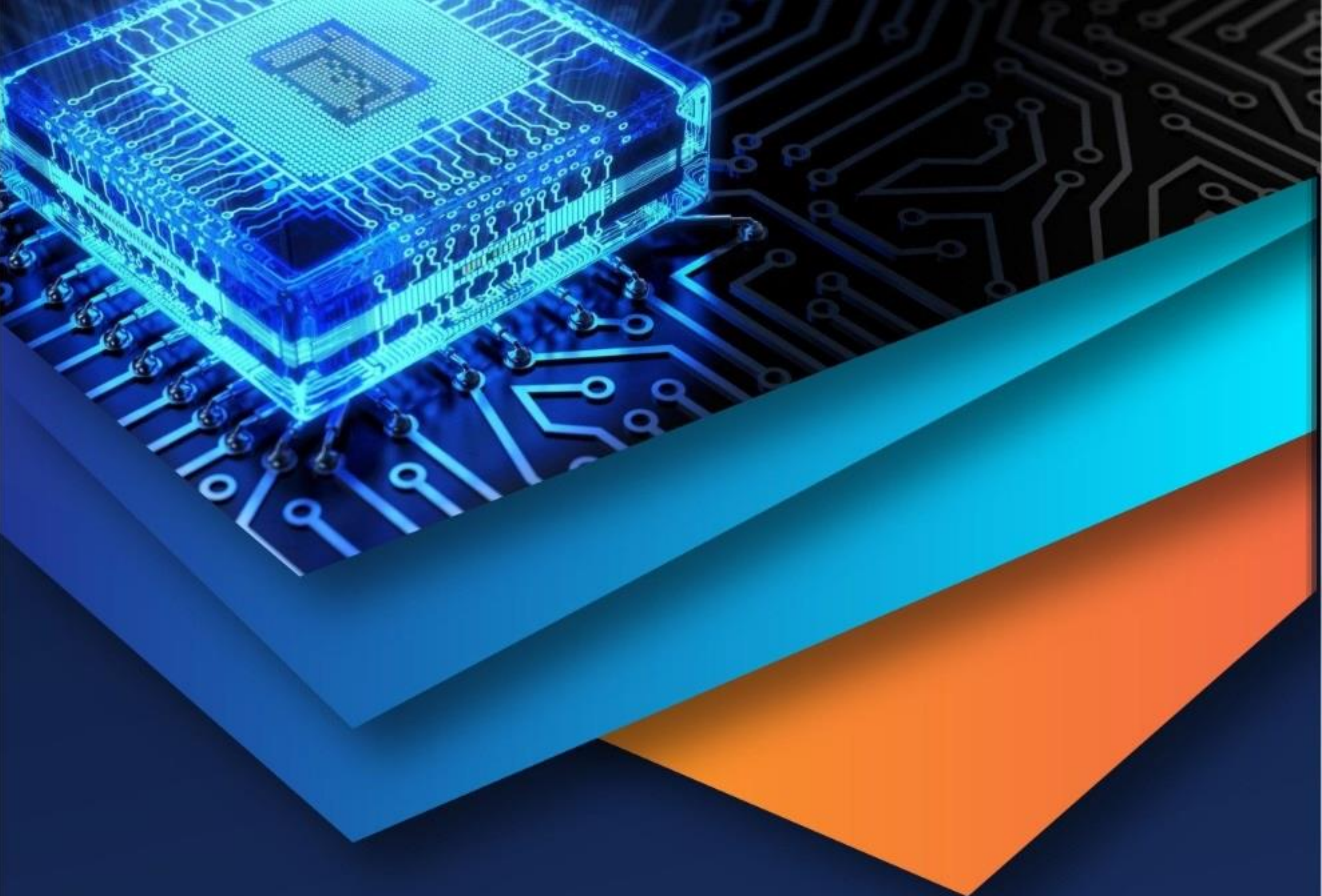

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